International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

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The economic impact of information technology on energy and autonomous transportation systems

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International Journal of Science and Research Archive, 2023, 09(01), 770–778

Publication history: Received on 02 April 2023; revised on 17 May 2023; accepted on 20 May 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.9.1.0363

Abstract

Autonomous transportation presents significant potential to enhance road efficiency, reduce traffic accidents, increase productivity, and minimize environmental impact. However, its adoption has faced resistance from various groups citing concerns about safety, cybersecurity risks, job displacement, and potential increases in environmental pollution due to the convenience of self-driving vehicles (SDVs). To fully realize the benefits of SDVs while mitigating these challenges, it is essential to proactively identify future obstacles and take strategic actions now to address them.

This paper employs a policy scenario methodology to construct a likely future for the year 2025, examining the implications of current trajectories in autonomous transportation. The purpose of this foresight analysis is to articulate the challenges we face today and project how they may evolve over the next six years. It highlights the key facilitators and inhibitors of change, as well as the economic impacts of autonomous transportation systems.

Specifically, the paper addresses critical issues such as autonomy, privacy, liability, cybersecurity, data protection, and safety, providing a comprehensive synthesis of the potential outcomes associated with SDV adoption. It will also offer actionable steps that policymakers, industry leaders, and other stakeholders can take to avoid these pitfalls while ensuring that society fully benefits from the advantages of autonomous transportation.

Keywords: Information Technology; Autonomous Transportation Systems; Economic Impact

1. Introduction

Self-driving vehicles (SDVs) have become a focal point of daily news, controversies, and public debates. Despite the frequent discussions, the need for continued evaluation of the potential challenges posed by this emerging technology remains critical. While substantial ethical, legal, and social research on SDVs has been conducted (e.g., De Sio 2017; Nyholm 2018; Nyholm & Smids 2016), these diverse concerns are rarely consolidated into a single comprehensive analysis. Moreover, previous research has not fully explored projected timelines for when these issues might arise or proposed specific policy responses. This paper seeks to address these gaps by offering a comprehensive analysis through a 'policy scenario' methodology. This stakeholder-focused approach will examine the societal impacts of SDVs by the year 2025. It is the first of its kind to provide such an in-depth, future-oriented examination, engaging with various stakeholders to ensure a holistic view of the emerging technology's effects. Much of the debate surrounding SDVs tends to focus on widespread Level 5 automation, where vehicles perform all driving functions under all conditions, a level of automation that is not anticipated for several decades. As a result, there has been a lack of urgency to address the more immediate impacts of SDVs. This paper advocates for a shift in focus to nearer-term developments, considering the challenges that may emerge over the next five to six years. To meet this need, the use of scenarios provides a powerful tool. A scenario is not a definitive future reality, but rather a plausible one, based on current

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knowledge of technological advancements and related issues (Durance & Godet 2010). The scenario developed in this paper offers a well-formulated, evidence-based projection of the state of SDVs in 2025 and the potential societal impacts they may bring. The scenario is grounded in expert opinions gathered during a one-day workshop, stakeholder engagement through iterative feedback, and a thorough review of existing scientific literature. By integrating these elements, this paper offers a forward-looking analysis that can help policymakers and industry leaders better prepare for the challenges and opportunities presented by SDVs in the coming years.

