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THE EFFECT OF ROADSIDE ON SPEED PERCEPTION

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Abstract. The study examines how various roadside elements, such as flat areas, trees, slopes, and buildings, influence speed perception. Data from multiple previous studies were combined and reanalyzed using newly established criteria to assess the proximity and nature of roadside features. The dataset includes 9 776 speed estimates, gathered from a wide range of road types and surroundings, allowing for an analysis of how these elements affect speed estimation accuracy.

The findings suggest that flat areas consistently lead to overestimations of speed, likely due to the lack of physical cues that provide visual references. In contrast, trees and forested environments have a stabilizing effect, helping individuals to estimate speed more accurately. Built environments, such as industrial zones and urban areas, tend to lead to significant overestimations of speed. These results highlight the importance of roadside environments in influencing speed perception, with natural settings like forests providing clearer visual cues that help drivers and observers better estimate speed.

Keywords: Speed perception, roadside, perception accuracy, speed estimation.

1. Introduction

The perception of speed is influenced by various roadside elements. Those can vary depending on the surrounding area and can include trees, barriers, slopes, buildings, etc. These visual stimuli can provide drivers feedback that affects their perception of how fast they are moving and understanding the role of roadside features in speed perception.

Dense roadside environments – trees, guardrails, and buildings – create a tunnel effect. This effect occurs when visual stimuli are placed close to the road, causing a sensation of increased speed as drivers pass them quickly. Drivers often respond by reducing speed, even if it is not excessive. This reaction has been well documented in urban environments, where buildings or other vertical elements close to the road create a feeling of restriction that prompts slower driving. Guardrails, similarly, add to this effect by reinforcing the sense of lane narrowing, which encourages cautious driving [1, 2].

In contrast, open landscapes, such as fields, sparsely vegetated areas, and wide, open spaces, lead to the opposite effect. These environments tend to provide fewer visual cues, which can cause drivers to underestimate their actual speed, leading to unintentional speeding. This effect is most commonly observed on highways and rural roads, with minimal visual feedback. Studies show that drivers on roads bordered by wide fields or open landscapes tend to accelerate beyond safe limits [3].

Roadside vegetation, such as shrubs and bushes, provides moderate visual feedback that can influence speed perception. While not as dramatic as large trees or buildings, roadside vegetation helps create a continuous visual flow that gently encourages drivers to maintain a slower speed, particularly in suburban or residential areas. Research has found that roads lined with trees or vegetation reduce perceived speed and promote safer driving practices [1, 2].

Road design plays a critical role in influencing speed perception through elements like slopes and guardrails. Guardrails close to the road's edge act as a visual boundary, narrowing the perceived road width and encouraging slower speeds. Additionally, sloping terrain, particularly slopes that rise away from the road, can create an open feel that leads to speed underestimation. Conversely, steep roadside slopes can enhance the tunnel effect by making the road feel more confined [1].

Recent studies using dynamic measurement techniques reveal that drivers continuously adjust their speed based on the real-time visual information they receive from their surroundings. Misjudgments, such as underestimating speed in open areas, can lead to excessive speeds in environments with fewer roadside cues. These studies emphasize the need for road designs that provide more consistent feedback, especially on highways and rural roads [2].

The effect of the roadside environment on speed perception is not purely visual; psychological mechanisms play a significant role. For example, when drivers feel that a road is narrow or enclosed due to roadside elements, they perceive a higher level of risk, leading to reduced speed. On the other hand, open roads with fewer obstacles are perceived as less risky, leading to faster driving speeds, often beyond the posted limits [3]. Understanding these psychological responses is essential for designing roadways that naturally encourage safe driving behavior.

Roads that transition from dense, visually stimulating environments (such as urban streets) to open, less stimulating environments (such as rural highways) can cause fluctuations in speed perception. Drivers moving from a visually confined area to an open space may suddenly feel that they are moving too slowly and accelerate, sometimes dangerously. This variability in speed perception highlights the need for carefully managed transition zones to maintain consistent speeds across different driving environments [1].

According to Hurwitz et al. [4], drivers tend to underestimate their speed, particularly in environments where visual cues, such as horizontal curves and surrounding landscape, play a role. These findings suggest that elements like road curvature, visual landmarks, and the type of environment (e.g., urban vs. rural) can significantly alter drivers' perception of speed. The study highlights that drivers' accuracy in estimating their speed decreases in more complex visual environments. This supports the idea that roadside features and the immediate surroundings impact speed perception. This observation aligns well with your focus on evaluating the influence of proximity to roadside elements and the broader environmental context on speed perception.

