# Examining Driver Behaviour along Motorway Exit Ramp Terminals


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## Introduction – Problem Statement

Adequate design of motorways speed changing lanes and ramps is important to ensure that drivers merge onto or diverge off a motorway safely, efficiently, and conveniently [1]. Nevertheless, even though these are designed to deliver high levels of safety and operational performance, research studies have proven that such road facilities experience excessive accident rates [e.g. 2, 3].

Current motorway design guidelines still follow a deterministic approach for defining the lengths of entry and exit speed-change lanes, selecting a single conservative speed value (e.g., average or 85th percentile) based on kinematic laws. This method overlooks modern factors such as driver merging/diverging behaviour and vehicle performance.

Travelling on deceleration lanes and exit ramps calls for even more complex skills for observing the motorway traffic during lane changing, keeping a safe distance from close vehicles, and adjusting speed in a way that conforms with driver's needs and expectations [4]. The latter requirement is even more critical since exit ramps often lack design consistency [successive design elements in a coordinated way (e.g. sharp horizontal radii)].

Accident analysis at interchange deceleration areas has pointed out the high speeds at the diverging area as the main cause. In most cases, vehicles cannot fully decelerate to the design speed of the ramp within the limited length of the deceleration lane [5]. This finding is even more critical at downgrade sections.

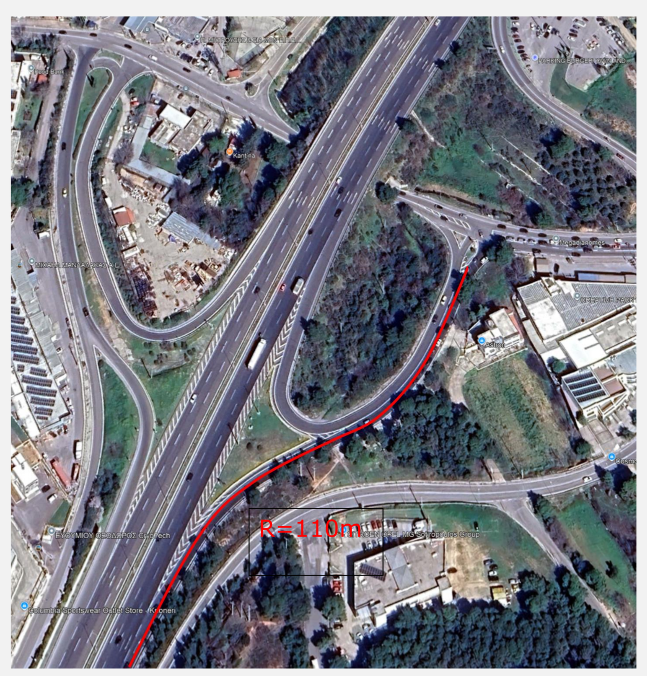
The solution of increasing the length at deceleration areas may improve safety at the diverging area [6]; however, at excessive deceleration lanes, vehicles were reported decelerating but also accelerating after entering the ramp [7]. Another research study [8] indicated that diverging drivers tended to utilize the motorway through lane for a considerable part of their deceleration and enter the deceleration lane within the first half of the supplied length. Additional studies regarding high speeds at motorways, revealed that skilled and male drivers tend to drive more aggressively at the diverging area, thus entering the ramp with higher speeds compared to the design speed [9].

Therefore, there is a clear need to re-examine the design of motorway speed-change lanes and exit ramps beyond deterministic, single-speed assumptions, incorporating actual driver behaviour, vehicle performance, and geometric consistency. This research addresses that need by analysing diverging and deceleration behaviour to identify design and operational measures that can better control speeds and improve safety at motorway interchanges.

## Methodology

This research examines driver behaviour and speed profiles at motorway exit ramp terminals under free-flow conditions, with particular emphasis on the transition segment where vehicles enter the deceleration lane and diverge from the mainline through the controlling curve. Along the ATHE Motorway, two exit ramps from different interchanges (Metamorfosi IC and Agios Stefanos IC) were analysed, each exhibiting distinct geometric characteristics. Both case studies correspond to Parclo AB interchanges and include a loop ramp and a semi-directional ramp, accommodating left-turning and right-turning exit movements, from the main roadway to the secondary network.

