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Evaluating Fuel Consumption Rates Based on Rising Travel Demands Generated by Autonomous Vehicles

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Autonomous Vehicles (AVs) are anticipated to revolutionize the transportation sector by enhancing mobility and efficiency. However, the rise in travel demand resulting from increased accessibility and convenience may counterbalance the potential fuel savings associated with AVs. For this reason, this study examines the relationship between travel demand and fuel consumption, considering factors such as travel time, number of trips, and travel patterns. Through a combination of theoretical analysis and empirical data, the research aims to quantify the net effect of travel demand increment under varying demand scenarios using AVs on fuel consumption. The results showed that with the convenience of AVs, people may be more willing to tolerate longer commutes. This has led to an increase in Vehicle Hours Travelled, which directly translated to higher fuel consumption. These findings provide valuable insights for policymakers and stakeholders in designing sustainable transportation strategies and optimizing the energy efficiency of AV-based mobility systems.

1. Introduction

In recent years, the rapid advancements in autonomous vehicle technology have sparked a significant transformation in the landscape of transportation systems. This paradigm shift towards self-driving vehicles has the potential to reshape not only the way we move but also the fundamental dynamics of travel demand, travel time, and fuel consumption. The integration of autonomous vehicles into our roadways brings forth a complex interplay of factors that can lead to both foreseeable and unforeseeable consequences. As we stand at the intersection of technological innovation and transportation evolution, it becomes increasingly crucial to examine and understand the multifaceted effects that autonomous vehicles might exert on travel patterns, the time people spend on their journeys, and the overall consumption of fuel resources. This exploration not only sheds light on the potential benefits but also raises critical questions about the challenges and trade-offs that society must address to harness the full potential of this transformative technology.
Many studies have explained that autonomous vehicles (AVs) are thought to possess significant benefits in other crucial aspects like diminishing energy usage (Baz et al., 2020), lowering fuel consumption and emissions (Wadud et al., 2016), decreasing travel duration (Narayanan et al., 2020), and alleviating traffic congestion (Park et al., 2021). Researchers have also shown that autonomous vehicles have the potential to optimize driving patterns and reduce energy wastage through features like adaptive cruise control, efficient route planning, and smoother acceleration and braking. These capabilities can lead to improved fuel efficiency on a per-vehicle basis, as the technology is designed to prioritize efficient driving techniques. Shi et al. (2022) found through conducting a comparison of fuel consumption calculations that AVs consume less fuel than human-driven vehicles. They concluded that increasing headway settings led to a remarkable decrease in energy consumption. Pusztai et al. (2021) thought their study showed that 7.1 % of energy savings had been achieved by lightweight vehicles compared to human-driven ones. Chen et al. (2019), through using the established model configuration and underlying presumptions, the analysis revealed that the effects of automation on fuel usage span a broad spectrum. This ranges from a potential 45 % decrease in fuel consumption in the most positive scenario to a potential 30 % increase in the most negative scenario. The introduction of automation in urban road settings might yield more substantial fuel conservation compared to applying it to highways, primarily due to the distinct driving characteristics of urban roads. Similarly, it was determined by Wu et al. (2011) that while

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maintaining driver safety, individuals utilizing a fuel-economy optimization system exhibited noteworthy fuel savings compared to those not using a fuel-economy optimization system in various acceleration scenarios (resulting in an overall reduction in fuel consumption by 22–31 %) and in the majority of deceleration scenarios (resulting in an overall decrease in fuel consumption by 12–26 %). While AVs themselves can be designed to operate more efficiently and reduce fuel consumption compared to traditional human-driven vehicles, the broader effects on travel behavior and demand could have a significant influence on overall fuel consumption. In a previous study (Mohammed and Horváth, 2023), it has been indicated that enhancing public understanding and knowledge regarding the concept of AVs, along with expanding their understanding of the novel capabilities offered by such vehicles, will lead to an increase in the number of journeys. However, the impact of this increment in travel demand on fuel consumption has not been considered. To overcome this shortcoming, this study has investigated the quantity of fuel that might be consumed due to the increase in the number of trips that will be generated by using autonomous vehicles in the future.
The remainder of this paper is organized as follows. Section 2 describes the methodology used to analyze the obtained dataset. Section 3 presents the results that have been achieved after analyzing the quantity of fuel consumed due to the number of trips generated using AVs. Section 4 discusses the results and mentions the surrounding circumstances of the conducted work. Section 5 draws some conclusions and future directions.