Additionally, research on speed perception has consistently shown that environmental factors, such as road geometry and surrounding visual cues, play a crucial role in influencing how drivers perceive their speed [5]. Studies, including those focusing on freeway curves, demonstrate that drivers often underestimate their speed when navigating certain road configurations, particularly curves with smaller radii or complex curve combinations. For example, research on freeway curves shows that drivers are most prone to underestimating their speed at a curve's tangent-to-spiral (TS) point, especially when the curve radius is tight. This highlights the importance of understanding how road characteristics and environmental visual feedback affect speed perception.

Such findings are directly relevant to this study's focus on how roadside environments – including proximity to the road and broader landscape features – affect drivers' speed estimation. By exploring the influence of roadside elements like trees, barriers, or open fields, this research aims to extend the understanding of how visual factors surrounding the road contribute to misestimations of speed, much like how curve geometry has been shown to influence drivers' perception in freeway settings.

Previous theses on speed perception have primarily focused on demographic factors, such as the age, gender, and driving experience of respondents, or on the estimated vehicles' characteristics. These studies aimed to understand how personal attributes or vehicle types influenced speed estimation [6–11]. However, this study diverges by focusing solely on the impact of roadside elements on speed perception, without considering other factors like respondent demographics or vehicle characteristics.

Data from earlier theses, where still available, were repurposed to create a new dataset for this research. This dataset has been reanalyzed with a specific focus on roadside environments, such as the proximity of trees, barriers, and open spaces, to understand better how these elements influence drivers' ability to perceive speed accurately. By eliminating the influence of demographic or vehicle-specific variables, this study aims to isolate the effects of roadside features on speed perception.

2. Dataset and method

This study builds upon data previously collected from several completed master's theses and one related study, repurposing the existing datasets to create a new, comprehensive dataset. While the original focus of these works was not specifically on the impact of roadside environments on speed perception, this new analysis shifts the attention to how different surroundings might influence drivers' and witnesses' ability to estimate vehicle speed accurately.

The newly formed dataset incorporates observations and speed estimates from various experiments but applies fresh evaluation criteria centered around the proximity and characteristics of the roadside environment. These criteria include elements such as the type of surrounding landscape (e.g., forest, urban, rural), distance of roadside features from the road (such as trees, barriers, or open fields), and visibility conditions. By reorganizing and analyzing the data through this new lens, the study aims to explore how these environmental factors affect speed perception in ways not considered in the original analyses. This approach provides a novel understanding of roadside environments' role in speed estimation, contributing to more effective traffic safety measures and road design.

2.1. Original datasets

The master thesis focuses on the perception of vehicle speed from the pedestrian's perspective [8], with an experiment designed to gather speed estimation data under various conditions. The measurement setup involved a sample of 13 respondents (7 men and 6 women) who participated in two days of measurements. The experiment was conducted at multiple locations, with vehicles traveling at specified speeds (e.g., $30\,\mathrm{km\,h^{-1}}$, $50\,\mathrm{km\,h^{-1}}$, and $90\,\mathrm{km\,h^{-1}}$). The participants observed these vehicles and provided estimates of their speeds.

The total dataset comprised 2 090 speed estimates, with 895 estimates from men and 1 195 from women. These estimates were later analyzed to understand the factors that influenced the accuracy of speed perception, such as vehicle type, gender, and the roadside environment.

The experiment in Barbora Formanová's thesis [9] took place on a 1.9 km-long road, chosen for its low traffic intensity and suitability for testing speeds at 30 km h^{-1}, 50 km h^{-1}, and 70 km h^{-1}. The road surface was asphalt but showed signs of wear, including cracks and potholes, providing a realistic driving environment.

The surroundings of the test road were primarily agricultural fields, offering minimal distractions, which allowed drivers to focus on estimating vehicle speed. 600-speed estimates were collected from 10 drivers across 10 test drives, with drivers estimating speeds in both their vehicles and borrowed ones. This setup allowed for investigating how drivers perceive vehicle speed in real-world conditions.

The thesis by Faruk Pršeš [10] focuses on passengers' perceptions of oncoming vehicle speed in moving vehicles. The objective was to evaluate how accurately passengers can estimate the speed of an oncoming vehicle under different conditions, considering factors such as age, gender, driving experience, and vehicle type.

