A Multi-level Approach to Link Smooth Driving with Safe Driver Behavior

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Abstract

Smooth driving is the most critical dimension of the general notion of eco-driving and may have a potential impact on accident risk. Nonetheless, research thus far has not shed light on the relationship between smooth driving and safety-related driving behavior. This paper aims to understand the strength of the relationship between smooth and safe driving. To this end, a methodological approach that combines a trip and driver level analysis is proposed based on the K-Means algorithm for trip clustering and driver evaluation and the Data Envelopment Analysis for safety efficiency evaluation of drivers. Data used are recorded during a naturalistic driving experiment with more than 760 participating drivers. Results indicate that there exist 3 clusters of different levels of smooth driving on a trip level. Drivers' efficiency evaluation demonstrated that there are significant differences in attributes of most and least efficient drivers. A strong relationship is then revealed between overall safe efficiency on a driver level and smooth driving on a trip level by estimating Kendall's tau and Spearman's rank correlation of the two rankings (safe and smooth driving). These findings show a potentiality for predicting the occurrence of safe driving through smoothness characteristics observed on a trip level and vice versa and could be exploited to provide personalized feedback to drivers to improve their driving behavior in terms of smoothness and safety.

Motivation

Different drivers execute a variety of behaviors while driving such as aggressive driving or driving over the speed limit. Therefore, **driving safety efficiency** has been studied previously to assess driving performance in terms of safety.

The modern shift towards the sustainability of transport highlighted the importance of another driving style the "eco-driving" or **smooth driving**, that involves a gradual approach to both accelerating and braking, as well as maintaining a constant speed.

Research Questions:
1. What are the dissimilarities, in terms of unsafe driving habits, among drivers that belong to different safety efficiency levels?
2. What are the different trip/driving profiles with respect to smooth driving and what is their average behavior?
3. Is there a relationship between smooth driving and safe behavior?
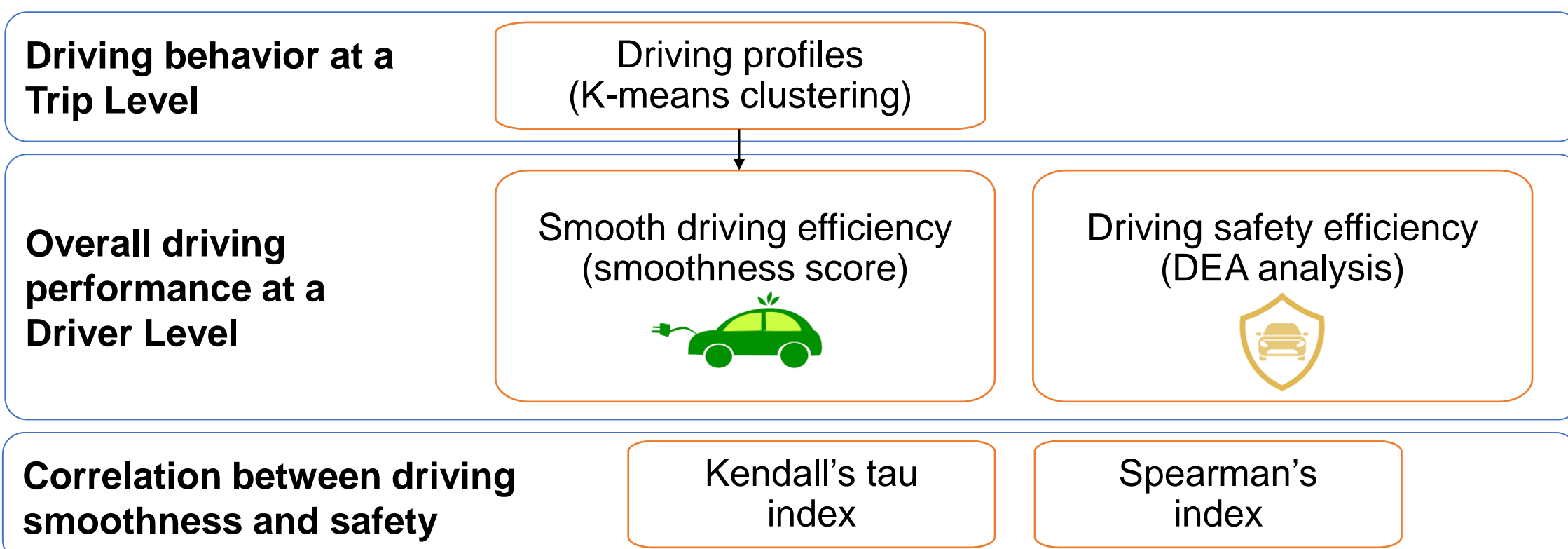
Methodological Approach

