DOI: https://doi.org/10.12700/btsz.2025.7.4.135

COMPARATIVE ANALYSIS OF BRAKING DISTANCES FOR SELF-DRIVING AND CONVENTIONAL VEHICLES

FÉKTÁVOLSÁG ÖSSZEHASONLÍTÓ ELEMZÉSE ÖNVEZETŐ ÉS HAGYOMÁNYOS JÁRMŰVEK ESETÉBEN

Patrik VIKTOR[1] – Gábor KISS[2]

Abstract

Road safety is of paramount importance to society, especially in an era when autonomous vehicle technology is gaining ground. The aim of our study is to compare the braking distances of self-driving and conventional vehicles, taking into account different road conditions and speed ranges. The focus of the study is on reaction time, which has a decisive influence on stopping distance. The results show that self-driving systems, with an average reaction time of 0.15 seconds, produce shorter braking distances than human drivers under all test conditions, where this value can vary between 0.8 and 2 seconds, especially when distracted (e.g. by mobile phone use). The research showed that self-driving vehicles can stop up to 4.86 metres earlier in urban environments and 23 metres earlier on motorways, which can make a critical difference in accident situations. The study confirms the safety benefits of autonomous systems and supports the hypothesis that self-driving technology can measurably reduce the number of road accidents.

Keywords

Braking distance, self-driving vehicles, conventional vehicles, safety.

Absztrakt

A közúti közlekedés biztonsága kiemelkedő társadalmi jelentőséggel bír, különösen az autonóm járműtechnológia térnyerésének korában. Tanulmányunk célja az önvezető és a hagyományos járművek féktávolságának összehasonlító elemzése, különböző útviszonyok és sebességtartományok figyelembevételével. A vizsgálat középpontjában a reakcióidő áll, mely döntő befolyással bír a megállási távolságra. Az eredmények azt mutatják, hogy az önvezető rendszerek – 0,15 másodperces átlagos reakcióidejükkel – minden vizsgált körülmény között rövidebb féktávolságot produkálnak, mint az emberi vezetők, akiknél ez az érték 0,8–2 másodperc között változhat, különösen zavaró tényezők (pl. mobiltelefon-használat) hatására. A kutatás kimutatta, hogy városi környezetben az önvezető járművek akár 4,86 méterrel, míg autópályán 23 méterrel korábban képesek megállni, ami kritikus különbséget jelenthet baleseti szituációk-ban. A tanulmány megerősíti az autonóm rendszerek biztonsági előnyeit, és alátámasztja azt a hipotézist, hogy az önvezető technológia mérhetően képes csökkenteni a közúti balesetek számát.

Kulcsszavak

Féktávolság, önvezető járművek, hagyományos járművek, biztonság.

[1] viktor.patrik@uni-obuda.hu | 0000-0002-8689-2753 | Assistant lecture, Óbuda University | tanársegéd, Óbudai Egyetem
[2] kiss.gabor@uni-obuda.hu | 0000-0002-0447-9376 | professor, Óbuda University | egyetemi tanár, Óbudai Egyetem

INTRODUCTION

The rise of the autonomous vehicle (AV) signifies one of the most significant technology advances in recent transportation history. With urban populations expanding and deaths from car accidents a serious global concern, autonomous driving could provide a welcome answer to an enduring human challenge: improving traffic safety. Human error, which accounts for about 94 percent of all accidents, could be the main concern when it comes to road injuries and fatalities. Here AVs have the potential to transform mobility: decreasing accidents is just the beginning, as overall traffic flow, fuel economy, and transportation access are also likely to be improved. With the advancement of AI, machine learning and sensors, with the release of autonomous vehicles being more real than science fiction concept and with the push from the car industry, companies in tech and the governments themselves, the work to realise the autonomous vehicle is well on the way. The idea is a modest one on its face but ambitious in scope: vehicles that can perceive the environment around them, understand complex traffic situations and make life-and-death driving decisions, all without human intervention. Yet, even as technology has made great leaps forward, the public response has been apprehensive, questioning whether AVs can really be as good as or even better than humans at driving safely. The hypothesis at the core of this research is, under real-world conditions, can autonomous vehicles be proven to be a safer option to your average human-operated cars?" The study analyses the braking ability of AVs and human-driven vehicles at different driving scenarios, speeds, and pavement types to achieve this. Braking distance as a measure of driving safety is the key metric for understanding whether AVs can react quicker and brake better as compared to humans.

First, preliminary results already make an important case for the safety of AVs. For example, AVs respond much more quickly than humans, taking approximately 0.15 seconds (on average) to react, while human reaction time is 0.8-1.5 seconds. This variation directly translates into stopping differences. For instance, travelling at 50 km/h an AV may be able to stop about 4.86m earlier than a skilled human driver. At 130 km/h on the highway, the distance is even greater-almost 23 meters, which can be the difference between a close call and a fatal crash. In addition to this, soec also exhibit the ability to transfer strategies to different road conditions (e.g., dry, wet, icy), generally achieving a higher degree of consistency and precision to human drivers.

Beyond braking, AVs have other advantages in terms of risk management and situational awareness. While human drivers can lose focus, get tired or drink, systems do not suffer attention lapses. Street robots, with cameras, radar, lidar, and cutting-edge software, keep a 360 degree view of the world around them and are processing traffic data in real-time to determine safe manoeuvres. Too keep up with this level of awareness, AVs can anticipate danger better than humans and swerve to avoid it more accurately. For all these auspices, however, much remains to be done. Sensor robustness and operation in uncertain situations, as well as intricate trolley problem scenarios, remain significant challenges for autonomous technology. For example, how should an AV respond when it is involved in an inevitable collision that could potentially cause injury to a passenger or a pedestrian? Moreover, the design of regulations for liability assignment on AV-related crashes is underdeveloped, and important questions such as accountability are raised. Cybersecurity risks also represent a serious threat, as AVs are largely software- and network-dependent, which may expose them to malicious activities. Broader socioeconomic implications of self-driving cars should be considered too. On the other, a well-executed deployment of AVs will mean a vast reduction in traffic deaths, lower healthcare and insurance costs, and greater mobility for the elderly and people with disabilities. Alternatively, the mass use of AVs may displace established industries, create unemployment in driving-oriented industries and add health risks associated with system failure and technology reliance. Taking these concerns into account, this study is focused on presenting an overall analysis of AV safety, with a particular focus on the braking performance as a measure of real-world effectiveness. By comparative testing, statistical analysis, and secondary literature, we hope to determine whether the safety benefits of AVs are sufficient to merit a greater degree of public confidence and policy backing.