Loop exit ramp of Metamorfosi IC

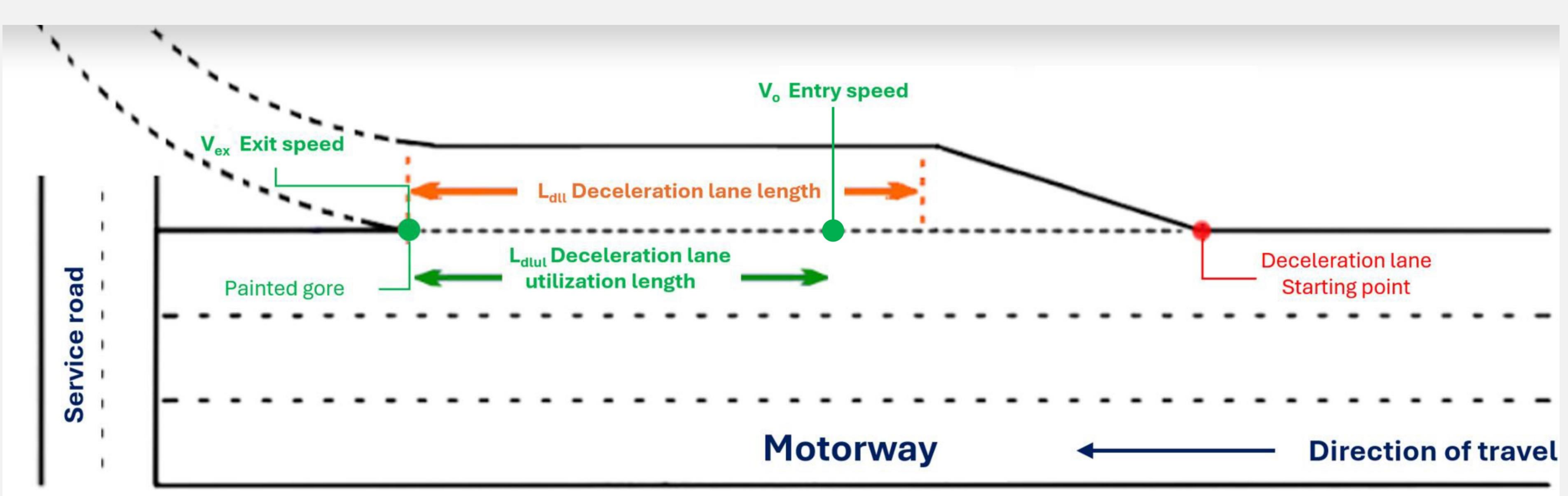


Semi-directional exit ramp of Agios Stefanos IC

Both exit speed changing lanes and ramps of Metamorfosi IC and Agios Stefanos IC constitute representative cases of grade-separated interchanges, with deceleration lanes of 350m and 200m respectively.

Detailed speed–position–deceleration data were collected using a high-precision accelerometer [Vericom 4000RG] operating at 10 Hz. A total of 39 drivers at the Metamorfosi interchange and 32 drivers at the Agios Stefanos interchange participated in the naturalistic driving experiment, with each participant completing one exit-ramp run. All drivers had more than five years of driving experience, were aged 24–35 years, and the sample comprised approximately 65% male and 35% female participants.

Per vehicle run, the following data were recorded: deceleration lane utilization length ($L_{dlul}$), vehicle entry speed at the deceleration zone ($V_0$), vehicle exit speed from the deceleration zone ($V_{ex}$), utilization length ratio ($L_{dlul}$ / $L_{dll}$), and mean deceleration during vehicle motion along the utilized deceleration zone (α).

