SESSION T: THEORETICAL CONSIDERATIONS

LECTURE T4 – SIGHT DISTANCE **PRESENTER: CD SCOTT**

1 INTRODUCTION

The driving task comprises navigation, guidance and control: reading maps and signs, following the road and maintaining a safe path in response to traffic conditions, steering and speed control. These tasks require the driver to receive and process inputs, consider the outcome of alternative actions, decide on the most appropriate, execute the action and observe its effects through the reception and processing of new information. The driver relies primarily on the visual sense to get information. Individuals who lack some or all of the senses other than visual can still hold driver's licenses. An eye test is the only requirement apart from driving skill and knowledge of the regulations to obtain or renew a driver's license.

After a person visually detects and recognizes a given situation, a period of time elapses before muscular reaction occurs. Reaction time is appreciable and differs between persons. It also varies for the same individual, being increased by fatigue, drinking, and other causes. The AASHTO brake reaction time for stopping has been set at 2,5 seconds to recognize all these factors. This value has been adopted in South Africa. Changes to "institutionalized" values, such as reaction time, is not done readily as this would make the existing system obsolete.

Often drivers face situations much more complex than those requiring a simple response such as steering adjustment or applying the brakes. Recognition that complex decisions are time-consuming leads to an axiom in highway design that drivers should be confronted with only one decision at a time, with that decision being binary, e.g. "Yes" or "No" rather than complex, e.g. multiple choice. Anything up to 10 seconds of reaction time may be appropriate in complex situations. Clear sight lines and adequate sight distances are provided to allow time for decision making and, wherever possible, margins are allowed for error and recovery.

2 THE PARAMETERS OF SIGHT DISTANCE

2.1 General

A critical feature of safe road geometry is adequate sight distance. As an irreducible minimum, drivers must be able to see objects in the road with sufficient time to allow them to manoeuvre around them or to stop. Other forms of sight distance are:

- Passing sight distance, which is required for substantial portions of the length of two-lane roads;
- Intersection sight distance, to allow a driver on the minor road to evaluate whether it is safe to cross or enter the opposing stream of traffic;
- Decision sight distance where, for example, a driver must be able to see and respond to road markings;
- Headlight sight distance, typically applied to sag vertical curves, and
- Centre line barrier sight distance.

It is also necessary to consider the terrain or obstructions on the inside of horizontal curves when evaluating adequate sight distance.

2.2 Deceleration rates

Although research in North America has shown that drivers can choose (or apply) a deceleration of greater than 5 m/sec^2, there is a large degree of variability in driver and vehicle capabilities and the 90th percentile deceleration is of the order of 3,4 m/sec^2. The Institute of Transportation Engineers' Traffic Engineering Handbook states that decelerations of up to 3,0 m/sec^2 are reasonably comfortable for passenger car occupants. The South African National Road Agency (SANRAL) has adopted this rate of deceleration for its own design purposes.

2.3 Object height

The object height to be used in calculation of stopping sight distance is often a compromise between the length of the resultant sight distance and the cost of construction. Stopping is generally in response to another vehicle or large hazard in the roadway. To recognize a vehicle as a hazard at night, a line of sight to its headlights or taillights would be necessary. Larger objects would be visible sooner and provide longer stopping distances. To perceive a very small hazard, for example, a surface obstruction, a zero object height may be necessary. However, at the required stopping sight distances for high speeds, small pavement variations and small objects (especially at night) would not be easily visible. Thus, most drivers travelling at high speeds would have difficulty in stopping before reaching a small obstruction. A driver will usually attempt to take evasive action rather than to stop for small objects on the roadway. Although not recommended as a design parameter, the time available to manoeuvre is a useful measure when examining variations of geometry in restricted situations or reconstruction projects. In this case, the appropriate object is the pavement surface.

The designer should adopt an object height based on the probability of a particular object occurring on the roadway. For stopping sight distance, a conservative tail light height of 0,60 metres is recommended. If fallen trees or rocks are a real risk, an object height of 0,15 metres is recommended. In this context, research has established that the probability of a collision involving an object of a height of 0,15 m or less is infinitesimally small. For passing sight distance, an object height of 1,30 m will allow the driver to discern the top of an oncoming car. An object height of zero is recommended where road washouts are a serious risk. It is also recommended for pavement markings in situations such as at intersections or interchanges, where these provide essential guidance.

3 STOPPING SIGHT DISTANCE

The minimum sight distance on a roadway should be sufficient to enable a vehicle travelling at the design speed on a wet pavement with bald tires to stop before reaching a stationary object in its path. Stopping sight distance is the sum of two distances:

- the distance traversed by the vehicle from the instant the driver sights an obstruction to the instant the brakes are applied, referred to as brake reaction distance $s_b = vt_r$ and
- the distance required stopping the vehicle from the instant the brakes are applied, called stopping distance.

