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# Driving into the Unknown: proposal of models to help designers anticipate the long-term impacts of autonomous vehicles on society

Robin Lecomte

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# Driving into the Unknown: Proposal of models to help designers anticipate the long-term impacts of autonomous vehicles on society

*Proposition de modèles pour aider les concepteurs à anticiper les impacts à  
long terme des véhicules autonomes sur la société*

## Thèse de doctorat de l'université Paris-Saclay

École doctorale n°573 : interfaces : matériaux, systèmes, usages (INTERFACES)  
Spécialité de doctorat : Génie industriel  
Graduate School : Sciences de l'ingénierie et des systèmes. Référent : CentraleSupélec

Thèse préparée dans les unités de recherche **Laboratoire Génie Industriel** (Université Paris-Saclay, CentraleSupélec) et **Centre de recherche en Design** (Université Paris-Saclay, ENSCI-Les Ateliers, ENS Paris-Saclay), sous la direction de **Bernard YANNOU**, professeur, le co-encadrement de **Roland CAHEN**, enseignant-chercheur HDR

Thèse soutenue à Paris-Saclay, le 10 janvier 2024, par

**Robin LECOMTE**

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**Titre :** Proposition de modèles pour aider les concepteurs à anticiper les impacts à long terme des véhicules autonomes sur la société

**Mots clés :** voiture autonome, usages, design, sociétal, impacts, long terme

**Résumé :** Depuis la Révolution Industrielle, les avancées technologiques ont eu des effets à la fois positifs et négatifs sur la société et l'environnement. Cette thèse se concentre spécifiquement sur les impacts des véhicules autonomes (VA) et souligne l'importance pour les entreprises d'anticiper dès maintenant leurs conséquences sur le long terme. Ce travail de recherche propose deux modèles dénommés Study-Method-Impact (SMI) et Representation-Usage-Impact (RUI), pour évaluer les impacts socio-économiques, environnementaux et sociaux des VA (par exemple, les impacts sur la consommation d'énergie, l'emploi ou la santé). Ces modèles sont intégrés dans un logiciel original appelé AutoVision, conçu pour aider les concepteurs à imaginer des véhicules autonomes responsables.

AutoVision a été testé au sein du groupe automobile Stellantis et a démontré sa capacité à générer des concepts convaincants et responsables, tout en fournissant de nouvelles connaissances à ses utilisateurs. De manière plus large, ces travaux veulent contribuer à responsabiliser les entreprises sur les futures technologies qu'elles développent. En particulier dans un contexte de réchauffement climatique.

*Résumé étendu en Français disponible dans le supplementary material 28 (p302).*

**Title:** Driving into the Unknown: Proposal of models to help designers anticipate the long-term impacts of autonomous vehicles on society

**Keywords:** autonomous vehicle, usages, design, society, impacts, long-term

**Abstract:** Since the Industrial Revolution, technological advancements have had both positive and negative effects on society and the environment. Specifically, this thesis focuses on the long-term impacts of autonomous vehicles (AVs) and emphasizes the importance for designers and companies to anticipate these consequences now. The research proposes two models, namely Study-Method-Impact (SMI) and Representation-Usage-Impact (RUI), to evaluate the socio-economic, environmental, and social impacts of AVs (for example, impacts on energy consumption, employment, or health). These models are integrated into an original software called AutoVision, which is designed to assist decision-makers and designers in defining responsible AV concepts.

AutoVision has been tested within the automotive group Stellantis and has demonstrated its ability to generate compelling and responsible AV concepts, while providing new knowledge to its users. In a broader sense, these work aims to contribute to holding companies accountable for the future technologies they develop. Particularly in the context of climate change.



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# **DRIVING INTO THE UNKNOWN**

Proposal of models to help designers  
anticipate the long-term impacts of  
autonomous vehicles on society









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## Summary

Since the Industrial Revolution, technological innovation has been the driving force behind many remarkable advances designed to positively transform our way of life. However, this race for innovation is also the cause of environmental and social problems. Companies and designers should take responsibility as early as possible for the influence their innovations might have in the future. This thesis focuses on the specific case of the autonomous vehicle (AV), which is a good example of a technology heralded as disruptive that will have many long-term consequences. Companies and designers are already making choices, the consequences of which they cannot always imagine, because they concern fields of knowledge they are not familiar with (economy, environment, urban planning, health, safety, sociology, uses) and in a future they do not know. Yet this knowledge and imagination of futures could be brought to them today within a design platform that would enable them to imagine new autonomous vehicle concepts and assess their likely long-term impacts, or vice versa.