2. Methodology

A comprehensive questionnaire was administered to a total of 5,679 individuals in Győr City, which boasts a population of 122,616, as well as 70 other villages within the agglomeration (as depicted in Table 1). This data collection effort was carried out as part of two distinct projects: one focused on enhancing public transportation through the procurement of electric buses within Győr and its economic zone, identified as "IKOP-3.2.0-15-2022-00042," and the other project aimed at improving suburban transportation in Győr, referred to as "IKOP-3.2.0-15-2022-00043". The survey, carried out in November 2022, sought to understand people's anticipations regarding an uptick in their average daily travel frequency in the coming years, provided they had access to autonomous vehicles (AVs). In addition, participants' travel time using current conventional vehicles (CVs) has been gathered and analyzed to represent Vehicle Hour Traveled (VHT). The calculated travel time will be the main factor in obtaining the expected quantity of fuel consumption by AVs once they alter conventional vehicles in the few coming years. The results will act as a considerable indicator to provide a prior understanding of the possible challenges that may impact the sustainability of future transport systems.

Table 1: Surveyed villages in the agglomeration

Village	Population	Village	Population	Village	Population
Abda	3,377	Öttevény	3,152	Nyúl	4,577
Bezi	528	Pér	2,665	Pannonhalma	3,571
Börcs	1,412	Rábapatona	2,677	Románd	1,282
Bőny	2,264	Rétalap	594	Sikátor	323
Dunaszeg	2,437	Sokorópátka	1,147	Tarjánpuszta	333
Dunaszentpál	761	Tényő	1,820	Táp	429
Enese	1,838	Töltéstava	2,600	Tápszentmiklós	741
Gönyű	3,381	Vámosszabadi	3,846	Románd	935
Tét	4,186	Vének	216	Veszprémvarsány	1,069
Győrladamér	1,876	Kóny	2,744	Árpás	268
Győrság	1,579	Ásványráró	2,157	Csikvánd	505
Győrsövényház	794	Darnózseli	1,627	Felpéc	995
Győrújbarát	7,983	Hédervár	1,329	Gyarmat	1,415
Győrújfalu	2,478	Lébény	3,351	Gyömöre	1,245
Győrzámoly	3,763	Lipót	855	Győrszemere	3,583
Ikrény	1,985	Mecsér	660	Kisbabot	242
Kajárpéc	1,316	Bakonygyirót	178	Mérges	113
Kisbajcs	968	Bakonypéterd	301	Mórichida	847
Koroncó	2,621	Bakonyszentlászló	1,734	Rábacsécsény	615
Kunsziget	1,385	Écs	2,228	Rábaszentmihály	494
Mezőörs	960	Győrasszonyfa	511	Rábaszentmiklós	150
Mosonszentmiklós	2,629	Lázi	531	Szerecseny	831
Nagybajcs	1,137	Nyalka	522		
Nagyszentjános	1,934	Pázmándfalu	1,165		

The survey included a well-structured questionnaire that captured the necessary information. Include questions about participants' demographic information (age, gender) and their interests or attitudes toward AVs. Also, include questions related to their travel patterns, such as their usual modes of transportation and typical travel times. As mentioned earlier, many of the outcomes, such as prior knowledge about AVs and the travel demand increment using AVs, have been obtained in the previous study (Mohammed and Horváth, 2023). In this study, the number of trips has been relied on to calculate the VHT by the questionnaire respondents. Then, the values of VHT are used to calculate the fuel consumption quantity for the current VHT using conventional vehicles, as well as future VHT using AVs. See Eq(1). It's worth mentioning that the engine capacity (size in number of cylinders) of the vehicles is taken into consideration when quantifying the consumed fuel. However, creating an accurate and comprehensive table of vehicle engine cylinders and corresponding hourly fuel consumption can be challenging due to the wide variety of vehicles, engines, and fuel efficiency factors, including engine size, type, load, driving conditions, and fuel type. For example, Krivoshapov et al. (2020) explained that when the engine is running without load, the hourly fuel consumption increases in proportion to the rotational speed of the crankshaft and the engine displacement. This study has provided a simplified example table that gives a rough idea of how fuel consumption might vary based on engine cylinders, which has been concluded from some fuel guides like (US DOE, 2023) and (Natural Resources Canada, 2023).