Stopping distance can be derived considering that kinetic energy must be dissipated as heat, which is equal to work done. Thus

$$\tfrac{1}{2} mv^2 = Fs = mgfs$$

where:
m = mass of object or vehicle
v = the speed in m/s
g = gravitation acceleration in m/s^2
f = skid resistance between tire and road, or coefficient of friction
s_s = distance over which force is applied to stop the vehicle in m

This can be rewritten as $s_s = v^2/2gf$

In theory, mass does not play a role in the stopping distance. However, the skid resistance or coefficient of friction is a complex variable, which is assumed here for the sake of simplicity to be constant. It in fact is speed dependent and varies with normal force, material compounds and heat build up during braking. The amount of energy that can be dissipated before braking efficiency is lost plays a big role in the difference in stopping distances between cars and trucks. Under normal driving conditions, the maximum skid resistance should not be required as this may lead to loose objects flying around in the vehicle and cause discomfort.

These two components, using a reaction time of 2,5 seconds and a deceleration rate of 3,0 m/s^2, result in the relationship

$$s = v\,(0{,}694 + 0{,}013v)$$

where: s = stopping sight distance, m

v = initial speed, km/h

Stopping sight distances calculated using this equation are given in Table 4-1, rounded up for design purposes. Also shown in the table for general interest are the values of stopping sight distance adopted in the 2000 AASHTO Policy on the Geometric Design of Highways and Streets, the “Green Book 2000”. These are based on a speed dependent skid resistance.

Table 4-1: Recommended stopping sight distances for design

Design Speed (km/h)	**Stopping Sight Distance (m) Calculated**	**Recommended for Design**	**Green Book 2000**
30	32,5	35	35
40	48,6	50	50
50	67,2	70	65
60	88,4	90	85
70	112,3	110	105
80	138,7	140	130
90	167,8	170	160
100	199,4	200	185
110	233,6	230	220
120	270,5	270	250
130	309,9	310	285

In the measurement of stopping sight distance, the driver’s eye height is taken as being at 1,05 metres and the object height is 0,6 metres. It is important however to consider the vast array of geometric design guidelines that are applicable across the African continent and around the world, and to apply the applicable values accordingly.

3.1 Effect of gradient on stopping sight distance

When a highway is on a gradient, the equation for stopping sight distance becomes

$$S = vt_r + v^2/2g(f + G)$$

Where: G = percentage gradient divided by 100, with upgrades being positive and downgrades negative and the other terms as previously stated.
The brake reaction time is assumed to be the same as for level conditions.

The sight distance at any point on the highway is generally different in each direction, particularly on straight roads in rolling terrain. As a general rule, the sight distance available on downgrades is longer than on upgrades, more or less automatically providing the necessary corrections for grade. This is because down grades are normally followed by sag vertical curves, with the following grade also being visible to the driver.

3.2 Variation of stopping sight distance for trucks

The recommended minimum stopping sight distance model directly reflects the operation of passenger cars and trucks with antilock braking systems. Trucks with conventional braking systems require longer stopping distances from a given speed than do passenger cars. However, AASHTO suggests that the truck driver is able to see the vertical features of the obstruction from substantially further because of the higher driver eye height. In addition, posted speed limits for trucks in South Africa are considerably lower than for passenger vehicles. Separate stopping sight distances for trucks and passenger cars are, therefore, not generally used in highway design.

There is, however, evidence to suggest that the sight distance advantages provided by the higher driver eye level in trucks do not always compensate for their inferior braking. Some reasons for the longer truck braking distances include:

- ❑ Poor braking characteristics of empty trucks. The problem relates to the suspension and tyres that are designed for maximum efficiency under load;
- ❑ Uneven load between axles;
- ❑ Propensity of truck drivers not to obey posted speed limits;
- ❑ Inefficient brakes of articulated trucks, and
- ❑ Effect of curvature. Some of the friction available at the road/tire interface is used to hold the vehicle in a circular path.

To balance between the costs and benefits in designing for trucks, truck stopping sight distances should be checked at potentially hazardous locations. In general, the deceleration rate for trucks is 1,5 m/s^2. The driver's eye height is taken as being at 1,8 m and the object height is as previously described. The designer should also consider measures such as additional signs to improve road safety if stopping sight distance is found to be inadequate for trucks and it is not possible to improve the geometric design. However, it is emphasized that provision of signage is not a substitute for appropriate design practices.

