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Modeling Slope-Ascending Sight Distance for Overtaking Manoeuvre in Double Lane Highway

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Abstract

Many vehicles on the highway move at speeds below the design speed obviating overtaking maneuvers by vehicles that move at the design speeds. The paper is an attempt to formulate a model to determine the minimum overtaking sight distance to be maintained by the slope-ascending overtaking vehicle driver on an inclined double lane divided highway. The vehicle and road user characteristics as well as the vertical road geometry are combined to assess the overtaking distance by formulating a mathematical model that satisfies the laws of the mechanics of motion.

Keywords: Overtaking maneuver, graphic model, one-way traffic, perception-reaction time, visibility.

INTRODUCTION

For proper movement of vehicles, roads must be visible to the driver for quite some long distance, to enable the moving vehicle slow down as may be required before any obstructions for safe motion. Visibility therefore, is a vital factor for vehicle operation and for acquiring high speeds on the highway.

Site Distance

Sight distance is the actual distance per length of road over which a driver sitting at a specific height in a vehicle can see objects either moving or stationary, on the road surface. Sight distance is affected by myriads of factors including the sharpness of curves (horizontal and vertical), objects obstructing visibility, buildings or corners at road intersections, etc.

Stopping Site Distance

Also the stopping sight distance for a vehicle in motion is the required distance for which the vehicle moving at a design speed can be stopped without colliding with a stationary object on the road. The stopping site distance depends on the features of the road ahead, height of the driver's eye above the road surface, height of the object above the road surface, the road horizontal and vertical curves, traffic conditions, positions of obstructions, etc. At the summit of curves, the stopping sight distance is that distance measured along the road surface which a vehicle driver whose eye is 1.22 m above the road surface can see an object of 10 cm height also situated on the road surface [1], [7].

The distinction between stopping sight distance and decision sight distance must be understood. Stopping sight distance is used when the vehicle is traveling at design speed on a poor wet pavement when one clearly discernable object or obstacle is present in the roadway. Decision sight distance applies when conditions are complex, driver expectancies are different from the situation, or visibility to traffic control or design features is impaired [2]. Most situations presented on arterials for access management require stopping sight distance at a minimum; however, decision sight distance should be provided for safety and smoother operations. More factors affecting sight distance include speed of vehicle, efficiency of brakes, total reaction time, longitudinal slope of the road, frictional resistance between the road surface and the vehicle tyres, etc.

Perception-Reaction Time

The reaction time is the time it takes the driver to apply the brakes effectively from the time the object is seen and the perception time is the time the average driver realizes a danger ahead for which the brake should be applied. Recent studies have checked the validity of 2.5

seconds as the design perception-reaction time. Four recent studies [3], [4], [5], [6] (Table 1) have shown a maximum of 1.9 seconds as the perception-reaction time for an 85th percentile time and about 2.5 seconds as the 95th percentile time.

Table 1. Brake Reaction Times Studies

Researcher	85^{th} Percentile Time (Seconds)	95 Percentile Time (Seconds)
Gazis et al	1.48	1.75
Wortman et al	1.80	2.35
M.S. Changl	1.90	2.50
M. Sivak	1.78	2.40

By road type, some researchers [6] have suggested that the perception-reaction should reflect the complexity of traffic conditions, expectancy of drivers and the driver's state. They suggest that the perception-reaction times may be altered accordingly (Table 2).

Table 2. Perception-Reaction Times Considering Complexity and Driver's State

Road Type	Driver's State	Complexity	Perception-Reaction time
Low Volume Road	Alert	Low	1.5 s
Two-Lane	Fatigued	Moderate	3.0 s
Primary Rural Road Urban Arterial	Alert	High	2.5 s
Rural Freeway	Fatigued	Low	2.5 s
Urban Freeway	Fatigued	High	3.0 s

Overtaking Graphic Cum Mathematical Model

For overtaking manoeuvre in the one-way traffic, the overtaking vehicle traveling at the design speed, V_d, has to leave its own track, overtake and return to the track, without expecting any traffic from the opposite direction. The distance visible to the driver of the vehicle intending to overtake another slow moving vehicle without causing any inconvenience or possible accident is called the overtaking site distance. This can be depicted graphically as in (Fig. 1). The model goes to show vehicle A initially at position A_1 and travelling at the design speed of V_d which takes a reaction time of t_r through the distance d_1 to start overtaking vehicle B which is moving at a slower speed and at position B_1 at that instant.

