Analysis of Overtaking Manoeuvres on Freight Corridors considering Road and Vehicle Parameters

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Outline

1. Introduction
2. Relevant PSD models
3. Research Objectives
4. PSD Test Runs in IPG TruckMaker ®
5. Analytical Model for Overtaking
6. Extended Work and Results
7. Conclusion
8. References

Introduction

- Upcoming freight corridors in India:
  - 60% of the freight movement in India is currently carried out on road networks.
  - It is intended to increase the freight load from 40% on National highways (NHs) to 70%.
- Geometric design needs revision for emerging vehicular technology.
- Passing Sight Distance (PSD):
  - Enhanced safety and efficiency - in terms of road usage as well as vehicle energy usage.
  - Potential use in Advanced Driver Assistance Systems (ADAS) – passing collision warning.
  - Existing standards are designed only for cars and do not consider road and vehicle dynamics.

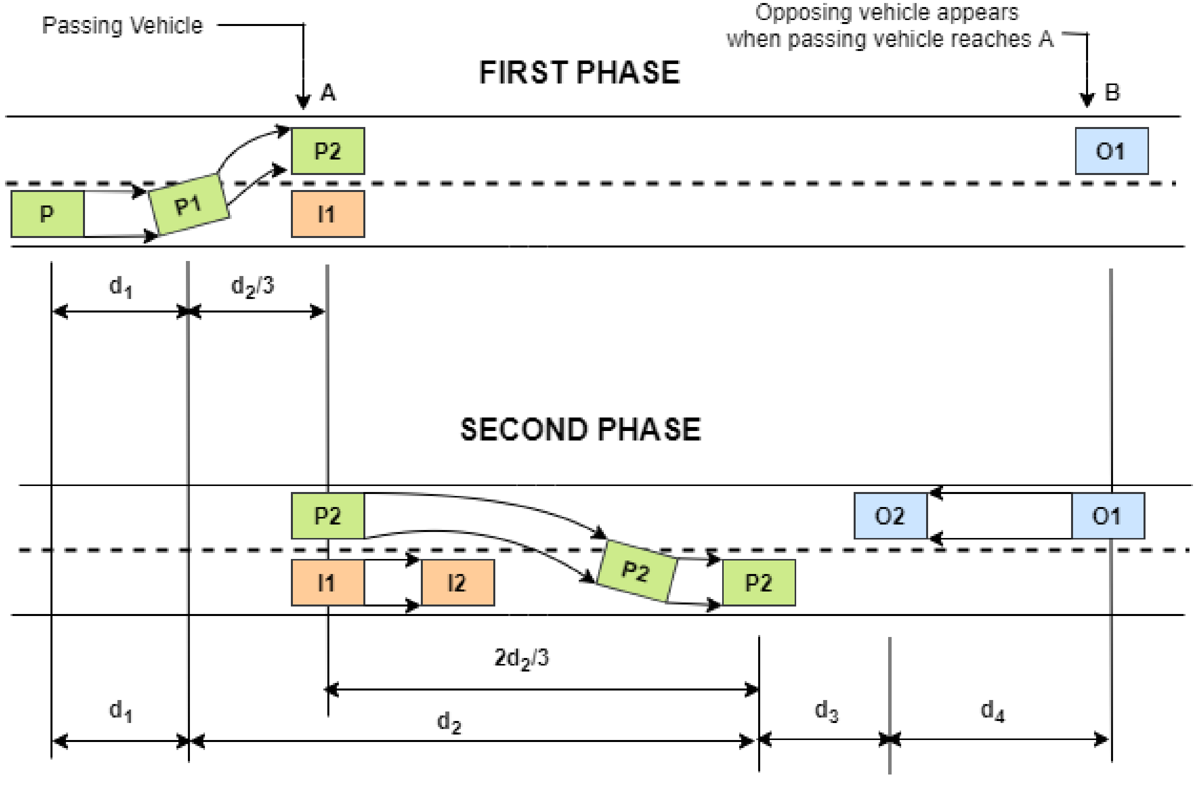

Figure: Components of PSD [AASHTO, 1954]

Relevant PSD Models

- Harwood and Glennon (1976)
  - One of the first to define PSD by considering aborted and completed pass.
- Indian Roads Congress (IRC 66:1976)
  - Design standards conceptually based on AASHTO's older model, but does not consider clearance distance at the end of the manoeuvre.
- Liebermann (1982)
  - Included performance capabilities of vehicles but assumed a constant speed differential.
- Glennon (1988)
  - Replicated actual passing manoeuvres by mathematical extensions of previous works.
  - Considered the critical position, where chances of abortion and completion are equal.
  - Widely used in current AASHTO standards.
- Harwood and Glennon (1989)
  - Obtained the minimum PSD required for different vehicle classes.
- Hassan et al. (1996)
  - Proposed a revised model based on fewer assumptions but was difficult to calibrate.