LITERARY PROCESSING

Self-driving technology

Self-driving technology has increasingly become a symbol of the revolutionisation of transport, with the rise of artificial intelligence (AI) and automation gaining more and more attention. The development and adoption of self-driving vehicles is closely linked to technological innovations, the transformation of transport infrastructure, and social and ethical considerations [1] [2] . Recent research has shown that the safety of self-driving cars is fundamentally influenced by the reliability of the vehicle's sensor systems, which is a key element in the development of AI-based technologies. Saudi Arabian examples also show that adequate infrastructure is essential for these systems to operate successfully [1] . The risk of traffic accidents, which self-driving technologies aim to minimize in the early stages, is influenced by various factors such as adverse weather conditions and cybersecurity threats [3] [4] . The emotional aspects of transportation and the trust of users in the technology are important factors for the adoption of self-driving vehicles. Research has shown that the experience provided by vehicles and the transparency of transport systems have a strong influence on user trust [5] [6] . The level of trust people have in self-driving cars depends on the reliability of the technology and the positivity of the first experience [6] [7]. The implementation of future transport systems and the integration of self-driving technologies also raises various legal and ethical issues. The realisation of societal expectations and legal frameworks are key to the widespread adoption of vehicles [2] [8] . Without these frameworks, developments and innovations could not have the desired impact, which is essential for the future of transport. Nevertheless, detailed statistical analysis and research into the technological challenges will help to define future directions [9] . The expectations of artificial intelligence, data processing and lifelong learning are constantly evolving, not only to improve transport safety but also to improve efficiency [4] [10] . Overall, self-driving technology not only poses technical challenges but also fundamentally transforms social norms, the way transport systems operate and the mobility solutions of the future. The development of an ethical legal framework is essential to ensure that self-driving systems are safely and efficiently integrated into the current transport ecosystem.

Self-driving cars

Self-driving car technology has emerged as one of the most important transport innovations of recent decades, with the potential to radically change social habits. The development of these vehicles is driven by the development of artificial intelligence, sensors and communication technologies, which together enable automated driving. For responsible innovation, it is also important to take into account the social impact and the readiness to adapt the technology, which in some cases may slow down its diffusion [11] [12] .

Among the determinants of user acceptance, safety has been identified as one of the most important aspects that have led to easier perception of self-driving vehicles [13] . Research has observed that consumer attitudes show considerable variability, with different groups reacting differently to technology, which involves not only technical but also social aspects [14] . Gender differences and cultural backgrounds have an impact on the perception of the acceptance of self-driving cars by a given audience [15] .

Furthermore, the business model of fleet use of vehicles offers the potential to reduce the number of cars entering cities, thus improving mobility and also reducing pollution [16] [17] . In addition, research has shown that the introduction of self-driving cars is expected to reduce the incidence of accidents, as artificial intelligence and sensor systems are able to navigate traffic with greater accuracy [18] .

However, the social acceptance of autonomous vehicles is not only a technical issue: there are also a number of ethical dilemmas related to decision-making algorithms and the handling of accident situations [19] . These issues are particularly important as future transport models will depend largely on society's attitude towards these technologies [20] .

Overall, self-driving cars will not only transform transport, but will also have a profound impact on social interactions, mobility patterns and urbanisation processes in the future. Responsible innovation is key to the societal acceptance of autonomous vehicles and to fostering the uptake of the technology [11] [12] .

Self-driving cars vs conventional cars

The comparison between self-driving cars and conventional cars covers a number of aspects, including technology, safety, environmental impact and social acceptance. The introduction of autonomous vehicles could radically transform our transport habits and the future of mobility, while conventional cars are ubiquitous and deeply embedded in everyday life. [21] One of the biggest advantages of self-driving cars is safety. Numerous studies show that the majority of accidents in traditional cars are due to human error, while self-driving cars can reduce the number of accidents by using artificial intelligence and advanced sensor systems [22] . Ujházi et al. (2023) pointed out that real-world experience and understanding of the technology is key to consumer acceptance of self-driving cars, as increasing the sense of safety and reliability is essential [23] .

In terms of environmental impacts, conventional cars provide significant carbon emissions, while self-driving electric vehicles, when properly integrated into transport systems, reduce urban air pollution [24] . In their study, Kecskés and Lukovics (2024) concluded that self-driving fleets can reduce the number of cars on the road, thereby alleviating congestion and environmental burden [24] .

The social dimensions of the adoption of self-driving cars are also controversial. [25] have pointed out that the ethical issues of self-driving cars and trust in the technology have been largely used to shape consumer attitudes [25] . Confidence in the action of self-driving vehicles over conventional cars is also subject to skeptical perceptions among different social groups, such as older and female groups [26] .

In conclusion, while self-driving cars offer various opportunities to improve the safety and sustainability of transport, the position of conventional cars is still very strong due to social and economic concerns. The future evolution of the technology and acceptance will be fundamentally based on the extent to which conventional cars remain in use over the coming decades.

Self-driving cars safety

The safety of self-driving cars (AVs) is one of the most important issues in the development of transport systems today. These vehicles offer significant potential advantages over conventional cars in reducing the number of collisions and accidents; technological, ethical and legal considerations all play an important role in social acceptance and safety Vaziri et al [27] [28] [29] . One of the main advantages of AVs is the minimization of human error. Research in the United States has shown that 94% of traffic accidents are caused by human error, while self-driving technologies such as artificial intelligence and advanced sensor systems that continuously monitor their environment can make quick decisions based on external conditions, thereby reducing the risk of accidents [29] [30] . Autonomous vehicles offer greater reaction time with more accurate positioning and speed determination, compared to the performance of human drivers [31] [32] . Continuous advances in technology and the integration of advanced driver assistance systems (ADAS) allow for increased road safety [29] . AVs are able to precisely control speed, acceleration and distance, which helps avoid accidents and increases vehicle efficiency [31] [32] .