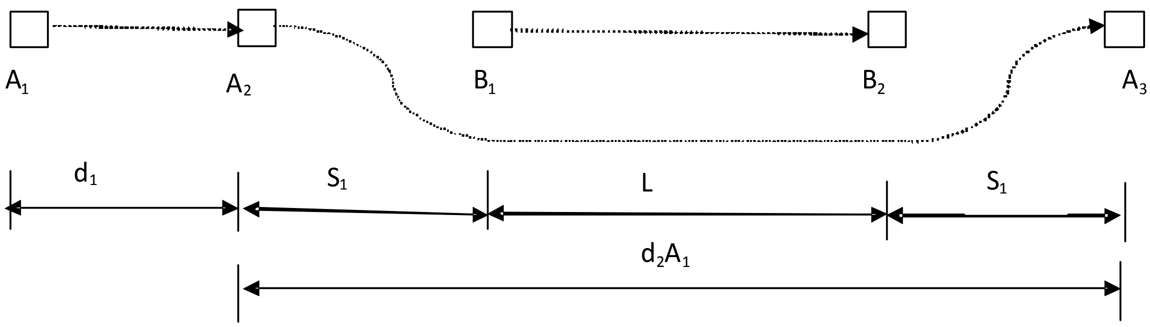

Fig1: Overtaking Manoeuvre Graphic Model

Now, vehicle A overtakes vehicle B through the distance d_2 in time t_2. This distance must not be less than the sum of the stopping site distances, S_1, between vehicles A and B before and after the overtaking movement of vehicle A moving from position A_2 to position A_3 plus the distance, L, covered by vehicle B moving from position B_1 to position B_2 within the same time of t_2 by which Vehicle A moved from position A_2 to A_3. For a one-way traffic in a double lane divided carriageway, no vehicle is expected from the opposite direction.

That is,

$d_1 = V_B t_r$ (1)

where d_1 = reaction distance,

V_B = velocity of vehicle B,

and t_r = reaction time of vehicle A driver.

From laws and mechanics of motion,

$d_2 = V_B t_2 + \frac{1}{2}\alpha_A t^2$ (2)

Also, from fig.1,

$d_2 = 2S_1 + L$ (3)

where d_2 = overtaking distance,

t_2 = overtaking time,

α_A = acceleration of vehicle A,

S_1 = stopping site distance,

and L = distance moved by vehicle B from position B_1 to position B_2.

But

$L = V_B t_2$ (4)

Combining Eqns (2), (3) and (4),

$$\frac{1}{2}\alpha_A t_2^2 = \frac{2S_1}{4S_1} \quad (5)$$

$$t_2 = \pm\ \alpha_A \quad (6)$$

$$t_2 = \pm\ \alpha_A \sqrt{\frac{4S_1}{\alpha_A}} \quad (6)$$

The work done against friction, W_f, in stopping a moving vehicle equals the kinetic energy, E_k, of the moving vehicle.

That is,

$W_f = \mu F S_1$ (7)

where F= braking force

S_1 = braking/stopping sight distance of moving vehicle in the single lane two-way traffic, a

μ= coefficient of friction between tyre and the brake pad.

Also

$E_k = \frac{1}{2}mV_d^2$(8) where m = mass of vehicle and

V_d = design speed of vehicle.

$= \frac{1}{2}\, W/g\ V_d^2$ (9)

where W= weight of vehicle and

S = stopping distance of vehicle.

When the vehicles is ascending on a slope of α^o the total work done to overcome friction is

W_f

$= (\mu W - W\mathrm{Sin}\alpha)S_1$ (10)

For small angle of slope,

$\mathrm{Sin}\alpha = \tan\alpha$

$$= \frac{h}{100} \quad (11)$$

where h=elevation.

Using Eqn (11) in Eqn (10),

$$Wf = (\mu W - \frac{Wh}{100})S_1 \quad (12)$$

Since $W_f = E_k$, Eqns (9) and (12) combine to give that

$$S_1 = \sqrt{\frac{V_d^2}{2g(\mu - \frac{h}{100})}} \quad (13)$$

Using Eqn (13) in Eqn (6),

$$t_2 = \pm\sqrt{\frac{V_d^2}{g(\mu - \frac{h}{100})\alpha_A}} \quad (14)$$

and hence, using Eqn (14) in Eqn (2),

$$d_2 = V_B t_2 \pm \sqrt{\frac{V_d^2}{2g(\mu - \frac{h}{100})}} \quad (15)$$

where V_d = design velocity

Hence, minimum overtaking distance, OSD_m, is

$OSD_m = d_1 + d_2$ (16)

and the safe overtaking zone OSD_z [1], [7] is given by

$$OSD_z = 3(d_1 + d_2) \qquad (17)$$

CONCLUSION

A comprehensive understanding of stopping distance and overtaking manoeuvring distance are essential requirements in planning, design and operation of transportation systems. Many researchers [2], [3] have investigated the stopping site distance and overtaking site distance (OSD) under homogeneous traffic conditions. The OSD is theoretically derived and the results indicate that the proposed model is able to represent the OSD of the heterogeneous and less lane-disciplined traffic stream under study with reasonable accuracy.

REFERENCES

G. Singh, J. Singh, *Highweay Engineering,* 5th Edition, reprint, India, 2013, ch. 6, pp. 138-152.

R. Layton, "Stopping Sight Distance and Decision Sight Distance", *Transport Research Institute,, Oregon State University, 1997, Discussion Paper 8A, pp. 1-25.*

D.C. Gazis, D. C. Azis, F.S Hiller, "The Problem of the Amber Signal in Traffic Flow," *Operations Research 8, March-April 1960.*

R.H.Wortman, J.S. Matthaas, "Evaluation of Driver Behavior at Signalized Intersections," *Transportation Research Record 904, T.R.B, Washington, D.C., 1983.*

M.S. Chang, "Timing Traffic Signal Change Intervals Based on Driver Behavior," *T.R. Record 1027, T.R.B, Washington, D.C., 1985.*

Sivak, M., "Radar Measured Reaction Times of Unalerted Drivers to Brake Signals," *Perceptual Motor Skills 55, 1982*

S. K khanna, C.E.J. Justo, *Highweay Engineering,* 8th Edition, reprint, India, 2001, ch. 4, pp. 86-114.