2. Methodology

This paper presents findings from the SHERPA Project, which was initiated to evaluate the societal implications of five emerging technologies by 2025, one of which is self-driving vehicles (SDVs) (for full details, see Wright et al. 2019). The project employed a scenario methodology to identify the ethical, legal, social, and economic issues that SDVs may face over the next six years. Scenarios, defined by Schwartz (1998) as "a tool for ordering perceptions about alternative future environments to help people make better decisions," offer significant benefits, but also pose challenges. For instance, scenario approaches can often lack structure, making it difficult to provide clear guidance on issues. Some scenarios remain as interesting thought experiments without offering practical advice, particularly when they are too vague or complex for policymakers to understand. Of the six scenario approaches outlined in the SHERPA project (see Table 1), we selected the policy scenario for the SDV case, as it provides the most coherent approach for policymakers. The goal was to construct one concise, understandable, and plausible scenario to highlight the most pressing issues and impacts of SDVs, and to offer actionable steps for achieving a desirable future. Policy scenarios are especially effective in identifying a range of issues, while also offering clarity and precision, which is critical for policymakers. These scenarios help by: "exploring possible consequences of current trends; engaging stakeholders; uncovering overlooked issues; aiding decision-making; considering desired and undesired futures; and determining steps to reach desired futures and avoid undesirable ones" (Wright et al. 2019, p. 5). The policy scenario in this paper aims to provide a plausible outcome, grounded in current scientific understanding and projections. Scenarios are particularly useful for policymakers when they maintain a strong degree of plausibility (Volkery & Ribeiro 2009). A scenario should offer a timeline with a certain level of predictability and avoid venturing into the realm of science fiction (Cairns & Wright 2018, pp. 34–45). As such, this scenario focuses on near-term developments in SDVs, specifically within the next 5-6 years. This shorter timeline also creates a sense of urgency for policymakers to act—an essential component of the policy scenario methodology. Furthermore, stakeholder engagement was a key element throughout the scenario's development (Duckett et al. 2017), with stakeholders involved from the scenario's inception to its final form. This engagement strengthens the scenario's findings and lends credibility to its scientific validity.
As outlined in the SHERPA report, the SDV scenario underwent four iterative stages, beginning with a one-day workshop attended by 20 experts from a diverse range of backgrounds, including standardization bodies, SDV testing, computer science, engineering, psychology, artificial intelligence, cybersecurity, ethics, and law. The workshop was structured around several key themes: SDV technological development in 2025; the driving forces and barriers for SDV adoption; ethical, legal, social, and economic impacts; strategies for mitigating negative impacts and maximizing positive ones; and pathways to achieve a desirable future. Participants engaged in group work, open discussions, and critical dialogue, fostering collective brainstorming and evaluations. Following the workshop, a draft scenario was distributed to participants for feedback. Additional insights were gathered from relevant journal publications to address any overlooked issues and to ensure the scientific robustness of the scenario. A third iteration of the scenario was shared with a wider group of experts (30+ individuals) before it was posted on a public platform for broader engagement (100+ people). This iterative process helped create a nuanced, cohesive, and consensus-driven scenario for SDV development over the next six years. The scenario was eventually deemed stable enough for dissemination on the SHERPA website. This paper offers a revised and more detailed analysis of the topics covered in the SHERPA project report. While some sections overlap with the original version, the revisions are designed to enhance clarity and coherence.

2.1. Scenario of Self-Driving Vehicles Between 2019 and 2025

By 2025, self-driving vehicles (SDVs) are becoming more common in urban areas worldwide. Hans Adrian, a 38-year-old software developer in Munich, uses his SDV to commute to work daily. Munich was among the first cities to roll out SDVs. "So far, so good," says Hans, who has been using his Waymo Centauri b for over four months. "I can work during my commute. With an hour each way, that's 10 hours a week I get back. I just sit with my laptop and listen to Spotify. It's great!" The Centauri b, one of the few self-driving models available on the market, offers level 4 automation—allowing automated, semi-automated, and manual driving options. However, fully automated driving is only permitted within certain designated areas of Munich. In other regions, Hans must switch to semi-automated or manual mode. "It's a bit annoying when I have to drive outside Munich," he admits. "It takes time to adjust to manual driving again. But I get that other cities need time to catch up." Currently, only seven cities globally have fully integrated SDVs, though the number is expected to rise dramatically by 2030. Experts estimate that 50 to 70 cities will adopt SDVs by the end of the decade. Significant innovation is coming from Silicon Valley, with the US, South Korea, the UK, Japan, China, and Germany leading in SDV development. The United States has been a major innovator, piloting SDVs in more than 40 cities as early as 2017 (Hao 2017). By 2025, 100 cities in the US are conducting SDV trials, with numbers set to increase significantly over the next few years. Although Hans enjoys the benefits of autonomous driving, he had to pass a specialized SDV driving test to do so. This test includes both theoretical and practical components, emphasizing the transition between manual and automated driving. In Germany, it is mandatory to complete 12 driving lessons before taking the in-car test. Cities introducing SDVs must be certified by the National Self-Driving Vehicle Transportation Board (NSDVTB), and vehicle owners must register with the Department of Self-Driving Vehicles Authority (DSDVA). The vehicles themselves must meet strict manufacturing standards before they are released to the market. Outside designated areas, SDVs are required to operate at level 3 automation, where the car alerts the driver to take control under specific conditions and provides enough time for the transition. While some manufacturers hoped to bypass this step, challenges related to technology, interactions with manual drivers, and infrastructure have made it necessary. In areas where both automated and non-automated vehicles share the road, SDVs must offer level 3 functionality for legal and safety reasons. Safety remains a key priority in the development of self-driving vehicles, one of the driving forces behind their regulatory framework.