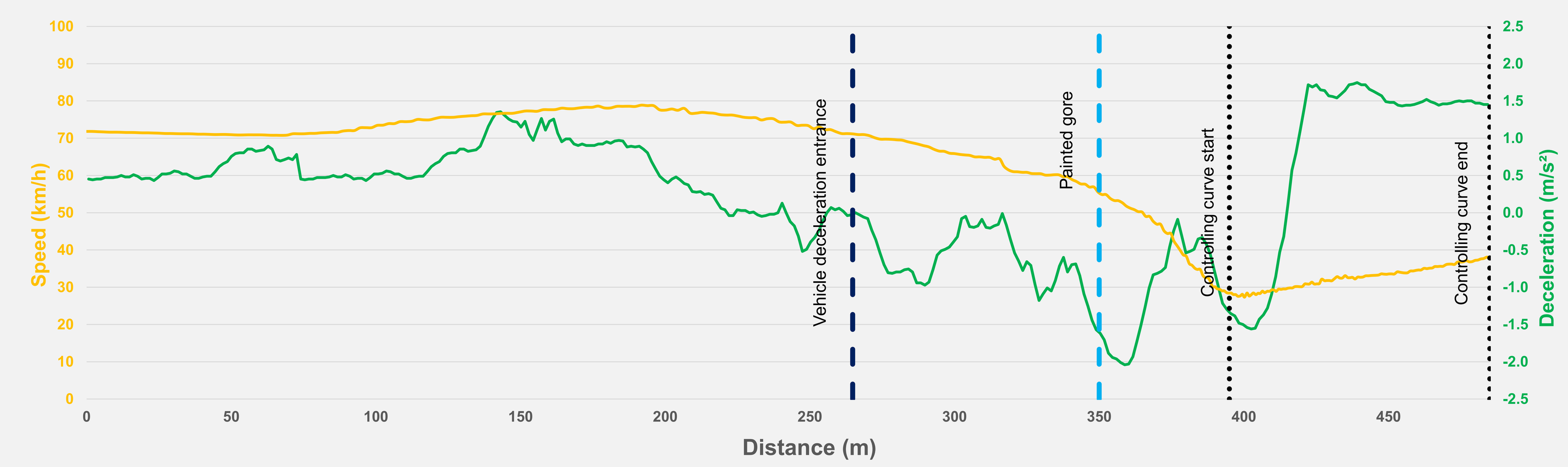



Exit ramp points of interest

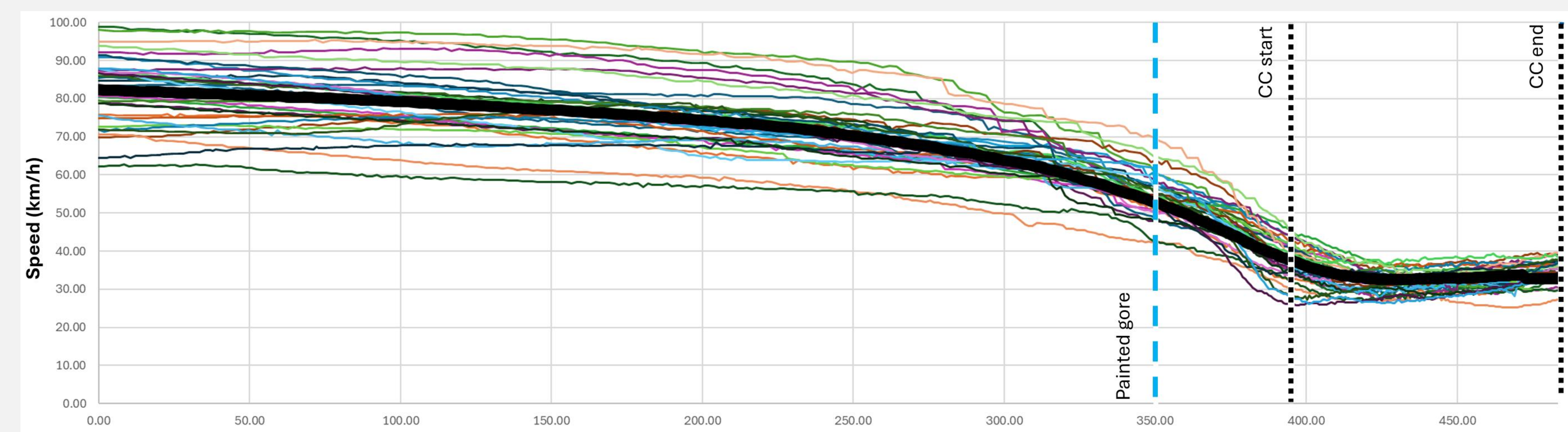
## Data Collection

The speed and deceleration profiles with respect to the defined points of interest during vehicle entry into the controlling curve of the Metamorfosi IC deceleration lane and ramp are presented below. As shown in the figure, the vehicle entered the deceleration lane at approximately 260 m from the starting point. Also another interesting fact is the abrupt speed reduction right before the area of the rather sharp controlling curve (CC).