This research aims to anticipate the long-term impacts of autonomous vehicles by proposing scientific models and industrial tools. First, it presents the Study-Method-Impact (SMI) model, which aims to help anticipate socio-economic and environmental impacts of AVs by exploiting scientific literature. The model's results are compared to external synthesis reviews, confirming its usefulness in providing accurate information to non-experts. The second model is called Representation-Usage-Impact (RUI) and combines the knowledge of experts such as sociologists to identify potential social impacts of AVs. It seeks to address the limitations of current methods for anticipating social impacts. Based on these two models, we present an original industrial tool called AutoVision. Its objective is to assist decision-makers or designers from automotive companies in defining concepts for AVs. It allows for the anticipation of social, socio-economic, and environmental impacts based on characteristics such as the usages permitted by the vehicle. AutoVision offers two modes tailored to decision-makers and designers. The first is a stimulation mode called Advisor. It was tested in an experiment with decision-makers of the industry, demonstrating its potential to help decision-makers generate convincing AV concepts with fewer long-term negative effects. The second is a simulation mode called Impact Guesser. It was tested in another experiment, confirming that the tool helps users acquire new knowledge and raise awareness of the potential impacts of their concepts.

Overall, this thesis has identified methodological gaps, addressed them with original proposals, and tested them in the field within an international automotive group. This research provides insights into anticipating the possible impacts of future technologies and offers practical models and tools to support decision-making for responsible innovation today.





"Electricity may be the driver" ad in the magazine Life in January 30, 1956



## CHAPTER 1

# Context, positioning, and general question

This chapter gives context to the research work by first explaining the concept of autonomous vehicle and its historical background. It then examines how the topic of autonomous vehicles is approached by the car manufacturer Stellantis, serving as an industry example. The chapter also defines the research fields relevant to the thesis work.

Finally, a general question is formulated.

# 1. Background and context of autonomous vehicles

## 1.1. General context

Transportation has played a significant role in the development of civilizations throughout history. From walking and domesticated animals to boats, ships, and stagecoaches, humans have always looked for more efficient ways to travel. Railroads revolutionized long-distance travel, while the automobile gave individuals the freedom to move independently. Commercial aviation reduced travel times and made far-off destinations more accessible. Public transportation systems such as buses and subways became essential elements of urban mobility in the 20th century. More recently, digital connectivity has led to the emergence of new transportation models, such as ride-sharing services and vehicle rental platforms, making it easier and more convenient to access transportation on demand.

These advances have led to an increase in the movement of people and significant expansion of spacing within communities, notably through urban sprawl. This expansion, in turn, has led to an increase in the number of trips that would previously have been considered unnecessary. In simple terms, bringing communities together is no longer about physically bringing them closer, but about developing mobility that enables people to connect. This has contributed to devastating consequences on the environment, with a huge contribution to global warming (Rafferty, 2023). This is especially true for road transport, which accounted for 10% of worldwide greenhouse gas emissions in 2022 (IPCC, 2023; Figure 1). In Europe, the percentage was 18% in 2020 according to the European Environment Agency (2021). Likewise, France also had an approximate 18% percentage as reported by Secten (2021).

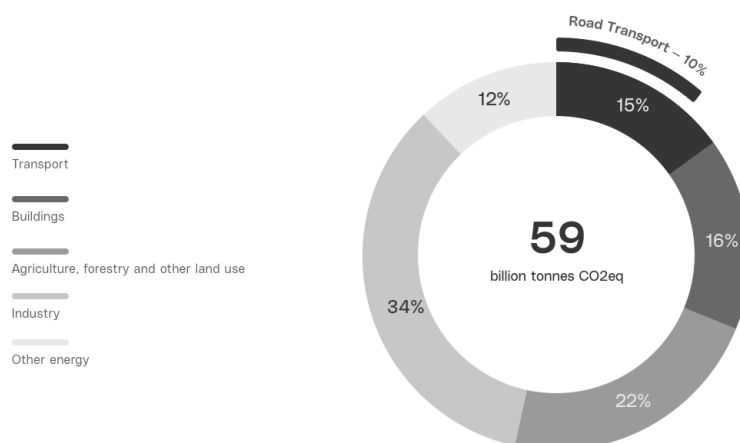


Figure 1. Global greenhouse gas emissions by sector for the year 2022 (data from IPCC, 2023).

Road accidents are also a significant concern linked to the increase in the number of cars. Although there have been efforts to improve road safety and reduce the number of deaths (as seen in Figure 2), fatalities continue to occur at unacceptably high rates. And as pointed out by Walker (2017), in addition to causes such as alcohol or drug consumption, simply being tired is enough to risk a fatal accident. According to Ritchie et al. (2018), road accidents caused 1.2 million fatalities worldwide in 2019, which is an alarming number. It is the twelfth leading cause of death in the world. To this are added other problems such as air pollution, traffic congestion, or increasing inequalities due to the cost of vehicles. These issues therefore appear as a heavy counterbalance that nuances all the benefits mentioned earlier.