Category	**Aspect**	**Details**
Advantages	Reduced Human Error	94% of accidents caused by human error; AVs eliminate most of these risks.
	Faster reaction time	Human: 0.8-1.5 sec; AV: ~0.15 sec
	Shorter Braking Distances	At 50 km/h: 4.86 m shorter; At 130 km/h: 23 m shorter
	Better Road Adaptability	AVs handle dry, wet, icy roads more reliably
Challenges	Technological Limitations	Sensor accuracy, AI decision limits
	Legal & Ethical Issues	Accident liability, moral dilemmas
	Cybersecurity Threats	Vulnerability to hacking, data manipulation
Expected Impact	Fewer Severe Accidents	Reduction of ~51.14% by 2033 (ADAS estimate)
	Fewer fatalities	Reduction of ~39% (EU forecast)
	Minor Accidents	Reduction of ~9.32%

Table 1 Safety of self-driving cars

If autonomous technologies are properly deployed, the cumulative impact of accidents could be dramatically reduced, saving thousands of lives [28] [33] . It is important to note that despite the maturity of the technology, investments in AVs do not guarantee 100% safety [34] . Autonomous vehicles can cause accidents, which poses challenges for the legal framework and the problem of establishing a proper one [34] . When analysing traffic data and accident conditions, future developments must constantly consider ethical dilemmas related to vehicle decisions and potential victims [35] [36] Moral issues in investigations will become increasingly important as more autonomous vehicles are put on the road, and their liability must be addressed from a legal perspective [35] . In addition to developing a liability framework for AVs, it is also essential to build social trust related to the benefits expected from reducing the number of road accidents [28] [34] .

In summary, the safety of self-driving cars is a key driver in shaping transport technologies, and exploring the factors that influence safety and reliability in social acceptance is an ongoing challenge for researchers and policy makers. Using the right technologies and frameworks, it is possible to make AVs a flagship for transport sustainability and safety [29] [32] [37] .

Stopping distance

Braking distance is the stopping distance of a vehicle, taking into account several factors such as vehicle speed, braking force, road surface conditions and vehicle weight. Determining the stopping distance is crucial for road safety, as knowing and planning the correct stopping distance is essential to avoid accidents.

Important factors for measuring stopping distances are:

1. Vehicle speed: Braking distance increases in proportion to the square of the speed. The braking distance is proportional to the speed of the vehicle. In addition, the weight of the vehicle and the load must also be taken into account, as these affect the braking force.
2. Braking force: The quality and quantity of braking force is a key element in determining stopping distances. The quality and quantity of the braking force is the key factor in determining the braking distance. The ABS system helps to lock the wheels, thus reducing the detection distance.
3. Road surface and weather conditions. On slippery, wet or icy roads, braking power is reduced, which increases stopping distance. The type and quality of the road surface, such as asphalt or concrete pavement, are also important factors. Environmental conditions, such as precipitation, fog or snow, also affect stopping distances in different conditions.
4. Tyres**.** Tyres that are properly maintained and inflated can reduce stopping distances, while worn, poorly inflated tyres can increase stopping distances.
5. Vehicle type: the type of vehicle, such as a heavy truck or a passenger car, requires different stopping distances. Light-weight passenger cars can stop faster than heavier vehicles, as the effectiveness of the brakes may also vary.

Stopping distances are typically measured using standard test procedures defined by manufacturers, where vehicles are stopped at different speeds. The testing takes into account the above factors and the measured data is analysed using statistical models to determine the behaviour of the vehicle under different conditions. Measurements are often made in a laboratory environment and in real-time traffic situations to obtain the most accurate data. Knowledge of braking distances is essential to improve road safety. Factors such as speed, braking force, road surface condition and vehicle type play a key role in influencing vehicle control. Measuring the correct braking distance and having a thorough knowledge of the factors involved is essential to avoiding accidents and driving efficiently.

MATERIAL AND METHODOLOGY

Comparative analysis of stopping distances for self-driving and conventional vehicles

When modelling a self-driving system, reaction time is a key factor that determines how quickly and efficiently a self-driving vehicle can react to different situations and environmental changes. Reaction time is the time that elapses between the detection of the system and its reaction. We can compare the reaction times of a conventional driver-driven vehicle and a self-driving vehicle in the following aspects:

Conventional Driving:

- Sensing: In the case of a driver-driven vehicle, perception relies on the driver's vision, hearing and other senses. The perception process can be time-consuming and is influenced by the driver's attention, responsiveness and experience. When analysing reaction time, it is important to consider that for human drivers, reaction time is highly dependent on driving routine and the speed of reflexes. It is generally accepted that the human reaction time to a sudden situation can vary between 0.8 and 1.5 seconds, which is the time it takes a person to initiate braking or other driving manoeuvres after detection and decision. The variability of this reaction time depends on a number of factors, including driving experience, reflexes, and physical and mental state. Fatigue, sharing attention with other activities, and the consumption of certain drugs and medicines are all factors that can affect human reaction time. In contrast, reaction times for self-driving systems can typically be significantly shorter, as machine learning algorithms and sensor systems can detect, analyse and respond to environmental changes much more quickly and efficiently. The adaptability and machine response time of autonomous vehicles is essential to manoeuvre effectively and safely in unexpected traffic situations. Therefore, the analysis of reaction times will lead to an understanding of the key differences between driver and self-driving systems and show why autonomous systems can be more effective and safer in handling unexpected situations in road traffic.
- Decision: The driver makes a decision about how to control the vehicle after sensing it. Many variables and subjective elements play a role in the decision process. For a fully human-driven vehicle, different reaction times are defined, such as a fast reaction time of half a second, while a medium reaction time is one second. A slow reaction time is defined by ADAS research as two seconds, and is usually used to include reaction in old age and under the influence of alcohol. [38]
- Control response: The reaction time of a driver-driven vehicle depends on the driver's judgment, including steering, acceleration and braking.

Physical limitations, such as reflexes, affect the duration of the control response.