2.2. Facilitators of SDVs Between 2019 and 2025 Safety Facilitators

Approximately 90% of traffic accidents are caused by human error, and while road fatalities have been decreasing, the toll was still as high as 1.4 million in 2015 (NHTSA 2013, 2017; WHO 2018). Over the last decade, improving road safety has been one of the primary drivers behind the push for self-driving vehicles (SDVs), although their limited adoption has prevented society from fully reaping these benefits. The National Safety Council's "Road to Zero" campaign aims for zero traffic-related deaths in the United States by 2050, a goal that may be achievable if SDVs are widely adopted (Ecola et al. 2018). Studies dating back to 2017 have suggested that even a slight increase in SDV safety—say, just 10% more than human drivers—could significantly reduce road fatalities. Policymakers worldwide agree that waiting for SDVs to reach a 75–95% safety improvement over human drivers is impractical due to the time required to achieve such advances (Kalra and Groves 2017).

2.3. Social Facilitators

The general public is excited about the convenience SDVs could offer, such as the ability to work, sleep, read, eat, or watch TV while commuting.

2.4. Environmental Facilitators

In cities where SDVs have been integrated, there are promising signs of reduced carbon emissions. Since the Kyoto and Paris climate agreements, environmental agencies have been advocating for more sustainable vehicle options, and electric SDVs are seen as a key solution for meeting EU carbon emission targets (European Environment Agency 2016).

2.5. Economic Facilitators

Although the cost of SDVs has been declining annually, they remain more expensive than non-automated cars. In response, SDV car-sharing and ride-sharing platforms have emerged, helping reduce expenses by ensuring that cars are in use throughout the day rather than sitting idle in garages or parking lots (Ohnsman 2018). SDVs also offer better fuel efficiency, which translates to lower fuel costs. Once SDVs reach widespread level 4 integration and safety is improved, production costs are expected to decrease, as airbags and steering wheels will no longer be necessary (Davies 2018). Between 2020 and 2025, non-traditional players such as ICT and data analytics companies have entered the SDV market. Some traditional automotive companies, like Fiat, have struggled to compete with larger firms that can invest more heavily in automation technologies. Fiat, for example, has closed several manufacturing depots, citing the shift to automation as a major factor impacting sales (Eisenstein 2019).

2.6. Market Facilitators

Many social critics have argued that the SDV market is largely supply-driven (McCarthy 2018). However, manufacturers recognize the potential of SDVs in goods transportation and data analytics (DHL 2014; Hawthorne-Castro 2018). The global race to develop SDVs has driven competition among automotive companies, bringing success and prestige to those leading the charge. To protect their innovations, companies are extensively patenting their SDV models, products, and services, effectively locking customers into their brands. Over recent years, the concept of automotive branding has shifted from traditional markers of luxury and status to new priorities such as efficiency, safety, and functionality.

2.7. Efficiency and Productivity Facilitators

Traffic management authorities have praised SDVs for their potential to improve traffic flow by reducing congestion, identifying better routes, and minimizing crashes that cause delays. SDVs also offer commuters extra time for rest or relaxation during their journeys. Many businesses view SDVs as a way to eliminate wasted "driving time," allowing employees to work productively while on the move.

2.8. Political Facilitators

National Ministers for Transportation are promoting the adoption of SDVs due to their potential to enhance driving efficiency, allowing for reductions in lane sizes and the number of lanes needed. However, implementing such changes has proven challenging in many large U.S. cities due to the complexity involved. SDVs are also expected to reduce road deaths, which could lower government healthcare spending. Additionally, as SDVs enable longer, more comfortable commutes, people may choose to live farther from their workplaces, helping to alleviate congestion in densely populated urban areas.

3. Economic Impacts of IT on Autonomous Transportation Job Loss Concerns

Historically, the introduction of self-driving vehicles (SDVs) has raised fears of job displacement in industries such as taxi driving, valet parking, car mechanics, meter attending, traffic enforcement, and potentially even bus and freight driving (Lari et al. 2015). Additionally, the shortage of truck drivers in countries like Canada (CBC News 2018) prompted truck manufacturers, such as Mercedes-Benz, to capitalize on this opportunity by advancing autonomous truck technology. Mercedes-Benz has been testing level 5 autonomous trucks in hazardous or unsuitable driving conditions. Similarly, Uber anticipated that SDVs could lead to unemployment for many of its drivers. To mitigate this, the company has launched programs in computer science, engineering, and vehicle maintenance to help drivers transition to new roles (Engelbert 2017).