Research Objectives

- Drawbacks of existing models:
  - Scope majorly restricted to passenger cars.
  - Only lengths of trucks considered by Harwood & Glennon (1989).
  - Only basic vehicle kinematic parameters considered with multiple assumptions.
  - Road and vehicle parameters have not been considered in design.
  - There is still no agreement on vehicle classes for design of PSD.
  - No consideration of electric powertrains and freight corridors has been done for PSD.

- Objectives:
  - Evaluation of present PSD models in practice (Glennon's and IRC) in IPG TruckMaker ®.
  - Analysis of the impact of road parameters such as gradients and vehicle characteristics such as vehicle type, vehicle speed and vehicular technology (IC Engine vs Electric) on PSD.
  - Proposal of analytical model based on vehicle dynamics and microscopic behaviour.
  - Extension of the present study to consider slow-moving vehicles in an adjacent lane.

PSD Test Runs in IPG TruckMaker ®

Road and Driver Parameters:

- Number of lanes, n = 2.
- Lane width = 3.5 m.
- Overtaking rate = 1.

Leader Vehicle (Impeder)
– Type 2-S1 truck (IRC).

Subject Vehicle (Passer) – Type 2 truck (IRC):

- Wheelbase of the passing vehicle = 2.55 m.
- Distance of CoG from front and rear axles = 2.023 m and 1.677 m respectively.
- Unladen mass of the passing vehicle = 6,488 kg.
- Front tyre cornering stiffness = 1,76,920 N/rad/tyre.
- Rear tyre cornering stiffness = 1,65,130 N/rad/tyre, double tyres.

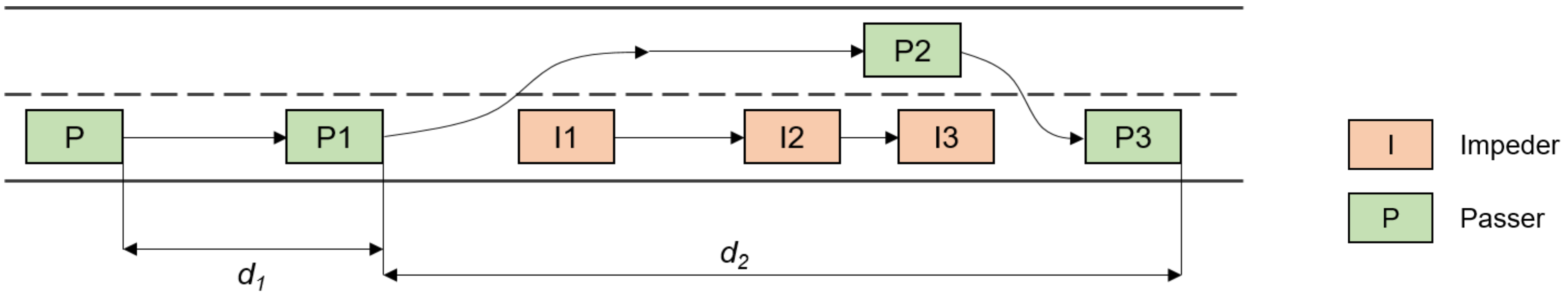

Figure: Minimum PSD

Note: d_3 is ignored due to absence of oncoming vehicle in case of divided highways.

PSD Test Runs in IPG TruckMaker ®

Table: Comparison of PSD from IPG-TM, Glennon's Model and IRC standards

Subject Truck Speed (V , km/h)	Speed differential (m, km/h)	Minimum PSD from Glennon's Model ($d_1 + d_2$, m)	PSD from IRC standards (m)	Minimum PSD from IPG-TM (m)	Percentage Difference in Glennon PSD (w.r.t TM, %)	Percentage Difference in IRC PSD (w.r.t TM, %)
40	10.07	182.2	165.0	331.6	45.1	50.2
50	9.57	270.5	235.0	460.3	41.2	48.9
60	9.07	378.4	300.0	606.1	37.6	50.5
70	8.57	509.6	385.0	788.4	35.4	51.2
80	8.07	669.2	470.0	997.3	32.9	52.9

- Length of subject truck (L_p) = 6 m.
- Length of leader truck (L_i) = 14.7 m.
- Despite consideration of oncoming vehicle in IRC standards with an additional component, the values are lower than IPG-TM PSD values.