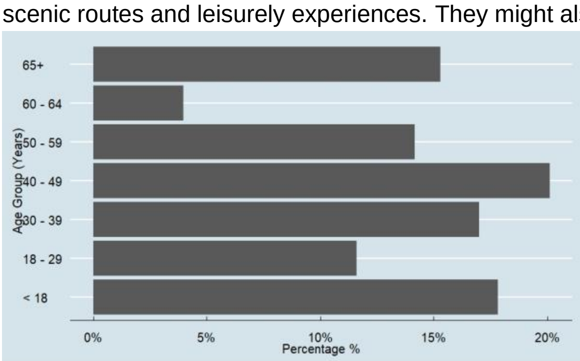
$$\text{Daily Fuel Consumption (L/day)} = [\text{VHT (h)} \times \text{Consumed Fuel per Cylinder per Hour (L/h)}]/60 \quad (1)$$

Table 2: Fuel consumption according to engine size (Natural Resources Canada, 2023)

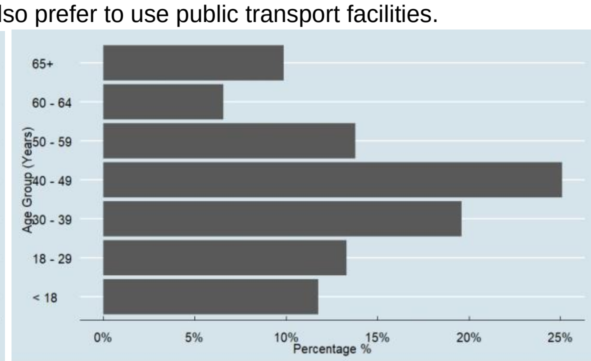
Engine Cylinders	Fuel Consumption per L/h (approx..)		
4	1.9	-	9.5
6	3.8	-	15.1
8	5.7	-	20.8
10	7.6	-	26.5
12	9.5	-	34

3. Results

The analysis of travel time data collected from a comprehensive survey has yielded intriguing insights into the variations of travel behaviors across different age groups. As it is always easier to collect data on the travel time of car users than collecting the distances traveled in such interviews, the survey results indicate distinct patterns in travel time preferences among these groups, as shown in Figure 1 (a) and (b). Young adults, typically aged under 29, exhibited a propensity for shorter travel times using cars, prioritizing efficiency and convenience. In contrast, individuals in the middle-aged group (30-59) demonstrated a more balanced approach, considering factors such as travel time, cost, and comfort. This is quite understandable as respondents in this age group have a more stable financial income, which enables them to travel more while using their own cars. The older demographic, aged 60 and above, showcased a willingness to spend moderate time traveling, often valuing scenic routes and leisurely experiences. They might also prefer to use public transport facilities.



(a) Gyor City

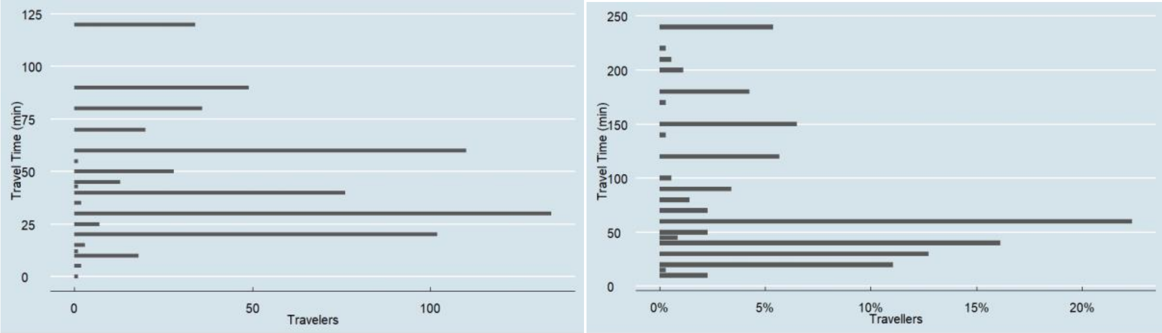


(b) Agglomeration

Figure 1: Age group vs travel time

On the other hand, the travel times in [min] are distributed according to the number of travelers, as shown in Figure 2. The total number of travel minutes in one day in Gyor City was 31,045 min for the sample interviewed. While for the agglomerations, the total number of travel minutes in one day was 26,880 min. This has led to obtaining a value of Vehicle Hour Traveled (VHT) of 517.4 and 448 for both Gyor City and the Agglomerations.