3.1. Competition and Market Shifts

The significant investments and technological advancements in SDV development have driven smaller automotive companies out of the market. While SDV start-ups initially thrived during the industry's early stages, larger players have since outpaced them through innovation, leading to a more concentrated and less competitive market for SDV manufacturers.

3.2. Impact on the Luxury Vehicle Sector

Luxury vehicle manufacturers initially expressed concern about how SDVs would affect their business models, particularly if driving became more of a hobby. However, brands like Audi and Mercedes have successfully adapted, becoming leaders in the SDV market (Autotech 2018). Meanwhile, companies such as Ferrari, Lamborghini, and Lexus are rebranding their offerings, focusing on "drive for fun" initiatives and investing in racing tracks to maintain their appeal to driving enthusiasts.

3.3. Digital Divide

The high cost of SDVs has restricted ownership to affluent individuals (Oliver et al. 2018), raising concerns about a growing digital divide. As SDVs become the dominant form of transportation, there is fear that non-autonomous vehicles (non-SDVs) may eventually be deemed unsafe and banned, leaving lower-income individuals unable to afford the more expensive SDVs.

3.4. Cost Reduction Expectations

While SDVs were initially expected to reduce insurance and energy costs, these anticipated savings have yet to materialize. Despite being touted as safer, SDVs have not resulted in significantly lower insurance premiums compared to non-autonomous vehicles. The cost reductions predicted in the past remain largely theoretical.

3.5. Road Infrastructure

A contentious debate has emerged over whether governments should continue maintaining traditional road infrastructure or invest in digital infrastructure specifically designed for SDVs (Peters 2017). To date, SDVs have been designed to interpret human road signs, rather than digital signals. Public opposition to government investment in SDV infrastructure has grown, with many arguing that automakers should share the financial burden.

3.6. Law Enforcement Revenue

There is concern in cities like London and Mountain View, California, that SDVs could reduce revenue for law enforcement. With more law-abiding autonomous vehicles on the road, there has been a gradual decrease in speeding and illegal parking infractions. While this improvement in road safety is positive, it could reduce a key source of income for local law enforcement (Marshall and Davies 2018).

3.7. Transition to Electric Power

Although SDVs currently rely on a mix of electric and traditional fossil fuel power, governments are pushing for a transition to fully electric vehicles. The UK government announced in 2018 that over half of all vehicles should be electric by 2030 (Harrabin 2018). While this target is unlikely to be met within the next five years, electric-powered SDVs are viewed as a crucial step toward reducing the automotive sector's dependence on fossil fuels.

4. Mitigating Negative and Accentuating Positive Impacts of Autonomous Transportation

Since 2019, significant efforts have been made to mitigate the negative impacts of self-driving vehicle (SDV) technology while amplifying its benefits through national, international, and supranational legislation and policies. One major step has been the development of national standardization protocols involving policymakers, automakers, computer scientists, and transportation agencies. These protocols address key areas such as cybersecurity, sensor technology requirements, and hardware safety standards, ensuring that various levels of vehicle automation undergo rigorous testing.

Many national governments have implemented a range of regulations to uphold safety standards, with several countries conducting independent testing to address concerns about potential biases in manufacturer-led evaluations. Notably, the U.S., Canada, and Japan have enhanced transparency in SDV regulation. A total of 65 countries have now developed SDV-specific driving tests, licensing laws, and mandatory safety regulations to ensure vehicles meet safety criteria before being sold.

Public awareness initiatives have also been bolstered, with efforts to educate drivers on SDV functionality and interactions between autonomous and non-autonomous vehicles. These efforts, combined with increased media campaigns by automakers, have fostered greater public trust in SDVs. Furthermore, strict procedures have been implemented to ensure personal data from SDVs is anonymized and encrypted in compliance with the GDPR, marking a significant milestone in privacy protection over the last seven years. The automobile industry has shifted its design processes to prioritize responsible innovation and value-sensitive design, driven by state-supported initiatives and the establishment of oversight bodies like the UK's Centre for Data Ethics and Innovation and Singapore’s AI Ethics Council. Manufacturers have also been required to enhance transparency and offer guarantees on vehicle lifespan. In markets such as the U.S., Canada, the EU, the UK, China, South Korea, and Japan, automakers must provide free software upgrades for a period of five years after the sale of any SDV. To support these software updates, manufacturers provide detailed guidelines to ensure compliance. SDVs are equipped with a locking system that prevents operation unless the software is up to date. Additionally, vehicles notify drivers of maintenance requirements and may restrict use depending on the severity of the issue. Collaborations like the SDV Fair Use Initiative (SDVFUI) have also emerged to promote the fair sharing of intellectual property, aiming to enhance vehicle safety.