- Distraction: It is a complex failure phenomenon that has been present since the beginning of driving, but with the increase in the achievable speed of vehicles and the advances in technology, the importance of whether or not a vehicle is involved in an accident has become even more pronounced. Looking at Valeo's research, stimulus influence has a very strong influence in the 21st century, based on this I identify 8 factors that influence the driver and their reaction time[39].

1. Telephone use,
2. Conversation,
3. Illness,
4. Dressing appropriately,
5. Sexual influence,
6. An external event, such as an accident,
7. Eating,
8. Harmful addiction.

Self-Driving System

- Perception: The self-driving system uses sensors to continuously sense its surroundings, including other vehicles, pedestrians, and road conditions. The sensors provide data in real time, minimizing the time required for the sensing process.
- Decision: The algorithms in the self-driving system quickly process the data provided by the sensors and make decisions. The computational power of the algorithms allows them to handle a large number of variables and optimise the decision-making process.
- Control response: Self-driving vehicles have the ability to control directly, such as steering, braking or accelerating, in response to decisions made by the system. At the current level of development of self-driving systems, the self-driving reaction time is 0.15 seconds.40 This number will decrease in the future as technology and data transfer speeds increase.Electronic control allows fast and accurate reactions, minimising the time required for a control reaction. In the case of self-driving systems, the response time can often be faster because the information provided by sensors is processed by computers and reacts instantaneously to changes in the environment. This can contribute to safer and more efficient transport. However, it is important to note that the performance and reaction time of self-driving systems still depends on the complexity of the hardware and software, as well as on the environmental challenges.
- Confounding factor: At self-driving level 3 or higher, there is no influence of distraction on driving, and at self-driving level 2, there is minimal influence.

Braking distance calculation for self-driving and conventional vehicles

The stopping distance is the sum of the distance calculated from the reaction time of a person driving a car or other vehicle and the distance travelled during braking (stopping distance). The formula that describes the stopping distance is as follows:

stopping distance = distance travelled during reaction time + stopping distance

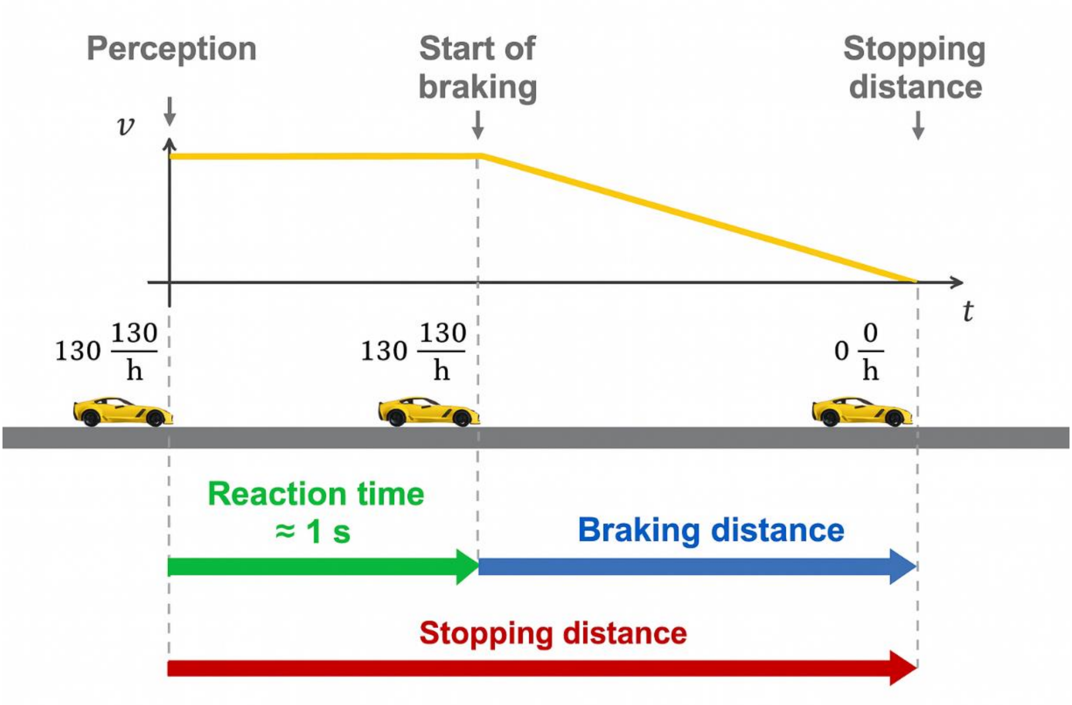

Figure 1 Braking distance. Source:[41]

- **Reaction Time Distance**: This distance is the time it takes the driver to react to the emergency and the distance the car travels at its speed. The longer the reaction time, the greater this distance will be.
- **Braking distance:** Braking distance is the distance the car will travel after the driver starts braking. The length of the braking distance depends on a number of factors, such as speed, road conditions (e.g. wet or dry road) and the condition of the vehicle's braking system.

As a result of this summation, the stopping distance is a distance that includes both the distance travelled during the reaction time and the distance covered by the stopping distance. Thus, overall, it characterises the braking performance of the car in emergency or normal traffic situations. [42]

Braking distance formula (1):

$$s = t_r v \frac{v^2}{2a} \qquad (1)$$

s - distance (metres)

t_r- reaction time (seconds)

v - speed (m/s)

a - deceleration m/s^2

Deceleration rate for different road conditions:

On dry road: 7,5 m/s^2

On wet roads: 4,5 m/s^2

On snowy/icy roads: 1,5 m/s^2

Braking force build-up: 0,5 s

In the case of a conventional vehicle, the distraction factor (e.g. looking at the telephone while driving) must also be taken into account (2):

$$s = t_r v \frac{v^2}{2a} + Z_t \qquad (2)$$

This modification can be interpreted in several ways, which I will explain in the following table. In the tables, I compare one typical distraction, phone use. This is a common problem according to several studies and affects 82-87% of Generation Y and younger, Chen et al. 2021 which is so common that these studies provide a detailed database. [43] For our study, 4 very important domains can be identified:

- 20 km/h: Used in residential zones where there are many active minors who can easily stray onto the road.
- 30 km/h: Speed limit in pedestrian zones around schools and kindergartens
- 50 km/h: km limit used in residential areas where there are many pedestrians crossing.
- 130 km/h: The speed limit on motorways, the highest speed allowed in Hungary. According to 2019 data, 17.63% of car accidents occur on Hungarian motorways, of which 41.8% are fatal.