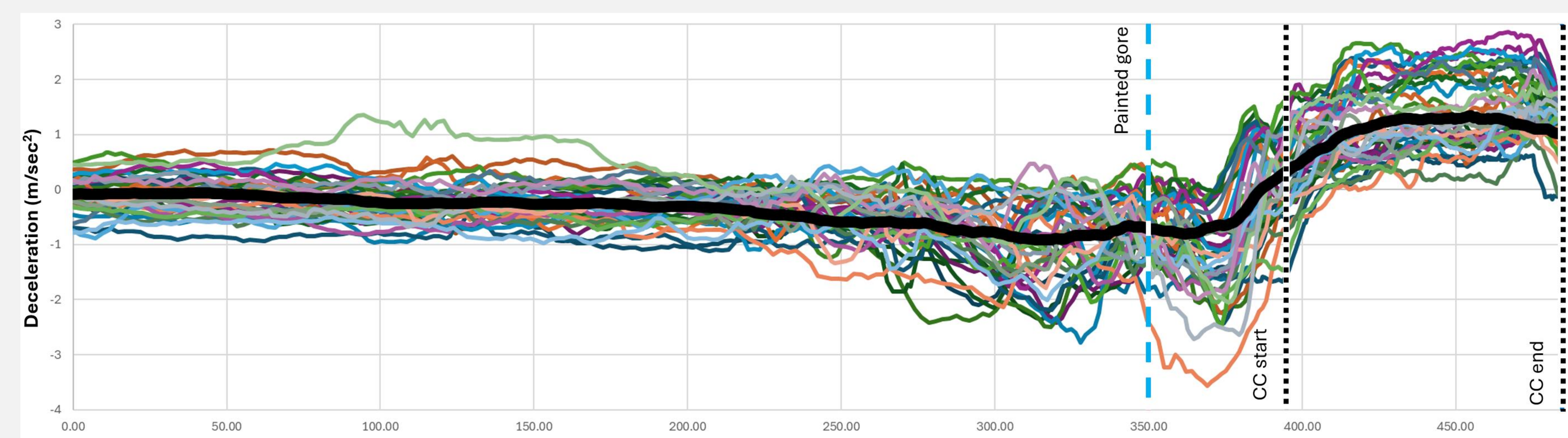
The aggregated speed and deceleration profiles for the two exit ramps are shown below.