The calculated VHT belongs to the currently used CVs by the questionnaire respondents in both study areas, which is also relevant to the number of trips conducted by the same sample of respondents.



(a) Gyor City *(b) Agglomeration*

Figure 2: Travel time vs. no. of travellers

Table 3: Daily fuel consumption in Gyor City Using CVs and Avs in Gyor City

Demand Increment	No. of trips	VHT	No. of Cylinders	Daily Min. Consumed Fuel (L/day)	Daily Max. Consumed Fuel (L/day)
	1,554	517.4	4	983	4,915
Current	1,554	517.4	6	1,966	7,813
Using CVs	1,554	517.4	8	2,949	10,762
	1,554	517.4	10	3,932	13,711
	1,554	517.4	12	4,915	17,592
	1,780	592.4	4	1,126	5,628
14.5%	1,780	592.4	6	2,251	8,945
Using AVs	1,780	592.4	8	3,377	12,322
	1,780	592.4	10	4,502	15,699
	1,780	592.4	12	5,628	20,142
	1,989	662.2	4	1,258	6,291
28.0%	1,989	662.2	6	2,516	9,999
Using AVs	1,989	662.2	8	3,775	13,774
	1,989	662.2	10	5,033	17,548
	1,989	662.2	12	6,291	22,515

Table 4: Daily fuel consumption in Gyor City Using CVs and Avs in Agglomerations

Demand Increment	No. of trips	VHT	No. of Cylinders	Daily Min. Consumed Fuel (L/day)	Daily Max. Consumed Fuel (L/day)
	1,830	448.0	4	851	4,256
Current	1,830	448.0	6	1,702	6,765
Using CVs	1,830	448.0	8	2,554	9,318
	1,830	448.0	10	3,405	11,872
	1,830	448.0	12	4,256	15,232
	2,477	606.1	4	1,152	5,758
35.3%	2,477	606.1	6	2,303	9,152
Using AVs	2,477	606.1	8	3,455	12,607
	2,477	606.1	10	4,606	16,062
	2,477	606.1	12	5,758	20,607
	2,684	656.7	4	1,248	6,239
46.6%	2,684	656.7	6	2,495	9,916
Using AVs	2,684	656.7	8	3,743	13,659
	2,684	656.7	10	4,991	17,403
	2,684	656.7	12	6,239	22,328

In order to find the current quantity of fuel consumption, the VHT values are multiplied by the fuel consumption amount in L/h for the corresponding number of cylinders of a vehicle's engine. Later, the travel demand increment rates obtained from (Mohammed and Horváth, 2023) are used to calculate corresponding VHT and Fuel consumption due to the use of AVs in the future. In those 14.5 % and 35.3 %, travel demand will be increased due to prior knowledge about AVs. While 28 % and 46.6 % of travel demand will be increased through widening the respondents' insights into the new features provided by AVs. Tables 3 and 4, as well as Figures 3 and 4, show all the above details for both Gyor City and Agglomerations study areas.