	Braking distance on dry roads								
	Autonomous vehicle	Fast reaction time	Braking distance difference	Medium reaction time	Braking distance difference	Slow reaction time	Braking distance difference	When looking at the phone	Braking distance difference
	Reaction time								
v (km/h)	0,15 s	0,5 s	Deviation compared to autonomous vehicle	1 s	Deviation from autonomous vehicle	2 s	Deviation from autonomous vehicle	4 s	Deviation from autonomous vehicle
15	3,87 m	5,32 m	1,46 m	7,41 m	3,54 m	11,57 m	7,71 m	19,91 m	16,04 m
20	5,67 m	7,61 m	1,94 m	10,39 m	4,72 m	15,95 m	10,28 m	27,06 m	21,39 m
30	10,05 m	12,96 m	2,92 m	17,13 m	7,08 m	25,46 m	15,42 m	42,13 m	32,08 m
40	15,45 m	19,34 m	3,89 m	24,90 m	9,44 m	36,01 m	20,56 m	58,23 m	42,78 m
45	18,54 m	22,92 m	4,38 m	29,17 m	10,63 m	41,67 m	23,13 m	66,67 m	48,13 m

	Braking distance on dry roads								
	Auto-no-mous ve-hicle	Fast reaction time	Braking dis-tance diffe-rence	Medium reaction time	Braking distance diffe-rence	Slow reaction time	Braking distance difference	When lo-oking at the phone	Braking dis-tance diffe-rence
	Reaction time								
50	**21,89 m**	26,75 m	4,86 m	33,69 m	11,81 m	47,58 m	25,69 m	**75,36 m**	53,47 m
60	29,35 m	35,19 m	5,83 m	43,52 m	14,17 m	60,19 m	30,83 m	93,52 m	64,17 m
70	37,84 m	44,65 m	6,81 m	54,37 m	16,53 m	73,82 m	35,97 m	112,71 m	74,86 m
80	47,37 m	55,14 m	7,78 m	66,26 m	18,89 m	88,48 m	41,11 m	132,92 m	85,56 m
90	57,92 m	66,67 m	8,75 m	79,17 m	21,25 m	104,17 m	46,25 m	154,17 m	96,25 m
100	69,50 m	79,22 m	9,72 m	93,11 m	23,61 m	120,88 m	51,39 m	176,44 m	106,94 m
110	82,10 m	92,80 m	10,69 m	108,08 m	25,97 m	138,63 m	56,53 m	199,74 m	117,64 m
130	110,41 m	123,05 m	**12,64 m**	141,10 m	30,69 m	177,21 m	66,81 m	249,43 m	**139,03 m**

Table 2 Stopping distances on dry roads Source:[39] own ed.

Table 38 compares the self-driving system with the conventional system on dry roads. It can be clearly seen that at a speed of 130 km/h, the vehicle stops 12.64 m slower without distraction. Whereas, when distracted, the braking distance is more than doubled, i.e. 139.03 metres, and it takes a quarter of a kilometre to stop. In other words, even under ideal conditions, using the self-driving system in zone 50, you can stop 3 thirds faster.

	Braking distance on wet roads as a function of reaction time				
	Autonomous vehicle	Fast reaction time	Medium reaction time	Slow reaction time	In case of telephoning
v (km/h)	0,15 s	0,5 s	1 s	2 s	4 s
15	4,64 m	6,10 m	8,18 m	12,35 m	20,68 m
20	7,04 m	8,98 m	11,76 m	17,32 m	28,43 m
30	13,13 m	16,05 m	20,22 m	28,55 m	45,22 m
40	20,94 m	24,83 m	30,38 m	41,50 m	63,72 m
45	25,49 m	29,86 m	36,11 m	48,61 m	73,61 m
50	**30,46 m**	35,32 m	42,27 m	56,16 m	**83,93 m**
60	41,70 m	47,53 m	55,86 m	72,53 m	105,86 m
70	54,65 m	61,45 m	71,18 m	90,62 m	129,51 m
80	69,31 m	77,09 m	88,20 m	110,43 m	154,87 m
90	85,69 m	94,44 m	106,94 m	131,94 m	181,94 m

	Braking distance on wet roads as a function of reaction time				
	Autonomous vehicle	Fast reaction time	Medium reaction time	Slow reaction time	In case of telephoning
100	103,79 m	113,51 m	127,40 m	155,18 m	210,73 m
110	123,60 m	134,29 m	149,57 m	180,13 m	241,24 m
130	**168,36 m**	181,00 m	199,06 m	235,17 m	**307,39 m**

Table 3 Stopping distances on wet roads Source: [39] owned.

On wet roads, 2 speed ranges were considered important to investigate. At 50 km/h, where the stopping distance increases by almost 2.5 times when using a phone. Or at 130 km/h, where the stopping distance increases by 83% when using a phone. This is a serious accident risk on motorways, where this speed is allowed.

	Braking distance on icy/snowy roads as a function of reaction time				
	Autonomous vehicle	Fast reaction time	Medium reaction time	Slow reaction time	In the case of telep-honing
v (km/h)	0,15 s	0,5 s	1 s	2 s	4 s
15	6,91 m	8,37 m	10,45 m	14,62 m	22,95 m
20	**11,62 m**	13,57 m	16,34 m	21,90 m	**33,01 m**
30	24,90 m	27,81 m	31,98 m	40,31 m	56,98 m
40	43,32 m	47,21 m	52,76 m	63,87 m	86,10 m
45	54,46 m	58,83 m	65,08 m	77,58 m	102,58 m
50	**66,88 m**	**71,74 m**	78,69 m	92,58 m	**120,36 m**
60	95,59 m	101,43 m	109,76 m	126,43 m	159,76 m
70	129,45 m	136,25 m	145,97 m	165,42 m	204,31 m
80	168,44 m	176,22 m	187,33 m	209,55 m	254,00 m
90	212,58 m	221,33 m	233,83 m	258,83 m	308,83 m
100	261,87 m	271,59 m	285,48 m	313,26 m	368,81 m
110	316,30 m	326,99 m	342,27 m	372,83 m	433,94 m
130	440,59 m	453,23 m	471,28 m	507,39 m	579,62 m

Table 4 Stopping distances on icy/snowy roads Source: [39] owned.