The experiment was conducted over two days with 23 participants (15 men and 8 women), including drivers and non-drivers. The participants were seated in various vehicles and tasked with estimating the speed of oncoming vehicles under real-world traffic conditions. The study was conducted on a 2 km road with low traffic intensity in a city. The experiment assessed speeds of 50 km h^{-1}, 70 km h^{-1}, and 90 km h^{-1}.

The experiment gathered 3 240 speed estimates – 1 620 estimates for the speed of oncoming vehicles and 1 620 estimates for the speed of the vehicle in which the participants were seated. The results were analyzed to assess the accuracy of speed estimations, focusing on how these estimations were influenced by the participant's age, gender, driving experience, and position in the vehicle.

Nela Budinová's thesis [11] examines passengers' perception of vehicle speed, focusing on the influence of driving experience and distractions. The experiment was conducted on a 12 km route, utilizing different road types such as urban, rural, and highway settings. Participants with varying levels of driving experience were asked to estimate the vehicle's speed under two conditions: one where they were fully focused on the road and another where they were distracted by solving sudoku puzzles.

The experiment aimed to assess how attention and distraction impact speed perception across different types of vehicles. 2 119 speed estimates were collected, with 2 174 actual speed measurements recorded. A slight discrepancy in the number of estimates was due to signal transmission issues encountered during the experiment. The results provided valuable insights into how distractions and driving experience affect passengers' ability to accurately estimate vehicle speed in real-world conditions.

An additional study [12] examined how accurately individuals can estimate vehicle speeds during nighttime conditions. The study involved 10 respondents (5 men and 5 women) who were tasked with estimating the speed of passing vehicles. The experiment was conducted over two days, with respondents positioned 15 meters from the road. A total of 1 593 speed estimates were collected during the experiment.

The results showed that women generally overestimated speeds, while men were likelier to underestimate them. The observer's position also influenced the accuracy, with estimates being more accurate when respondents observed vehicles from a 30-degree angle compared to a 90-degree angle. Other factors, such as visual and auditory abilities, also contributed to variations in speed estimates.

Overall, the new dataset used in this study consists of 9 776 estimates.

2.2. New criteria

This study builds on data from previously conducted theses and one related study, creating a new dataset to explore the impact of roadside environments on speed perception. Although the original research was not focused on this specific area, the existing data has been reanalyzed using new criteria designed to assess how different surroundings influence the accuracy of speed estimates.

The new criteria are based on the proximity of roadside features, which were divided into several categories. These include the area directly adjacent to the road, defined as within 1 meter of the road's edge ("surroundings at 1 m"), and the immediate surroundings, which extend up to 5 meters from the road ("surroundings at 5 m"). A broader category considers the wider surroundings beyond 5 meters and approximately up to 15 meters ("surroundings beyond 5 m"). In addition to these proximity-based factors, the study also evaluates the overall location of the landscape, such as whether the road is situated in an urban area, rural environment, or near forested regions ("landscape").

By applying these criteria to the dataset, the study aims to analyze how the presence of nearby objects, open spaces, and various types of development influence drivers' and witnesses' ability to estimate vehicle speeds accurately.

Table 1 shows individual categories that were identified within the defined variables.

The Mann-Whitney U test was used to evaluate the differences between two independent groups. The *p*-value (also referred to as significance or simply *p*) was calculated for each factor, which is a numerical value used in statistical hypothesis testing. A significance level (95 %) was established, after which the *p*-value was computed and compared with the significance level. If the calculated *p*-value was less than 0.05, the null hypothesis (that the examined factor affects speed estimates) was considered credible.

Variable	**Category**					
Surroundings at 1 m	Flat area	Ditch	Guardrails	Uphill slope	Downhill slope	
Surroundings at 5 m	Flat area	Trees	Fence	Buildings	Uphill slope	Downhill slope
Surroundings beyond 5 m	Flat area	Trees	Buildings			
Landscape	Urban area	Industrial area	Forest	Field		

Table 1. Variables and their categories.