Figure 1 Methodology for driving behavior identification at different levels

Profiling at a trip level and driver performance evaluation

Driving behavior is defined at **a trip level,** which corresponds to the way the driver performed a specific trip → "trip profile"

TABLE 1 Clustering centers and number of trips per trip profile

Driving profiles	Average acceleration	90th percentile of acceleration	Average deceleration	90th percentile of deceleration	Kinetic energy indicator (smoothness)	Acceleration from stop	Number of trips [%]
rough driving	1.671	3.728	-1.839	-0.246	0.402	5.502	53,205 [23.2%]
intermediate behavior	1.275	2.827	-1.442	-0.198	0.305	3.922	126,749 [55.3%]
smooth driving	0.950	2.083	-1.091	-0.155	0.230	2.239	49,349 [21.5%]

Smooth driving is characterized by significantly low values of acceleration and deceleration and, at the same time, the range of values is significantly smaller compared to that in the rough driving profile (Figure 2).

Smooth driving **score** per driver is given by:

$$Smoothness\ score\ (i) = P_{smooth} * 3 + P_{intermediate} * 2 + P_{rough} * 1$$

where P_x is the percentage of the trips in each of the three driving profiles.
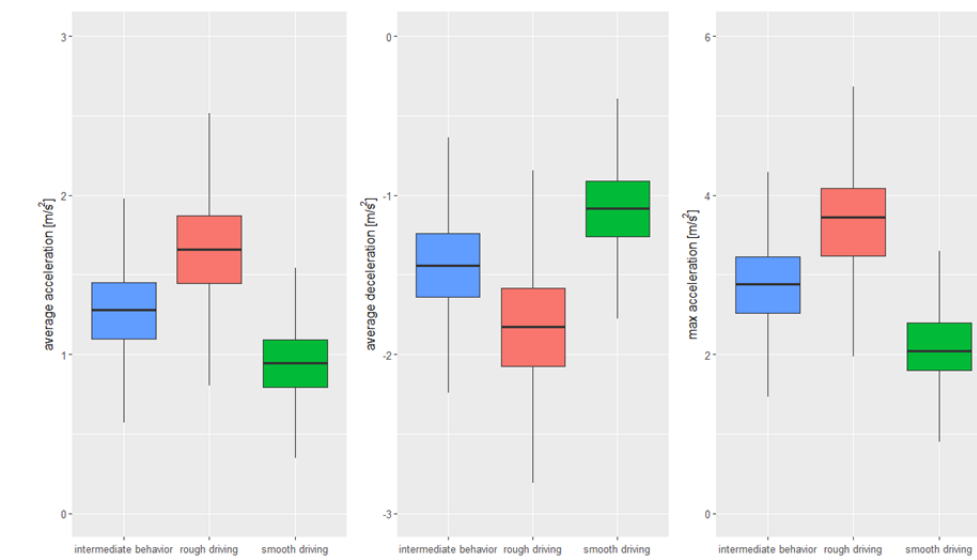

Figure 2 Boxplots of acceleration measurements for the three trip profiles

Driving safety benchmarking

The **DEA** method assigned a safety efficiency index to each driver. Drivers are divided into 4 groups based on this efficiency index using the 4 quartiles ranging from 0% to 100%, with 100% being the highest possible efficiency.