When looking at the reaction time on icy/snowy roads, it can be seen that there is approximately a 3% difference between the stopping time of public transport vehicles and conventional vehicles, but once disturbance is taken into account, this difference increases. What I would like to highlight is the stopping distance at 50 km/h, where it is 66.88 metres for a public transport vehicle and almost double that at 120.36 metres with distraction. As this speed range is the typical urban speed. As well as in the 20km/h hour category, which is a typical speed limit in suburban areas, there you can see that compared to a self-driving system, you can stop 3 times as far while driving by phone while driving conventionally. In all cases, people using self-driving systems stop faster, as the system has a reaction time of

0.15s, whereas an average person with a fast reaction time reacts in 0.5s. Continuing this line of thought, here could be the difference in the injury and death that can occur at different speed ranges. From my investigation it is clear that there are substantial differences in the different conditions using the self-driving system. Thus the number of accidents and fatalities that occur can be reduced. Based on this, ADAS estimates that by 2020, if self-driving vehicles on the road reach level 3 or higher of self-driving technology, road accidents could be reduced by 38%, to be achieved by 2033. [166] In the EU, ADAS estimates that fatal accidents will decrease by approximately 39%, while serious injury accidents will decrease by 51.14%. But even the self-driving system needs to improve, because current estimates suggest that the number of minor collisions will fall by only 9.32%. Taking my research above into account, using a self-driving system will reduce stopping distances by a third in many cases, and can even reduce fatal collisions to serious ones. Based on these and the above conclusions, I conclude that the safety of self-driving technology can be measured from a road safety perspective. In other words, this technology will reduce and, as it spreads, will reduce the number of road accidents.

My hypothesis I assumed that self-driving technology has the potential to reduce the number of road accidents.

Based on my analysis of stopping distances and computational data, I can state that it can reduce the number of road accidents by reducing the number of hit-and-run accidents by allowing faster reaction times of self-driving systems resulting in shorter stopping distances.

My hypothesis I/A assumed that the safety of self-driving technology in traffic terms can be measured.

Based on braking distance analyses, it can be stated that on dry roads at urban speeds, a self-driving vehicle, typically the size of a car, will stop 4.86 metres faster than a routine driver. At highway speeds, the difference is 23 metres, which is about 4 car lengths. On wet, snowy roads, this difference increases further. We can see that not only can self-driving technology be shown to reduce the number of road accidents, but also that its safety can be measured in this area.

Based on the above, Hypotheses I and I/A can be summarised in a single thesis.

SUMMARY

In recent years, autonomous vehicle (AV) technology has become a central topic in discussions surrounding the future of transportation. With the increasing presence of AVs on public roads and the pressing need to improve road safety, this study explores the hypothesis that self-driving vehicles offer measurable safety benefits compared to conventional, human-driven cars. Specifically, it examines whether the braking distance-a key indicator of traffic safety-can be reduced through autonomous driving systems.

Braking distance is composed of two critical elements: the distance a vehicle travels during the driver's or system's reaction time, and the distance required to come to a full stop once braking is initiated. This research places special emphasis on reaction time, as it significantly influences the overall braking distance and the likelihood of preventing accidents.

One of the most striking findings of the study is the dramatic difference in reaction times between human drivers and AV systems. Autonomous vehicles exhibit an average reaction time of approximately 0.15 seconds, thanks to their advanced sensors and real-time data processing capabilities. In contrast, human drivers have a reaction time that typically ranges from 0.8 to 2 seconds, depending on factors such as age, alertness, and the presence of distractions-most notably mobile phone use. This variation in human response introduces significant safety risks, especially in high-speed or complex traffic environments.

By analyzing real-world data and simulated braking scenarios, the study demonstrates that self-driving vehicles consistently achieve shorter stopping distances across all tested conditions. At a moderate urban speed of 50 km/h, AVs can stop up to 4.86 meters earlier than human drivers. This difference becomes even more substantial at highway speeds of 130 km/h, where AVs can come to a stop approximately 23 meters sooner than their human-operated counterparts. These figures represent distances that could mean the difference between a collision and a near miss, particularly in densely trafficked or high-risk environments. The analysis also considers a wide range of environmental variables such as dry, wet, and icy road conditions. On slippery surfaces, braking performance becomes even more critical. AVs demonstrate superior consistency and adaptability in these conditions, maintaining more reliable control than human drivers. Even when human drivers are not distracted, they still tend to perform worse under adverse conditions due to delayed perception and slower manual responses. To illustrate the danger posed by distractions, the study evaluates the impact of mobile phone usage during driving-a widespread and well-documented issue. In scenarios involving phone use, braking distances increased dramatically. For example, under wet road conditions and travelling at 50 km/h, distracted human drivers required nearly 84 meters to stop, while an AV under the same conditions needed just 30 meters. This difference highlights the vulnerability of human attention and the potential of AVs to reduce accident severity through faster and more reliable reactions.

Despite these clear benefits, the study acknowledges that autonomous technology still faces several important challenges. While AVs outperform human drivers in controlled and repeatable situations, complex ethical dilemmas-such as choosing between two harmful outcomes in an unavoidable collision-remain unresolved. Furthermore, the reliability of sensor systems under extreme weather conditions, and the cybersecurity risks associated with networked, software-dependent systems, present ongoing technological and regulatory concerns.

The study also touches on the legal and ethical implications of AV deployment. Questions about liability in the event of an accident, moral decision-making by algorithms, and the general lack of regulatory frameworks are critical areas that require further attention. Nevertheless, the projected benefits of AV implementation remain substantial. According to forecasts from the European Union and other sources cited in the research, the adoption of advanced autonomous systems could lead to a 38-51% reduction in serious accidents and a 39% decrease in fatalities by the year 2033.