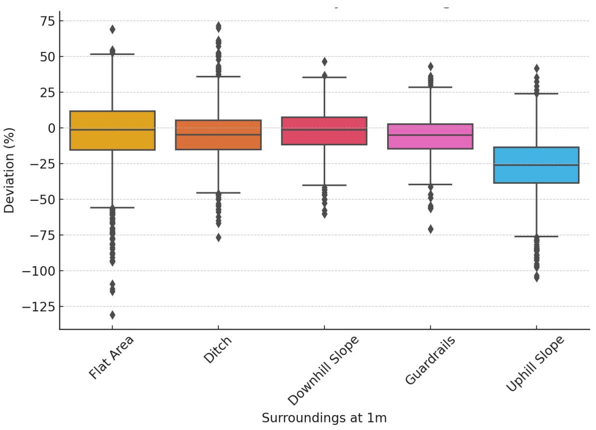

Figure 1. Deviation distribution by "Surroundings at 1 m".

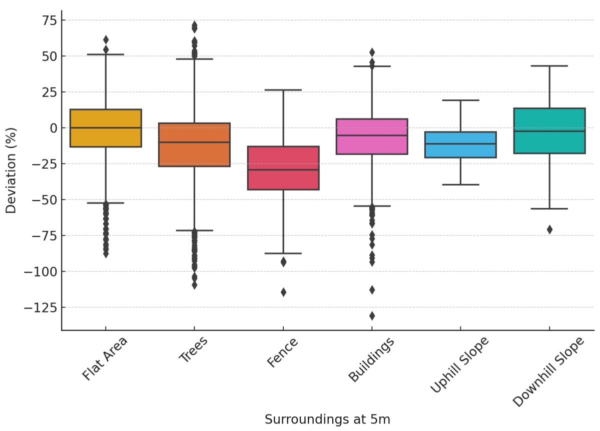

Figure 2. Deviation distribution by "Surroundings at 5 m".

3. Results

In the variable "surroundings at 1 m", significant differences were found between several categories. "Flat area" has a positive effect on the deviation, meaning the estimated speed is higher than the actual speed, while "Ditch" also has a positive but smaller effect. A significant difference was found between "Flat area" and "Ditch" (p-value < 0.05), with the flat area causing a larger deviation. Similarly, "Flat area" increases the deviation compared to "Guardrails" (p-value < 0.05), where guardrails have a negative effect on the deviation, meaning the actual speed is closer to the estimate. In the comparison between "Flat area" and "Uphill Slope" (p-value < 0.05), the flat area has a positive effect on the deviation. In contrast, the uphill slope has the opposite effect – reducing the deviation.

However, the difference between "Flat area" and "Downhill slope" (p-value $= 0.395$) was not statistically significant. Additionally, the difference between "Ditch" and "Guardrails" (p-value $= 0.206$) was also not significant. Figure 1 shows the deviation distribution of each category.

In the variable "surroundings at 5 m", significant differences were found between categories. "Flat area" increases the deviation compared to "Trees" (p-value < 0.05), which have a stabilizing effect and reduce the deviation. "Flat area" also shows a higher deviation compared to "Fence" (p-value < 0.05), where the fence has a slightly negative effect and reduces the overestimation of the estimated speed. A significant difference is also found between "Flat area" and "Buildings" (p-value < 0.05), where both categories increase the deviation, but buildings have a stronger effect.

However, some "surroundings at 5 m" comparisons were insignificant. The differences between "Flat area" and "Downhill slope" (p-value $= 0.605$), "Trees" vs. "Downhill slope" (p-value $= 0.222$), and "Trees" vs. "Uphill slope" (p-value $= 0.187$) were all not statistically significant. Figure 2 shows the deviation distribution of each category.

In the variable "surroundings beyond 5 m", significant differences were found between categories. "Flat area" increases the deviation compared to "Trees" (p-value < 0.05), which have a stabilizing effect and reduce the deviation. Buildings increase the deviation more than "Trees" (p-value < 0.05), where trees stabilize the difference between actual and estimated speed.

However, the comparison between "Flat area" and "Buildings" (p-value $= 0.224$) was not statistically significant. Figure 3 shows the deviation distribution of each category.