Single vehicle speed and deceleration data along exit ramp of Metamorfosi IC

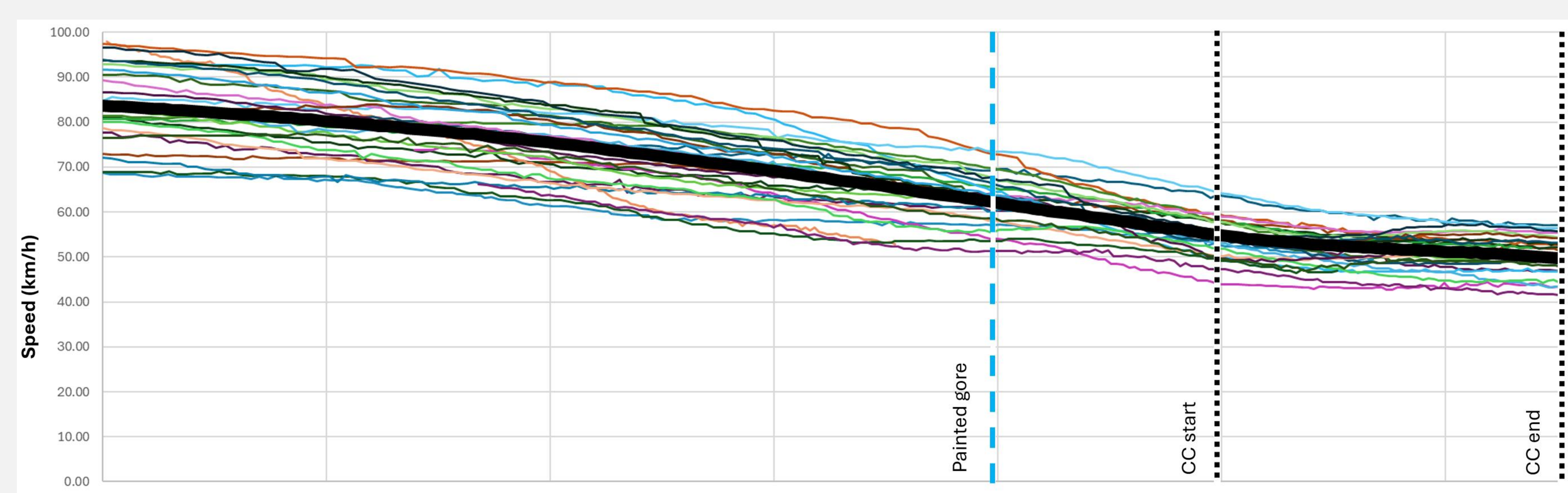



Metamorfosi IC - Speed vs distance data

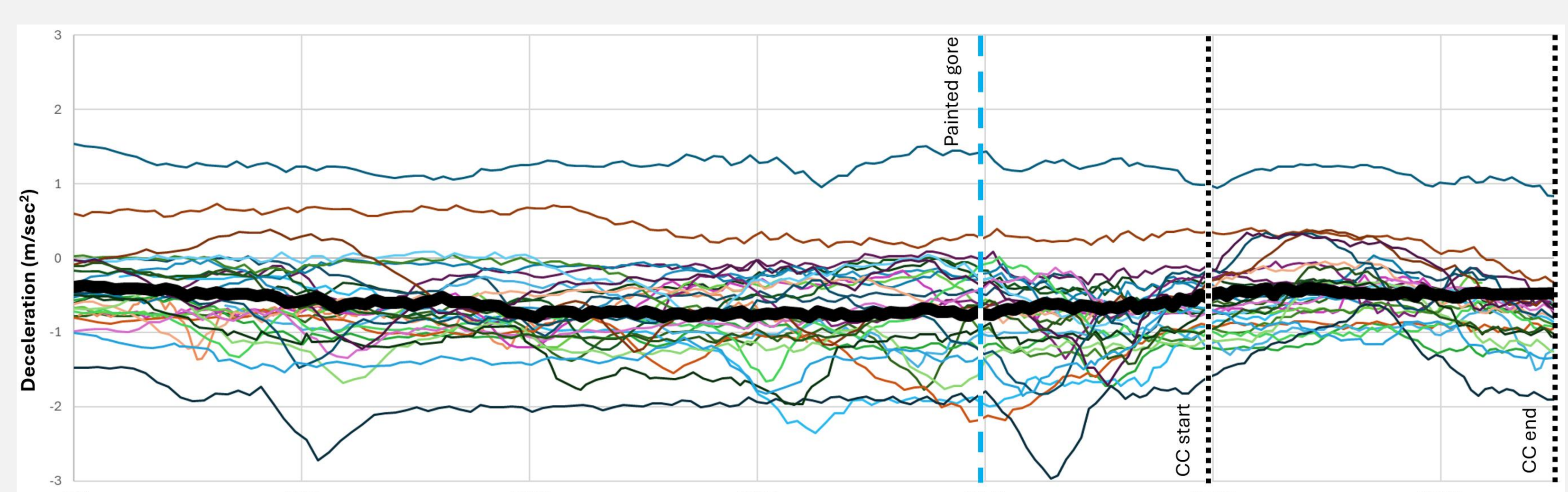



Metamorfosi IC – Deceleration vs distance data

The primary difference between the two exit ramps, aside from the deceleration lane lengths, lies in the curvature of the controlling curve. Specifically, the controlling curve at Metamorfosi IC has a much tighter radius (R = 28 m) compared to that at Agios Stefanos IC (R = 110 m). Consequently, the speed reduction and deceleration profiles at Metamorfosi IC are considerably more abrupt than those observed at Agios Stefanos IC.




Agios Stefanos IC - Speed vs distance data




Agios Stefanos IC – Deceleration vs distance data

## Analysis

The specification of vehicle exit speed and deceleration rate models during vehicle motion along the deceleration lane were determined on the basis of a thorough descriptive analysis of the data revealing linear associations of the above mentioned with the examined variables. A histogram of the response variable led to the identification of a symmetrical density function, suggesting a linear distribution.