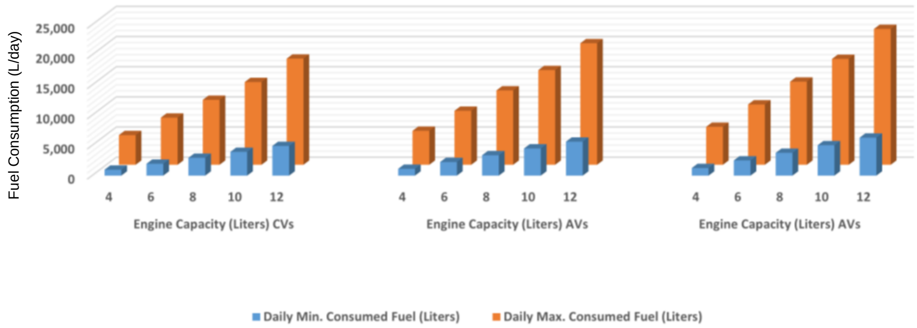


Figure 3: Daily fuel consumption using CVs and AVs in Gyor City

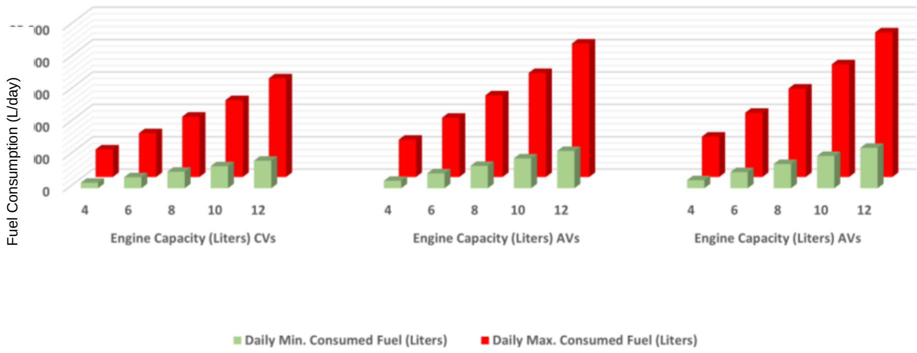


Figure 4: Daily fuel consumption using CVs and AVs in Agglomerations

4. Discussion

The results illustrate how fuel consumption changes based on the number of cylinders, demand increment, and vehicle type (conventional or autonomous). Regarding the number of cylinders, the results are provided for vehicles with different numbers of cylinders: 4, 6, 8, 10, and 12. This seems to be a factor affecting the efficiency and performance of the vehicles. Generally, vehicles with more cylinders might offer better performance but consume more fuel. In terms of demand increment, the study results are presented for three different levels of demand increment for both Gyor City and Agglomerations. As the demand increases, the transportation system experiences higher levels of activity and resource consumption. It is also well known that fuel consumption, which is a significant contributor to environmental concerns and energy sustainability, is commonly assessed through metrics such as Vehicle Kilometer Traveled (VKT) or Vehicle Hours Traveled (VHT). For this study, VHT is used due to the ease of travel time data collection through the questionnaire, but it still factored in variables like speed and congestion. One more point that should also be discussed is that transitioning from conventional vehicles (CVs) to autonomous vehicles (AVs) appears to result in increased fuel consumption, particularly as the number of cylinders and demand increase. This is somewhat counterintuitive, as AVs are often expected to be more efficient due to optimized driving patterns.

Overall, it's important to note that newly utilized modern vehicles might incorporate certain automated functions. Nevertheless, our research exclusively focused on completely self-driving cars, gathering respondents' viewpoints on the potential increase in trips facilitated by these vehicles. Consequently, the outcomes derived from our calculations based on household interviews regarding the rise in trips are essentially a study of expressed preferences, as respondents lacked prior exposure to autonomous vehicles. While we can assert that the advent of autonomous vehicles will lead to heightened travel requirements, establishing sustainable transportation systems, particularly in large urban areas, would pose a significant challenge.

5. Conclusions

The rise of Autonomous Vehicles (AVs) has the potential to significantly impact travel demand, fuel consumption, and overall transportation sustainability. While AVs offer promises of increased safety, efficiency, and convenience, their widespread adoption could also lead to certain challenges that must be carefully managed. The increased travel demand brought about by AVs could contribute to higher fuel consumption initially, as empty or lightly occupied AVs circle the roads or provide convenient alternatives to public transit. However, with proper planning and coordination, AVs could be optimized for ride-sharing and more efficient routing, potentially reducing overall fuel consumption in the long term. The success of this approach depends on effective urban planning, regulatory measures, and the adoption of shared mobility models.

In terms of transportation sustainability, AVs present both opportunities and concerns. On the positive side, AVs have the potential to reduce traffic congestion, greenhouse gas emissions, and the need for extensive parking infrastructure. Additionally, AVs could enhance accessibility for people with limited mobility, improving overall transportation equity. However, there are challenges to address. For example, AVs require significant amounts of energy to operate, which could lead to increased fuel consumption if not powered by renewable sources. In this study, although the percentages of travel demand increment have been adopted to quantify the fuel consumption using AVs in Gyor City and Agglomerations. The results obtained by the questionnaire respondents show an undeniable amount of fuel consumption. The amount has reached the expected maximum of 22,515 L/day and 22,328 L/day for both study areas. To maximize the benefits of AVs and enhance transportation sustainability, policymakers, urban planners, and industries must work together. Implementing policies that encourage electric and shared AV fleets, investing in renewable energy sources, and fostering public transportation alongside AVs are crucial steps. Additionally, ongoing research and development should focus on improving the energy efficiency of AV systems and addressing any environmental and social challenges that arise.

Overall, the impact of increasing travel demand using AVs on fuel consumption and transportation sustainability is complex. With thoughtful planning, regulation, and innovation, it is possible to harness the potential of AVs to transform transportation into a more efficient, accessible, and environmentally friendly system.

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