From a broader societal perspective, AVs also offer the potential to transform urban mobility. Through fleet optimization, reduced congestion, and enhanced access for the elderly and disabled, autonomous vehicles may bring about more sustainable and inclusive transportation systems. However, public acceptance remains a key obstacle. Trust in the technology is influenced by factors such as user experience, cultural attitudes, gender, and age. The transition from traditional to autonomous driving will depend not only on technical reliability but also on successful public engagement and education.

In conclusion, the research confirms the hypothesis that autonomous vehicles can significantly improve road safety, particularly by reducing braking distances. This advantage is grounded in their superior reaction times, consistent performance under various conditions, and immunity to human distraction. While challenges remain in terms of technology, legislation, and societal acceptance, the evidence suggests that AVs represent a safer alternative to conventional driving. If these systems are properly implemented and integrated into existing transport infrastructure, they hold the potential to drastically reduce the number and severity of road accidents, ultimately saving lives and reshaping the future of mobility.

LITERATURE

[1] F. Alsubaei, "Reliability and security analysis of artificial intelligence-based self-driving technologies in Saudi Arabia: a case study of openpilot", Journal of Advanced Transportation, vol. 2022, p. 1-25, 2022. https://doi.org/10.1155/2022/2085225

[2] R. Nagashree and K. Gowda, "Review of self-driving cars - technologies, standards and safety", International Research Journal of Modernization in Engineering Technology and Science, 2023. https://doi.org/10.56726/irjmets35638

[3] A. Chougule, V. Chamola, A. Sam, F. Yu, & B. Sikdar, "A comprehensive review on limitations of autonomous driving and its impact on accidents and collisions", Ieee Open Journal of Vehicular Technology, vol. 5, p. 142-161, 2024. https://doi.org/10.1109/ojvt.2023.3335180

[4] K. Muhammad, A. Ullah, J. Lloret, J. Ser, & V. Albuquerque, "Deep learning for safe autonomous driving: current challenges and future directions", Ieee Transactions on Intelligent Transportation Systems, vol. 22, no. 7, p. 4316-4336, 2021. https://doi.org/10.1109/tits.2020.3032227

[5] F. Hartwich, C. Hollander, D. Johannmeyer, & J. Krems, "Improving passenger experience and trust in automated vehicles through user-adaptive hmis: "the more the better" does not apply to everyone", Frontiers in Human Dynamics, vol. 3, 2021. https://doi.org/10.3389/fhumd.2021.669030

[6] S. Tolbert and M. Nojoumian, "Cross-cultural expectations from self-driving cars",, 2023. https://doi.org/10.21203/rs.3.rs-2432387/v1

[7] E. Rovira, A. McLaughlin, R. Pak, & L. High, "Looking for age differences in self-driving vehicles: examining the effects of automation reliability, driving risk, and physical impairment on trust", Frontiers in Psychology, vol. 10, 2019. https://doi.org/10.3389/fpsyg.2019.00800

[8] W. Ratoff, "Self-driving cars and the right to drive", Philosophy & Technology, vol. 35, no. 3, 2022. https://doi.org/10.1007/s13347-022-00551-1

[9] J. Gwak, J. Jung, R. Oh, M. Park, M. Abdu, K. Rakhimovet al., "A review of intelligent self-driving vehicle software research", Ksii Transactions on Internet and Information Systems, vol. 13, no. 11, 2019. https://doi.org/10.3837/tiis.2019.11.002

[10] Y. Li, Y. Zhou, X. Ma, & Y. Zhang, "Forecasting the development of self-driving technology in china by multidimensional information," Journal of Advanced Transportation, vol. 2021, pp. 1-12, 2021. https://doi.org/10.1155/2021/1693459

[11] M. Lukovics and N. Nádas, "The role of responsible innovation in the relationship between autonomous vehicles and society", Civic Review, vol. 18, no. 4-6, p. 295-317, 2022. https://doi.org/10.24307/psz.2022.1221
[12] M. Lukovics, T. Ujházi, & S. Prónay, "Social science aspects of the adoption of self-driving vehicles: research opportunities and methodological limitations", Polgári Szemle, vol. 19, no. 4-6, p. 266-280, 2023. https://doi.org/10.24307/psz.2023.1220.
[13] T. Ujházi, M. Lukovics, Z. Majó-Petri, & S. Prónay, "Investigating consumer preferences towards self-driving vehicles after an actual test drive",, 2023. https://doi.org/10.62561/emok-2023-29
[14] B. Nagy, S. Prónay, & M. Lukovics, "I drive, you drive or self-drive? - five perspectives of self-driving car acceptance in hungary", Marketing & Management, vol. 56, no. 2, p. 23-34, 2022. https://doi.org/10.15170/mm.2022.56.02.03
[15] M. Lukovics and B. Gábor, "Self-driving cars and Hungarian women", Polgári Szemle, vol. 17, no. 1-3, p. 178-193, 2021. https://doi.org/10.24307/psz.2021.0713
[16] E. Kecskés and M. Lukovics, "The potential impact of the cost benefits of self-driving fleet use on the mobility of Hungarian cities", North-Hungarian Strategic Notes, vol. 21, no. 1, p. 82-97, 2024. https://doi.org/10.32976/stratfuz.2024.7
[17] B. Zuti and M. Lukovics, "Adoption of self-driving vehicles in behavioural economics. the role of nudge in the development of sustainable urban mobility", Közgazdasági Szemle, vol. 70, no. 2, p. 149-166, 2023. https://doi.org/10.18414/ksz.2023.2.149
[18] L. Gál and T. Sipos, "The impact of autonomous vehicle penetration on specific economic loss values", Transport Economics Review, vol. 68, no. 4, p. 74-82, 2018. https://doi.org/10.24228/ktsz.2018.4.6
[19] M. Miskolczi, K. Ásványi, M. Jászberényi, & L. Kökény, "Hogyan döntsön a mesterséges intelligencia? az ön-driving autók morális kérdései - how should artificial intelligence decide? moral challenges of self-driving cars", Hungarian Science, 2021. https://doi.org/10.1556/2065.182.2021.3.6
[20] G. Kiss and P. Bakucz, "Handling unavoidable accident situations by self-driving vehicles", Gradus, vol. 10, no. 2, 2023. https://doi.org/10.47833/2023.2.csc.023
[21] M. Lukovics, T. Ujházi, & S. Prónay, "Social science aspects of self-driving vehicle adoption : research opportunities and methodological limitations", Citizen Review, vol. 19, no. 4-6, p. 266-280, 2023. https://doi.org/10.24307/psz.2023.1220
[22] L. Gál and T. Sipos, "The impact of autonomous vehicle penetration on specific economic loss rates", Transport Science Review, vol. 68, no. 4, p. 74-82, 2018. https://doi.org/10.24228/ktsz.2018.4.6
[23] T. Ujházi, M. Lukovics, Z. Majó-Petri, & S. Prónay, "Investigation of consumer preferences towards self-driving vehicles following an actual test drive",, 2023. https://doi.org/10.62561/emok-2023-29
[24] E. Kecskés and M. Lukovics, "The potential impact of the cost benefits of self-driving fleet use on the mobility of Hungarian cities", North-Hungarian Strategic Notes, vol. 21, no. 1, p. 82-97, 2024. https://doi.org/10.32976/stratfuz.2024.7
[25] M. Miskolczi, K. Ásványi, M. Jászberényi, & L. Kökény, "Hogyan döntsön a mesterséges intelligencia? az öndriving autók morális Frageni - how should artificial intelligence decide? moral challenges of self-driving cars", Hungarian Science, 2021. https://doi.org/10.1556/2065.182.2021.3.6