In the variable "Landscape", significant differences were found between categories. "Industrial zone" greatly increases the deviation compared to "Forest" (p-value < 0.05), where the forest has a stabilizing effect and reduces the deviation. Field increases the deviation, but less so than the industrial zone, while "Forest" again reduces the deviation (p-value < 0.05). In the comparison between "Urban area" vs. "Forest" (p-value < 0.05), the urban area increases the deviation, but less than the industrial zone. In contrast, the forest has a negative effect and stabilizes the dif-

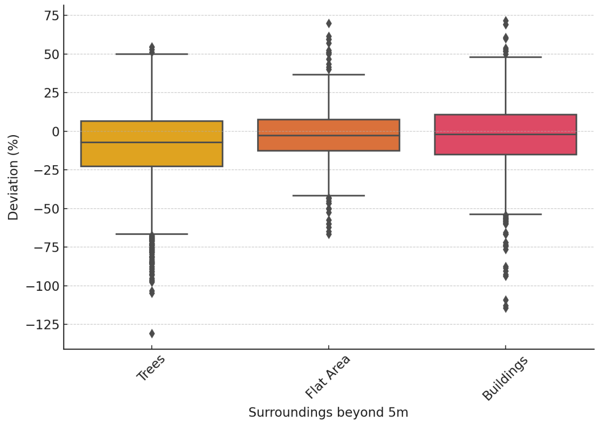

Figure 3. Deviation distribution by "Surroundings beyond 5m".

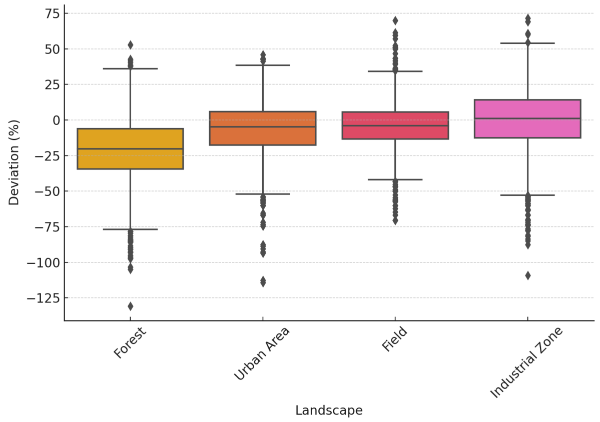

Figure 4. Deviation distribution by "Landscape".

ference between actual and estimated speed. Figure 4 shows the deviation distribution of each category.

4. Discussion

Analyzing the surroundings at various distances (1 m, 5 m, beyond 5 m) and landscape provides valuable insights into how different environments influence human perception of speed. One clear pattern is that flat areas tend to lead to overestimation of speed. This suggests that in environments characterized by flat terrain, people are likely to think vehicles are moving faster than they actually are. The lack of visual obstacles or cues, such as changes in elevation, might contribute to this overestimation, as it may create a sense of openness where objects appear to move faster.

On the other hand, trees consistently show a stabilizing effect on speed perception. In areas with trees, people tend to estimate speed more accurately, possibly due to the visual references trees provide or the environmental factors like shading and wind buffering that help moderate their perceptions. This suggests that in more structured environments where natural elements are present, people have a better sense of the actual speed.

In contrast, built environments like buildings and particularly industrial zones significantly increase the overestimation of speed. These areas are likely more complex visually, with large structures and potential obstacles that distort people's ability to accurately gauge how fast vehicles are moving. The confined spaces and obstructions in these areas could create a false sense of speed, making vehicles seem faster than they are.

Moreover, forests and urban areas generally reduce the deviation between perceived and actual speeds, with forests showing the most substantial stabilizing effect. This finding indicates that natural settings with consistent environmental features allow for more accurate speed assessments, perhaps because the surroundings provide regular, predictable visual cues that help people judge motion.

There were also instances where the differences between certain categories, such as Flat Area vs Downhill Slope or Flat Area vs Buildings, were not statistically significant. This indicates that while the environment often affects speed perception, it does not do so uniformly across all situations and settings.

5. Conclusions

This study shows that the roadside strongly influences human perception of speed. Natural settings, such as trees and forests, help people estimate speed more accurately, while flat areas and built environments, like industrial zones and buildings, often lead to overestimations. The lack of visual cues or the complexity of these environments distorts how fast vehicles are perceived.

Future research should explore why people overestimate speed in these environments, considering visual complexity, environmental familiarity, and weather conditions. All these factors – demographics of the observers, traffic intensity, road surface, lighting conditions, and types of intersections – must be measured simultaneously to capture their combined effect on speed perception. We can only fully understand how they interact and shape perception by studying them together.

Understanding these factors could lead to better insights into how humans perceive speed, with practical applications in urban planning and road safety.

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