It is observed that average metric values are lower for driver groups with higher efficiency, with the highest similarity being observed between drivers that belong to the 50-75% and 75-100% quartiles. For instance:
- the least efficient drivers use their mobile phones 2.8 times more and they drive over the speed limit 2.2 times more than the most efficient ones
- Regarding harsh events, the least efficient drivers perform 3.9 times more HA and HB events than the most efficient drivers
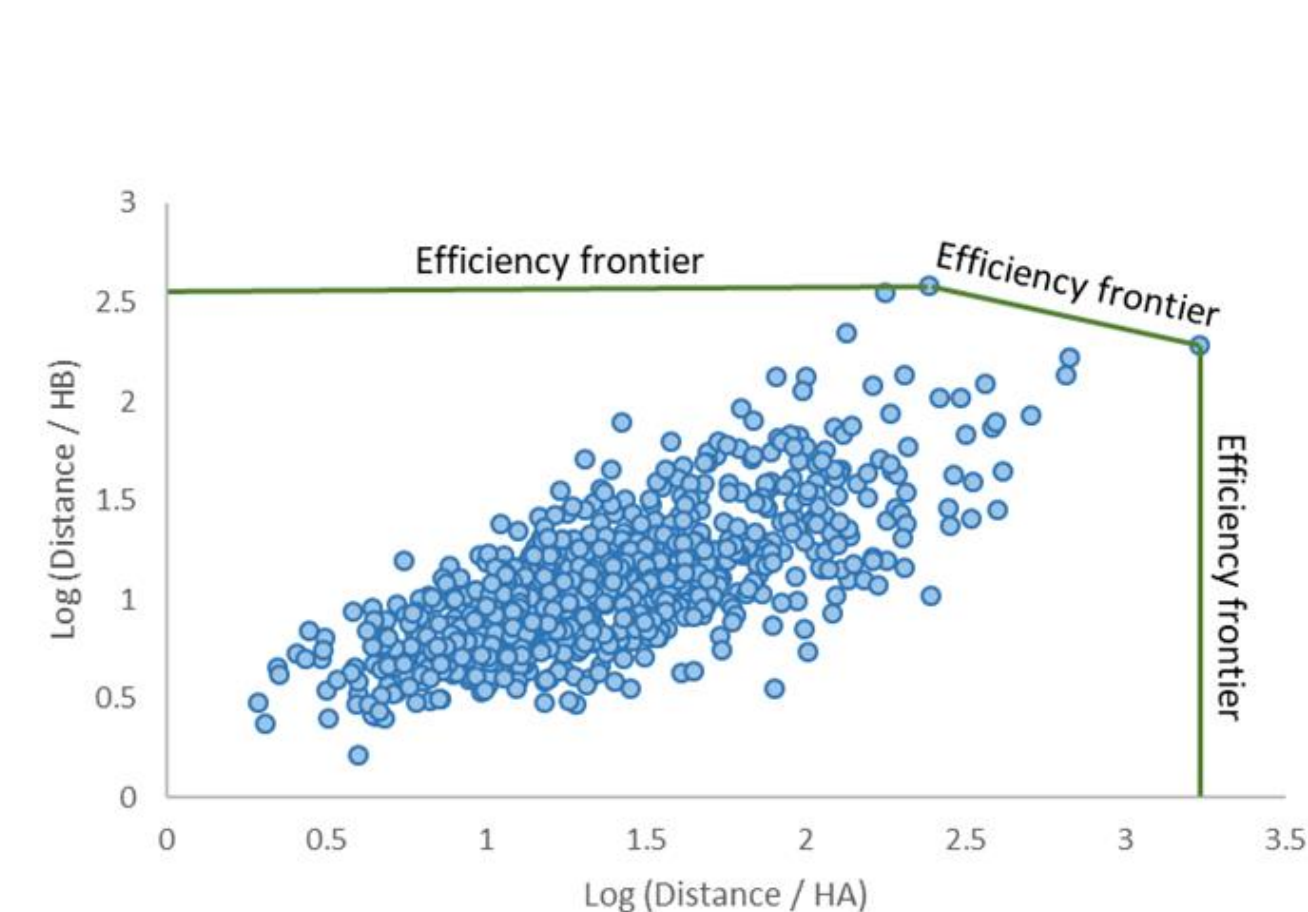

Figure 3 Indicative efficiency frontiers for drivers' safety based on harsh acceleration and braking events

Main Findings and Discussion

The percentage of smooth trips is steadily **increasing** when moving to quartiles of more efficient drivers (Figure 4).

For example, 15% of the trips performed by the drivers that belong to the first quartile range of safe driving efficiency were trips characterized by rough driving, whereas 52% and 33% of total trips refer to smooth and intermediate driving behavior, respectively.

The above are an indication of an **existing relationship** between smooth driving and safe behavior.

