Poster: Platooning Revisited: What is the Personal Benefit Compared to ACC and Human Driving?

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***Abstract*—Platooning has been researched for decades but debate about its lasting impact is still ongoing. Meanwhile, adaptive cruise control (ACC) became de facto standard for all new cars as well as for automated driving on the freeway. An evaluation of the personal benefit these systems offer remains difficult. To this end, we propose to assess driving systems by looking at the overall trip cost to incentivize drivers accordingly. For this, we define a novel metric to quantify the total trip cost, combining fuel cost and travel time within a monetary unit. We show the application of our new metric in a case study, comparing human driving, ACC, and platooning. Our results indicate that human driving always loses against ACC and that platooning has a significant advantage in mid to high traffic densities.**

I. INTRODUCTION

Road traffic has been constantly growing in recent years, leading to increasing congestion and environmental pollution. To cope with these adverse effects, modern vehicles are being equipped with advanced driver assistance systems and V2X communication technologies like 5G and DSRC. These technologies not only improve driving safety and comfort, but also efficiency by enabling new driving systems, like adaptive cruise control (ACC) and platooning [1]. Today, ACC is the de facto standard for all new cars and for automated driving on the freeway. Platooning goes one step further and allows multiple vehicles to drive in convoys with small but stable safety gaps using cooperative adaptive cruise control (CACC). Thereby, it improves traffic flows and safety by better synchronization and fuel consumption due to the slipstream effect [2].

Although the benefit is rather obvious for certain use cases, e.g., truck platoons aim to minimize fuel consumption, individual drivers cannot precisely assess their immediate benefits by using such systems on freeways according to their unique expectations. Alongside several qualitative expectations like safety and comfort [3], a natural driver incentive to employ a driving system is a potential reduction in the overall trip cost. For instance, an optimal driving speed can result in less fuel cost but causes an extended trip time compared to driving faster yet fuel-inefficient.

To quantify driver incentive, we introduce a novel metric combining the consumed fuel and travel time into a single trip cost value, which can be computed according to the drivers' personal preferences. By giving a personal monetary value for time spending, drivers can use this metric to estimate their overall trip cost induced by different driving systems and employ the one with minimum cost, which is assumed to be their primary incentive. We also present preliminary results based on real-world monetary data to illustrate the applicability of our metric for assessing driving systems. We are able to demonstrate that human driving always lacks behind standard ACC. Furthermore, our results show that platooning outperforms ACC, especially in medium to high-density traffic.

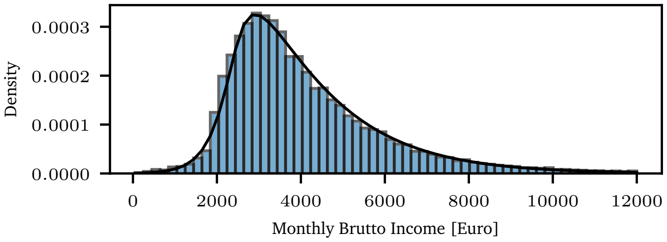

Figure 1. Distribution (and fit) of monthly brutto income (in Euro) of German full-time workers in April 2023. Statistisches Bundesamt (Destatis) 2024.[2]

II. MINIMIZING TRIP COST AS DRIVER INCENTIVE

When computing driver incentive, it is an inherent trade-off to optimize fuel consumption and travel time simultaneously as both are directly proportional to the driving speed. We aim for an intuitive metric by mapping these factors into a common monetary unit that drivers can easily grasp and use for understanding their personal benefit from driving systems, e.g., fuel and time savings due to reduced air drag and improved traffic flow in platooning [2]. Therefore, we propose to assess the total cost of a trip C_{trip} by summing up the cost of the consumed fuel and the travel time as follows:

$$C_{\text{trip}} = \text{fuel}_{\text{trip}} \times C_{\text{fuel}} + \text{time}_{\text{trip}} \times C_{\text{time}} \tag{1}$$

The fuel cost is calculated as the product of the (estimated) fuel consumption ($\text{fuel}_{\text{trip}}$) and a typical cost of fuel (e.g., gasoline) per liter (C_{fuel}). For electric vehicles, electric energy consumption and battery charging cost can be used accordingly. Based on the nominal values of C_{fuel} and C_{time}, the prioritization between fuel consumption and travel time can be adjusted.

Then, we calculate the time cost as the product of the estimated travel time ($\text{time}_{\text{trip}}$) and a monetary value for time (C_{time}). The latter value can be configured by drivers during trip planning via the navigational system, depending on their personal preference. In this study, we consider a traditional mapping from time to money by looking at the typical earnings of a German full-time worker. Using the statistical data, we fit a generic hyperbolic distribution as shown in Figure 1.

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[2] https://www.destatis.de/DE/Themen/Arbeit/Verdienste/_Grafik/_Interaktiv/verteilung-bruttomonatsverdienste-vollzeitbeschaeftigung.html, March 6, 2024.