5. Steps Towards a Desired Future and Avoidance of an Undesired Future

This scenario outlines various issues, risks, and opportunities associated with self-driving vehicles (SDVs) in 2025. It is essential to reflect on these developments, distinguishing between desirable outcomes and those to be avoided, and to consider the actions necessary to achieve this. National, international, and supranational institutions must ensure that citizens are protected from manufacturers' eagerness to deploy vehicles prematurely. The scenario highlights that the primary drivers of SDV manufacturing will be market, economic, and efficiency incentives. However, these incentives must not compromise public safety, security, or employment. As such, the SDV industry must be subject to strict regulations to ensure safety through effective regulatory institutions. In terms of privacy, both ethical and legal concerns demonstrate that under-regulated SDV development could negatively impact drivers, passengers, pedestrians, and other road users. This also raises legal questions related to data protection and privacy laws. Adherence to current regulations is necessary to control the data generated, collected, and used by SDVs. Clear distinctions must be made between essential data required for vehicle mobility and any personal or private information it may contain. If essential data includes such information, it must be anonymized, aggregated, and secured to protect privacy. For non-essential data, appropriate policies must prevent its collection or storage unless explicit and informed consent is provided. As discussed in the legal section of this scenario, European governments must ensure the automotive industry integrates the principles of the GDPR to assure citizens that their personal data will be protected when using SDVs. Automakers are responsible for defining the purposes for which data is collected, demonstrating compliance with data protection laws. For example, if the data is intended for advertising, personalized pricing, or additional product sales, manufacturers must either obtain clear consent from the vehicle owner or prohibit such data use entirely. A current legal concern is the potential for SDVs to be used for malicious, illegal, or fraudulent activities. If SDVs are hacked or controlled by criminals or terrorists, the safety and security of passengers, pedestrians, and cities could be at risk. In such cases, law enforcement officials may need access to data collected by the vehicle to identify illegal activities. However, this must be balanced against the need to protect the privacy of innocent citizens. Effective cybersecurity measures, such as DENM, certifications, cryptographic signatures, and attestation methods, require significant investment by automakers and must be fit for purpose. The tension between safety and economic concerns discussed in this paper underscores the need for statutory regulation, third-party testing, and strategic planning to secure these technologies. While this may delay SDV deployment, it will ultimately enhance vehicle security. One of the primary social and economic challenges for the future is the transition from non-autonomous to autonomous vehicles. A key issue will be the implementation of digital infrastructure to support SDVs. Policymakers must ensure a smooth transition from traditional road infrastructure to digital systems. In the short term, SDVs will continue to rely on current road signs, traffic lights, and markings for navigation. However, the eventual shift to digital infrastructure will be a costly and time-consuming process. While this is unlikely to happen by 2025, governments and companies should begin preparations now. Although SDVs offer potential benefits such as reduced ecological impact, less traffic congestion, and shorter travel times, there is also a risk that their convenience will lead to increased usage, which could negate many of these advantages. Policymakers must take steps to prevent overuse by investing in SDV public transportation systems that ensure convenience, cost savings, and energy efficiency. This approach could also help bridge the digital divide and prevent poorer citizens from being excluded from the transportation system, as highlighted in the economic section of this scenario. Additionally, there must be a focus on making SDVs more inclusive, particularly at levels 4 and 5 automation. Ensuring accessibility for the elderly, disabled, and those unable to drive is critical to addressing rights-based issues in the evolving transportation landscape, as discussed in the ethics section.

6. Conclusion

Self-driving vehicles (SDVs) are poised to significantly reshape our lives, yet the timeline for these transformations remains uncertain. Often, the future is perceived as distant, reducing the urgency for current policy action. This paper introduces a policy-focused scenario approach as a method to address emerging concerns related to SDVs. Scenarios are valuable tools for forecasting and strategizing around the potential trajectories of emerging technologies, offering policymakers clear visions of possible futures. They provide a framework to help establish steps toward achieving desirable outcomes. The scenario approach outlined in this paper identifies various facilitators and inhibitors of SDV development by 2025, highlighting key concerns and considerations for policymakers in the years ahead. It also examines the ethical, legal, social, and economic impacts of SDVs, emphasizing steps that can be taken to maximize benefits while mitigating potential negative outcomes. Though scenario planning is not a precise science, it equips policymakers with valuable insights into how their decisions today will influence the future of emerging technologies like SDVs, guiding informed and proactive policymaking.

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