PSD Test Runs in IPG TruckMaker ®

Table: PSD with Longitudinal Gradient

Subject Truck Speed (V , km/h)	Speed differential (m, km/h)	Longitudinal Gradient (%)	Min. PSD from IPG-TM (m)	Percentage Difference in Glennon PSD (w.r.t TM, x% Gradient)
80	8.07	2	1020.4	34.4
		4	1091.7	38.7
		6	1527.2	56.2

Table: PSD with Changes in Loading

Subject Truck speed (V, km/h)	Speed differential (m, km/h)	Loading	Min. PSD from IPG-TM (m)	Percentage difference in Glennon's PSD for load change (%)
80	8.07	6488 kg (min.)	997.3	52.9
		16200 kg (max.)	1476.2	54.7

Table: PSD with Electric Truck

Subject Truck Speed (*V* , km/h)	Speed differential (*m*, km/h)	Min. PSD from Glennon's Model ($d_1 + d_2$, m)	Min. PSD from IPG-TM (m)	Percentage Difference (w.r.t TM, %)
40	10.07	182.2	455.3	60.0
50	9.57	270.5	615.4	56.0
60	9.07	378.4	797.2	52.5
70	8.57	509.6	1005.7	49.3
80	8.07	669.2	1427.0	53.1

Analytical Model for d_2

- Trajectory constraint on passing distance:
  - Cubic polynomial trajectory curvature:

$$K_{max} = \left| \frac{-6y_p}{(x_p)^2} \right| . \qquad (1)$$

  - K_{max} depends on the vehicle's steering angle limit, lateral traction available and the maximum allowable lateral acceleration (tuned parameter).
- Gap constraint on passing distance:
  - Minimum gap to be maintained based on Forbes model:

$$d_x = r_t v + L_i . \qquad (2)$$

  - Overtaking should be completed in accordance with this maintained gap.
  - Passing distance is calculated using the length of the cubic polynomial trajectory.
- d_2 is taken as the maximum of these values.
- More details in Deshpande et al. (2020) and Yang et al. (2018)

Analytical Model Results

Table: Results of Analytical Model

Subject Truck Speed (*v*, km/h)	Speed differential (*m*, km/h)	PSD d_2 from Analytical Model (m)	PSD d_2 from IPG-TM (m)	Percentage Difference in d_2 values (%)
40	10.07	270.4	284.8	5.1
50	9.57	392.4	403.1	2.6
60	9.07	546.4	545.0	0.3
70	8.57	737.7	713.0	3.5
80	8.07	973.4	913.0	6.6

- Lateral acceleration = 0.5 m/s^2
- Reaction time for headway spacing = 1.5 s (Forbes model)

Extended Work – Slow-moving Vehicle as an Impeder

- Previous studies have not considered PSD in design for divided highways.
- Slow-moving vehicles in adjacent lanes require consideration similar to PSD for oncoming vehicles on two-lane undivided highways.

- Raj et al. (TRB 2021) have studied the shortfalls in the existing models for critical PSD for two-lane highways:
  - Developed an analytical model to study microscopic behaviour;
  - Used a vehicle trajectory approach to obtain PSD.

The Overtaking Distance (OD) in this scenario is given by x_p, which is the longitudinal distance required for the reverse lane change from the critical point.

- Based on minimum distance required for passing, considering trajectory curvature and safe gaps.