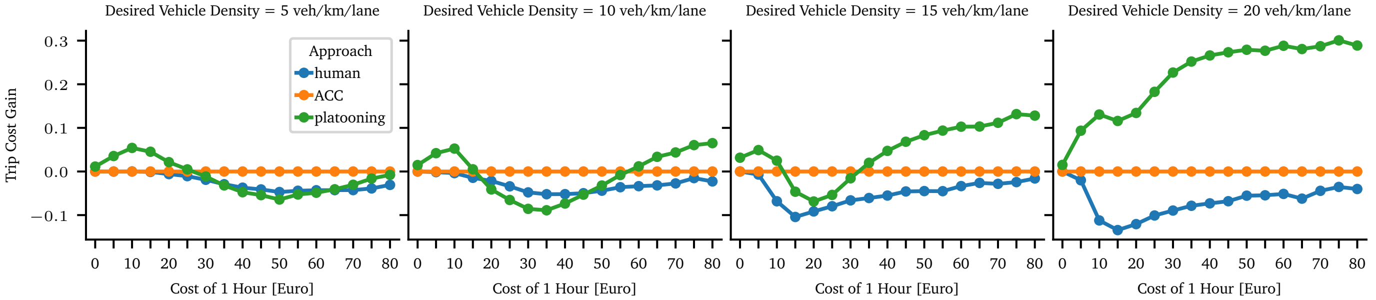

Figure 2. Average trip cost C_{trip} (our metric) gain in relation to ACC calculated by $\frac{\text{ACC}-\text{Approach}}{\text{ACC}}$. The x-axis shows various values for C_{time} as cost of 1 hour.

We sample values from this distribution to assign a monetary value to drivers' time (cost), proportional to their income. Our rational here is that travel time, although not paid directly, is considered wasted time. As shown in the figure, the values are in 0–12 000 € with a mode of 3000 €. Since the data and the samples are values for the monthly income, we divide a sampled number by 160 to transform it into a cost of 1 h. This results in a distribution of 0–75 € with a mode of 18.1 €. Note that many other factors, such as demographics, culture, and personal preferences can be decisive on drivers' monetary value of time. We will investigate this further in future work.

III. CASE STUDY

We demonstrate the application of our metric using the PlaFoSim simulation framework [4]. We consider a 3-lane freeway of 100 km length with periodic on-/off-ramps, which vehicles use for random trips of 50 km length (cf. [5]). At trip start, drivers sample an hourly value for C_{time} based on Figure 1 and a correlated desired driving speed in 80–160 km/h with a mode of 120 km/h. All vehicles use $C_{\text{fuel}} = 1.87$ €/l.[3]

Vehicles start their trips driving individually, using either the Krauss model [6] for human driving or a standard ACC. Platoon formation is performed every 60 s using the distributed greedy approach from [5]. After formation is completed, platoon members use a standard CACC with constant spacing. Vehicles spawn via a flow with constant insertion, keeping a fixed traffic density (cf. [5]). We perform multiple simulation runs of 2 h.

Figure 2 shows the average gain on trip cost C_{trip} (our metric) for human driving (blue) and platooning (green) compared to ACC (orange) calculated by $\frac{\text{ACC}-\text{Approach}}{\text{ACC}}$. A positive gain indicates a lower trip cost, while a negative value indicates a larger C_{trip} in comparison to ACC. The x-axis shows various (rounded) values for C_{time} as cost of 1 hour and the facets show various values for a desired vehicle density in the scenario. We observe that the total trip cost C_{trip} is related to the time cost C_{time}. While the desired driving speed of vehicles is correlated with C_{time} in all approaches, the actual driving speed depends on the approach and the vehicle density. Human driving is suffering from traffic effects starting at $C_{\text{time}} = 20$ € and density 5 veh/km/lane. Here, automated driving with ACC always achieves faster driving speeds by synchronizing the traffic. Or in other words, human driving is never a good option for optimizing trip costs.

Platooning achieves a positive gain due to the slipstreaming effect when fuel cost is prioritized over time cost (low values of C_{time}). Increasing C_{time}, platooning sees similar effects as human driving, leading to negative gain in comparison to ACC. Here, fuel consumption or travel time is increased depending on the adjusted driving speed due to the way the similarity-based platoon formation algorithm works [5]. However, platooning helps in cases with larger C_{time} by allowing for a faster driving speed. Increasing the vehicle density underlines these effects: ACC suffers from traffic effects starting at density 15 veh/km/lane. In contrast, the range of negative gains for platooning becomes smaller and the minimum gain shifts towards lower C_{time} until platooning completely outperforms ACC. Especially for large C_{time}, platooning helps to keep up the driving speed in medium to high densities.

IV. CONCLUSION

We propose a novel metric to evaluate the personal benefits of individual drivers for human driving, ACC, and platooning. We assume drivers want to minimize the overall trip cost, which consists of costs for fuel and travel time. Accordingly, our metric combines these optimization factors into a single monetary value by assigning a corresponding value for the opportunity cost of time. Based on this metric, our evaluation indicates that human driving always loses against ACC and that platooning has a significant advantage in mid to high traffic densities. In future work, we will use our metric for further improved platoon formation to maximize drivers' benefits.

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