[26] M. Lukovics and B. Gábor, "Self-driving cars and Hungarian women", Polgári Szemle, vol. 17, no. 1-3, p. 178-193, 2021. https://doi.org/10.24307/psz.2021.0713
[27] I. Vaziri, F. Ahmadi, Z. Rizi, & M. Saffarzadeh, "The impact of interactions between resources, technology, and technical aspects of autonomous vehicles on urban smart spaces", IJIMOB, vol. 4, no. 2, p. 142-154, 2024. https://doi.org/10.61838/kman.ijimob.4.2.17
[28] T. Gill, "Ethical dilemmas are really important to potential adopters of autonomous vehicles", Ethics and Information Technology, vol. 23, no. 4, p. 657-673, 2021. https://doi.org/10.1007/s10676-021-09605-y
[29] E. Huff, K. Lucaites, A. Roberts, & J. Brinkley, "Participatory design in the classroom: exploring the design of an autonomous vehicle human-machine interface with a visually impaired co-designer", Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 64, no. 1, p. 1921-1925, 2020. https://doi.org/10.1177/1071181320641463
[30] A. Papadoulis, M. Quddus, & M. Imprialou, "Evaluating the safety impact of connected and autonomous vehicles on motorways", Accident Analysis & Prevention, vol. 124, p. 12-22, 2019. https://doi.org/10.1016/j.aap.2018.12.019
[31] U. Montanaro, S. Dixit, S. Fallah, M. Dianati, A. Stevens, D. Oxtobyet al., "Towards connected autonomous driving: review of use-cases", Vehicle System Dynamics, vol. 57, no. 6, p. 779-814, 2018. https://doi.org/10.1080/00423114.2018.1492142
[32] M. Garg and M. Bouroche, "Can connected autonomous vehicles improve mixed traffic safety without compromising efficiency in realistic scenarios?", Ieee Transactions on Intelligent Transportation Systems, vol. 24, no. 6, p. 6674-6689, 2023. https://doi.org/10.1109/tits.2023.3238889
[33] A. Bakar, M. Abas, M. Said, & T. Azhar, "Synthesis of autonomous vehicle guideline for public road-testing sustainability", Sustainability, vol. 14, no. 3, p. 1456, 2022. https://doi.org/10.3390/su14031456
[34] Q. Yao, T. Li, C. Yan, & Z. Deng, "Accident responsibility identification model for internet of vehicles based on lightweight blockchain", Computational Intelligence, vol. 39, no. 1, p. 58-81, 2022. https://doi.org/10.1111/coin.12529
[35] M. Mayer, A. Buchner, & R. Bell, "Humans, machines, and double standards? the moral evaluation of the actions of autonomous vehicles, anthropomorphized autonomous vehicles, and human drivers in road-accident dilemmas", Frontiers in Psychology, vol. 13, 2023. https://doi.org/10.3389/fpsyg.2022.1052729
[36] B. Wang, "Approaches to autonomous driving vehicle traffic accidents liability in china", Lecture Notes in Education Psychology and Public Media, vol. 26, no. 1, p. 167-174, 2023. https://doi.org/10.54254/2753-7048/26/20230901
[37] A. Botezatu, A. Burlacu, & C. Orhei, "A review of deep learning advancements in road analysis for autonomous driving", Applied Sciences, vol. 14, no. 11, p. 4705, 2024. https://doi.org/10.3390/app14114705
[38] ADAS, 'Guest commentary: Unlocking the future of autonomous vehicle safety through ADAS simulation', Automotive News. Accessed: Jan. 19, 2024. [Online]. Available: https://www.autonews.com/guest-commentary/how-adas-simulation-can-enhance-autonomous-vehicle-safety

[39] fbilly@wordappeal.com, 'Valeo report 2022', Valeo. Accessed: Jan. 19, 2024. [Online]. Available: https://www.valeo.com/en/2022-financial-results/
[40] Why We should be Careful when Using Self-driving Vehicle Features! | IEEE Conference Publication | IEEE Xplore'. Accessed: Jan. 19, 2024. [Online] Available: https://ieeexplore.ieee.org/abstract/document/9570269
[41] Juhász A. and Molnár M. S., 'The effect of mobile phone use while driving on attention', BELÜGYI Szle. BELÜGYMINISZTÉRIUM SZAKMAI TUDOMÁNYOS FOLYÓIRATA 2010-, vol. 70, no. 6, Art. no. 6, 2022.
[42] Stopping distance, stopping distance, reaction time, stopping delay time. Accessed: Jan. 19, 2024. [Online]. Available: https://www.netfizika.hu/tudas/node/7894
[43] T. Chen et al, 'The Genome Sequence Archive Family: Toward Explosive Data Growth and Diverse Data Types', Genomics Proteomics Bioinformatics, vol. 19, no. 4, pp. 578-583, Aug. 2021, doi: 10.1016/j.gpb.2021.08.001.