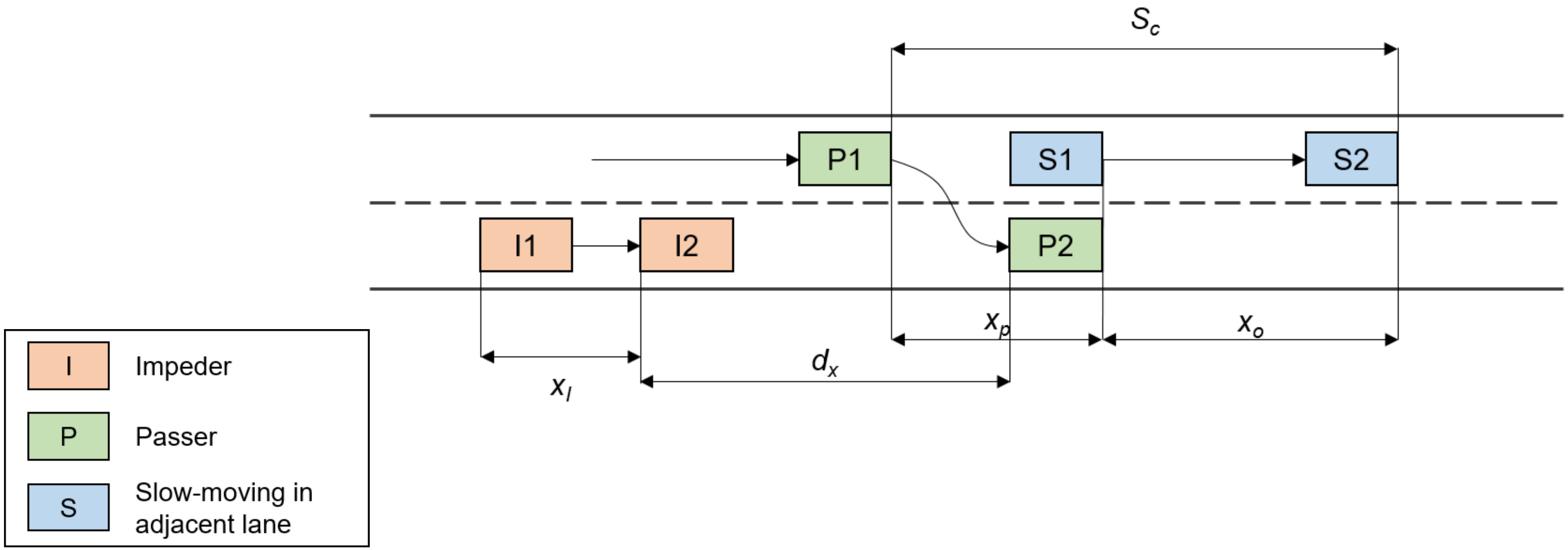

Figure: Slow-moving Vehicle in Adjacent Lane

- Length of overtaking trajectory for gap constraints:
  - Cubic polynomial length:

$$L_{total} = \int_0^{x_p} \sqrt{1 + \left(x\frac{6y_p}{x_p^2} - x^2\frac{6y_p}{x_p^3}\right)^2}\, dx. \qquad (3)$$

Extended Results

Table: Overtaking Distance Results for Slow-Moving Vehicle

Subject Truck Speed (*V* , km/h)	Speed differential (*m*, km/h)	OD from modified Glennon's CP model (m)	OD from IPG-TM (m)	OD from analytical model (m)	Percentage diff. In mod. Glennon OD w.r.t TM (%)	Percentage diff. in analytical OD w.r.t TM (%)
40	10.07	110.2	52.5	58.8	109.9	12.0
50	9.57	172.8	64.8	73.5	166.7	13.4
60	9.07	250.3	76.7	88.2	226.3	15.0
70	8.57	345.4	118.5	126.3	191.5	6.6
80	8.07	463.6	129.3	144.0	258.5	11.4

- Length of subject truck (L_p) = 6 m
- Length of leader truck (L_l) = 14.7 m
- Length of slow-moving truck in adjacent lane (L_a) = 14.7 m.

Conclusion

- This research analysed PSD in from the perspective of freight corridors and proposed the use of analytical models to aid the development of standards.
- As compared to IPG Truckmaker ®, differences of more than 50% were observed in PSD values obtained from Glennon's model and IRC standards.
- Road and vehicle characteristics such as gradient, loading and powertrain have considerable effect on PSD and should be considered for freight corridor design.
- An analytical model is closer to the values from IPG TruckMaker ®:
  - Physical basis as well as calibrated parameters such as lateral acceleration.
- Adequate PSD increases average vehicle speeds, and thus logistic efficiency.

Future scope:

- Development of an analytical model for d_1 with vehicle powertrain dynamics.
- Adoption of the analytical model for ADAS.

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