The correlation between the two behavior rankings is calculated using Kendall's (concordance) tau index and Spearman's rank order correlation index:
- **Kendall's tau** is 0.42 and the concordance index is 0.71, which can be interpreted as that 71% of the driver pairs are ranked in the same way in both rankings.
- **Spearman's rank order correlation coefficient** is 0.69, which also indicates a significant and positive correlation, i.e. a safer driver's behavior is also smoother and vice versa.
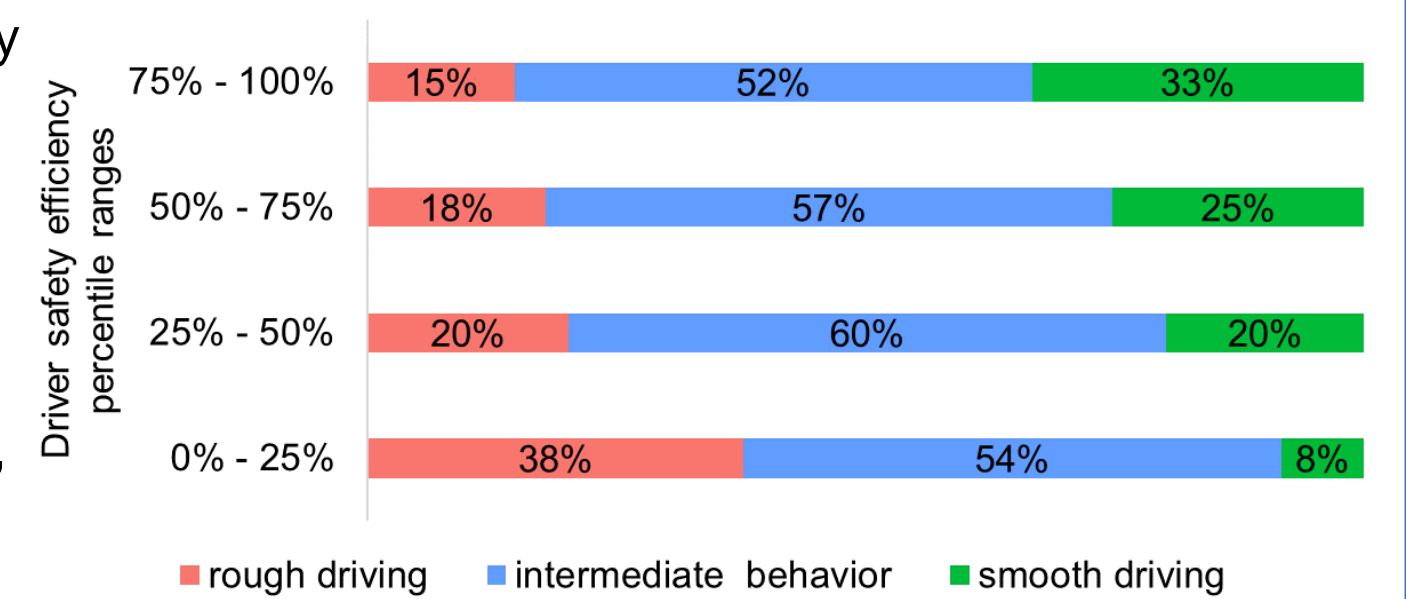

Figure 4 Distribution of trips across smooth driving trip clusters for each quartile of driver safety efficiency

Conclusions

- ☐ Three driving profiles were identified at a trip level based on different levels of smoothness during driving: smooth, rough and intermediate driving.
- ☐ Driving safety efficiency was investigated at a driver level and findings revealed significant differences between the driving parameters among the four quartiles of driving efficiency.
- ☐ The percentage of rough and smooth trips that most efficient drivers perform is remarkably lower and higher, respectively, than the respective percentage of the least efficient drivers.
- ☐ A strong relationship between smooth driving and safe driving behavior which is statistically significant, was identified.
  - ☐ This relationship indicates the potential of predicting safe driving behavior through smooth driving parameters, when information on safety parameters is not available, and vice versa

Potential applications:
Development of a driving evaluation – scoring system based on smooth and safety behavior indicators as well as of recommendation systems that provide feedback to drivers in order to improve driving behavior in terms of smoothness and safety.

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