4 PASSING SIGHT DISTANCE

On a two -lane rural road, the passing manoeuvre is one of the most significant yet complex and important driving tasks. The process is relatively difficult to quantify, primarily because of the many stages involved, the relative speed of vehicles and the lengthy section of road needed to complete the manoeuvre. Road safety, capacity and service levels are all affected by the passing ability of faster vehicles. This ability is influenced by a variety of factors, including traffic volumes, speed differentials, road geometry and human factors. The minimum sight distance required by a vehicle to overtake safely on two -lane single carriageway roads is the distance which will enable the overtaking driver to pass a slower vehicle without causing an oncoming vehicle to slow below the design speed. It should be pointed out that there are a variety of models defined for the overtaking manoeuvre. The distances usually given are those required to enable an overtaking driver to complete or abort a manoeuvre already commenced, with safety. In addition to this distance, the Austroads approach introduces a distance that is needed for the driver to identify a length of road as a potential overtaking zone. This “establishment” distance is considerably longer than the overtaking manoeuvre distance.

Table 4-2 shows the minimum overtaking sight distances generally used for various design speeds.

Passing manoeuvres involving trucks, particularly in South Africa, require longer distances than those indicated. Designers must take this into account for roads where significant percentages of heavy vehicles are expected in the traffic stream. As mentioned above, the designer should seek opportunities to introduce passing lanes on two –lane roads, particularly where the terrain limits sight distance. A report on a review and evaluation of research studies concluded that passing and climbing lane installations reduce collision rates by 25 per cent compared to untreated two-lane sections. They provide safer passing opportunities for drivers who are uncomfortable in using the opposing traffic lane and for those who become frustrated when few passing opportunities exist, owing to terrain or traffic density.

Table 4-2: Passing sight distance		
Design Speed (km/h)	**Absolute Minimum Passing Sight Distance (m)**	**Desirable Minimum Passing Sight Distance (m)**
30	220	250
40	290	350
50	350	400
60	410	450
70	490	550
80	550	650
90	610	750
100	680	900
110	730	1000
120	800	1100
130	860	1200

Sections with adequate passing sight distance should be provided as frequently as possible. The appropriate frequency is related to operating speed, traffic volumes and composition, terrain and construction cost. As a general rule, if passing sight distance cannot be economically provided at least once every 2 km, passing lanes should be considered. The 2+1 cross-section currently in vogue in Europe has some merit. This three-lane cross-section has two lanes in one direction and a single lane in the opposing direction. At about two to three kilometre intervals, the second lane is allocated to movement in the opposite direction. A minimum shoulder width is required.

5 DECISION SIGHT DISTANCE

Stopping sight distances are usually sufficient to allow reasonably competent and alert drivers to stop under ordinary circumstances. However, these distances are often inadequate when:

- ❑ Drivers must make complex decisions;
- ❑ Information is difficult to perceive, or
- ❑ Unexpected or unusual manoeuvres are required.

Limiting sight distances to those provided for stopping may also preclude drivers from performing evasive manoeuvres, which are often less hazardous and otherwise preferable to stopping. Even with an appropriate complement of standard traffic control devices, stopping sight distances may not provide sufficient visibility for drivers to corroborate advance warning and to perform the necessary manoeuvres. It is evident that there are many locations such as exits from freeways, or where lane shifts or weaving manoeuvres are performed where it would be prudent to provide longer sight distances. In these circumstances, decision sight distance provides the greater length that drivers need. If the drive r can see what is unfolding far enough ahead, he or she should be able to handle almost any situation.

Decision sight distance, sometimes termed anticipatory sight distance, is the distance required for a driver to:

- detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered;
- recognize the hazard or its potential threat;
- select an appropriate speed and path; and
- initiate and complete the required safety manoeuvre safely and efficiently.

Because decision sight distance gives drivers additional margin for error and affords them sufficient length to manoeuvre their vehicles at the same or reduced speed rather than to just stop, it is substantially longer than stopping sight distance.

Drivers need decision sight distances whenever there is likelihood for error in either information reception, decision-making, or control actions. Critical locations where these kinds of errors are likely to occur, and where it is desirable to provide decision sight distance include:

- Approaches to interchanges and intersections;
- Changes in cross-section such as at toll plazas and lane drops;
- Design speed reductions, and
- Areas of concentrated demand where there is apt to be “visual noise”, e.g where sources of information, such as roadway elements, opposing traffic, traffic control devices, advertising signs and construction zones, compete for attention.

The minimum decision sight distances that should be provided for specific situations are shown in Table 4-3. If it is not feasible to provide these distances because of horizontal or vertical curvature or if relocation is not possible, special attention should be given to the use of suitable traffic control devices for advance warning. Although a sight distance is offered for the right side exit, the designer should bear in mind that exiting from the right is in total conflict with driver expectancy and is highly undesirable. The only reason for providing a value is to allow for the remote eventuality that a right-side exit has to be employed. In measuring decision sight distances, the 1 050 mm eye height and 0 mm object height have been adopted.