A collinearity test was conducted, to ensure that the independent variables were not correlated with each other, in terms of Variance Inflation Factors (VIFs). As shown in the following table, the independent variables (predictors) have low VIF values (lower than 5.00), which means that the independent variables of each model demonstrate a non-linear relationship between them.

Table (a,b). Parameter Estimates of Linear Regression Models and VIFs.

(a) Vehicle Exit Speed ($V_{ex}$)

| Parameter | B | Std. Error | t-value | p-value | VIF |
|---|---|---|---|---|---|
| (Intercept) | 26.7174 | 5.6078 | 4.764 | <0.001 | - |
| $L_{dlul}$ | -0.0723 | 0.0082 | -8.776 | <0.001 | 2.164 |
| $V_0$ | 0.7148 | 0.0754 | 9.479 | <0.001 | 1.171 |
| $Ratio_{ul}^3$ | -8.9257 | 2.0481 | -4.358 | <0.001 | 1.191 |
| $α^2$ | -6.1011 | 0.8777 | -6.951 | <0.001 | 2.087 |
| df | | 4 | | | |
| Adjusted R-squared | | 0. 687 | | | |

(b) Deceleration (α)

| Parameter | B | Std. Error | t-value | p-value | VIF |
|---|---|---|---|---|---|
| (Intercept) | 0.4902100 | 0.3072750 | 1.595 | 0.116 | - |
| $L_{dlul}$ | 0.0045440 | 0.0003770 | 12.062 | <0.001 | 1.557 |
| $V_0$ | -0.0390400 | 0.0046330 | -8.425 | <0.001 | 1.523 |
| $Ratio_{ul}^3$ | 0.4261040 | 0.1130500 | 3.769 | <0.001 | 1.251 |
| $V_{ex}^3$ | 0.0000030 | 0.0000005 | 6.664 | <0.001 | 1.841 |
| df | | 4 | | | |
| Adjusted R-squared | | 0. 743 | | | |

where: $L_{dlul}$: deceleration lane utilization length | $V_0$: vehicle entry speed at the deceleration zone
$L_{dll}$: deceleration lane length | $V_{ex}$: vehicle exit speed from the deceleration zone
$Ratio_{ul}$: utilization length ratio ($L_{dlul}$ / $L_{dll}$)
α: mean deceleration during vehicle motion along the utilized deceleration zone

The results highlight that speed and exit ramp geometry—such as taper length and controlling curve—and normalized deceleration distance—defined as the deceleration ratio along the deceleration lane—play a decisive role in driver behaviour.

## Conclusions

The main findings of the present study are summarized as follows:

**Prediction of unsafe operating conditions:** The models identify parameter combinations (e.g., high entry speeds and limited available deceleration distance) that may lead to excessive deceleration and increased safety risk.

**Identification of critical geometric features:** The analysis highlights geometric configurations that induce abrupt or excessive speed reductions along deceleration lanes.

**Support for design optimization:** The models assist in defining appropriate geometric parameters, including deceleration lane length and curvature, to ensure smooth and safe speed adaptation.

**Basis for predictive safety assessment tools:** The regression framework provides a foundation for evaluating interchange safety at the design stage and for comparing alternative design solutions.

**Potential integration with ITS applications:** The models can support driver warning or assistance systems by enabling timely speed adjustment prior to interchange entry.

**Overall contribution:** The proposed regression framework transforms field measurements into practical tools for safety evaluation and geometric design, supporting informed decision-making and risk reduction at grade-separated interchanges.

**Future research** should focus on expanding the experimental dataset by including a larger and more diverse sample of drivers and ramp configurations to strengthen the generalizability of the findings.

Additional measurements should be conducted across ramps with varying geometric and traffic characteristics—such as different grades, curvature, and speed-change lane lengths—to capture a broader range of driving behaviours.

Moreover, incorporating a wider demographic spectrum of participants, including different age groups and experience levels, would help better understand behavioural variability.

Future studies could also benefit from combining accelerometer data with other advanced data collection techniques, such as vehicle-mounted sensors, to obtain more comprehensive and high-resolution behavioural measurements under real-world conditions.

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