Table 4-3: Decision sight distance					
	Situations				
Design Speed (km/h)	**Interchanges : Sight distance to nose (metres)**		**Lane drop, closure, merge. Sight distance to taper area (metres)**	**Lane shift Sight distance to beginning of shift (metres)**	**Intersections Sight distance to turn lane**
	Left Exit	**Right Exit**			
50	N/A	N/A	150	85	150
60	200	275	200	100	200
80	250	340	250	150	250
100	350	430	350	200	350
120	400	500	400	250	400

6 HEADLIGHT SIGHT DISTANCE

Headlight sight distance is typically used in establishing the rate of change of grade for sag vertical curves. At speeds above 80 km/h, only large, light-coloured objects can be perceived at the generally accepted stopping sight distances. A five-fold light increase is necessary for a 15 km/h increase in speed and a 50 per cent reduction in object size.

For night driving on highways without lighting, the length of visible roadway is that which is directly illuminated by the headlights of the vehicle. This length is typically shorter than the minimum sight distance. When headlights are operated on low beam, the reduced candlepower at the source and the downward projection angle significantly restrict the visible length of roadway surface. For crest vertical curves, the area beyond the headlight beam point of tangency with the roadway surface is shadowed and receives only indirect illumination. Also, a general limit of 120 to 150 metres sight distance is all that can be safely assumed for visibility of an unilluminated object on a bitumen surfacing. This corresponds to a satisfactory stopping sight distance for 80 to 90 km/h or a decision time of about 5 seconds at 100 km/h. Since the headlight mounting height (typically about 600 mm) is lower than the driver eye height (1 050 mm for design), sight distance is controlled by the height of the vehicle headlights and a one degree upward divergence of the light beam from the longitudinal axis of the vehicle. Any object within the shadow zone must be high enough to extend into the headlight beam to be directly illuminated.

7 BARRIER SIGHT DISTANCE

Barrier sight distance is not a geometric design factor but is rather an operational guide to the driver to promote safety on two-lane roads. Barrier sight distance is the limit below which overtaking is legally prohibited, in order to ensure that two opposing vehicles travelling in the same lane should be able to come to a stop before impact. A logical basis for the determination of the barrier sight distance is that it should at least equal twice the stopping sight distance. Values given in the SADC Road Traffic Signs Manual approximate this approach.

Barrier sight distance is be measured to an object height of 1,3 metre from an eye height of 1,05 m. The object height is the height of an approaching passenger car. Hidden dip alignments are poor design practice but are found on many rural roads. They typically mislead drivers into believing that there is more sight distance available than actually exists. In checking vertical alignment, designers should pay attention to areas where this deficiency exists and ensure that drivers are made aware of any such inadequacies.

8 RESTRICTIONS ON SIGHT DISTANCE

8.1 Obstructions to sight distance on horizontal curves

Physical features, such as a concrete barrier wall, a bridge pier, a tree, foliage, the back slope of a cutting, or the outside of the travelled way can affect available sight distance. Accordingly, designs need to be checked in both the horizontal and vertical planes for obstructions.

Minimum radii of horizontal curvature are often determined by application of vehicle dynamics and not through sight distance controls. It is, therefore, possible that the selected radius may not be adequate to ensure the safe stopping sight distance requirements. If the obstructions to sight distance are immovable, re- alignment may be necessary.

8.2 Climatic restrictions to stopping sight distance

Certain areas of the country are prone to misty conditions and others subject to high rainfall. Both are factors that have to be taken into account in design. Mist and rain both cause reduced visibility. Where these are a regular occurrence, they tend to lie in belts, sometimes fairly narrow, across the landscape. Designers should acquire local knowledge about the quirks of the weather patterns and seek ways to reduce their effect. Where it is not possible to avoid a mist belt, the designer should pay particular attention to the concept of the “forgiving highway”, by providing flat side slopes and avoiding alignments where short radius curves follow each other in quick succession.

Steep downgrades followed by short radius horizontal curves are particularly to be avoided. A real effort should also be put into avoiding high fills. In conditions of heavy mist, vehicles will tend to move very slowly but, even at speeds significantly below the design speed of the road, the restricted visibility will lead to high levels of stress. Drivers are more likely to make incorrect decisions when under stress and designers should thus do everything possible to keep stress levels within manageable limits.

8.3 Bridge decks

Where a road passes under another on a sag curve it is possible that the deck can offer an impediment to sight distance. The line of sight is then restricted to that allowed by the soffit (bottom) of the deck. This is not a common occurrence but it is nevertheless necessary for the designer to be aware of this possibility.