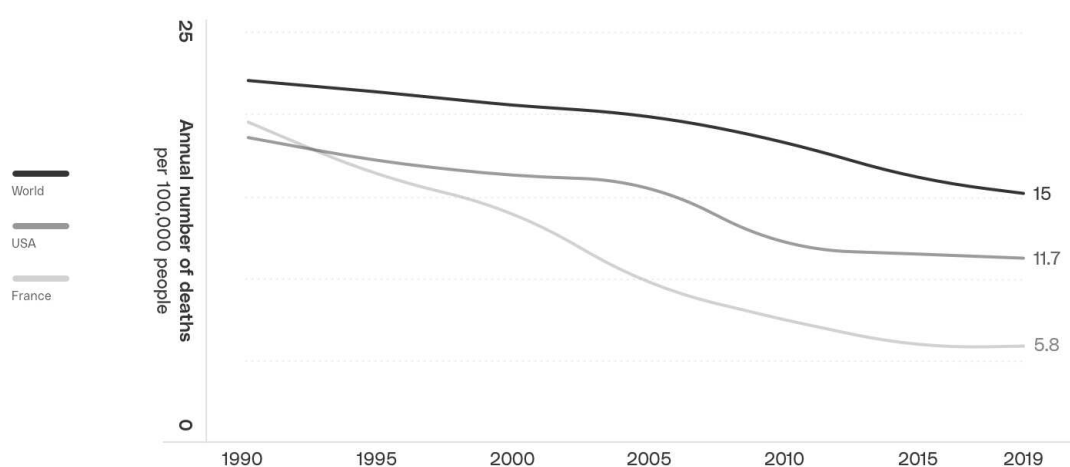


Figure 2. Death rate from road injuries. Deaths include those from drivers and passengers, motorcyclists, cyclists and pedestrians (Global Burden of Disease Study, 2019).

In this context, autonomous vehicles (AVs) are set to become the next big step in the the transport industry. As urbanist Anthony Townsend explains in his book *Ghost Road*, "the revolution [of AVs] will strike with surprise, surgical precision, and overwhelming force" (Townsend, 2020). Unlike traditional cars driven by humans, AVs can navigate roads independently, offering several advantages like reducing road accidents caused by human errors, saving travel time and optimizing driving to make transportation more sustainable. Furthermore, they offer economic potential by providing companies with new business opportunities and reaching new customers, including disabled individuals. This revolution is likely to bring new types of vehicles and more services to meet mobility needs of people. However, if left unchecked, it also has the potential to create new problems or worsen current ones, such as greenhouse gas emissions. Therefore, it is crucial to take a step back and analyse the long-term overall effects of this technology on society and the environment before deploying it. So it is essential that decision-makers do not assume that autonomous vehicles are the only solution to transport problems (Winner, 1989).

This thesis aims to investigate the long-term effects of the AV technology and provide a comprehensive understanding of its impact on society and the environment. By doing so, we hope to equip designers and decision-makers with knowledge to make responsible, safe, and sustainable choices. This work's aim is to lead the way for others to ensure that the use of autonomous vehicles, if deemed beneficial, is done responsibly and sustainably.

## **1.2. What is an autonomous vehicle?**

### **1.2.1. General definition**

The dream of autonomous transportation has been a long-standing pursuit of humanity, leading to numerous technological innovations aimed at replacing humans behind the wheel. The first of these innovations dates to 1891 and is called the sheet-to-tiller. It was a nautical system that enabled a sailboat to be automatically steered by the force of the wind alone, using a few ropes, blocks, and elastics (Townsend, 2020). The objective was to allow sailors to rest during lengthy voyages. Many other automation systems have followed, including more complex ones like urban subway automation and airplane automation. The latter allowed pilots to rest during long flights and minimize errors during important tasks like landing. Today, machines can automatically harvest crops, vacuum cleaners can do the housework, lawnmowers can mow the lawn by themselves, and robots can move around on the surface of Mars by themselves. However, automating road vehicles is still work-in-progress. The system needs to replace a human driver who must navigate a fast, heavy, and dangerous machine in a two-dimensional environment with infinitely varied and variable obstacles that change by the second. And unlike airplanes and ships, vehicles also need to avoid harming not only passengers but also pedestrians. Before going any further, it is now necessary to define what we mean by autonomy, and specifically by autonomous vehicle.

According to the Oxford English Dictionary, autonomy is "freedom from external control or influence." The consulting firm Gartner defines AVs as vehicles that can drive themselves from a starting point to a predetermined destination using various in-vehicle technologies and sensors, including adaptive cruise control, active steering (steer-by-wire), anti-lock braking systems (brake-by-wire), GPS navigation technology, lasers, and radar (Gartner, 2023). However, listing all these technical characteristics does not seem very relevant to define what an autonomous vehicle is. This is mainly because the technology is still in its early stages and is sure to evolve. A good definition wouldn't have to change every time a new sensor is added or removed. So we preferred the definition from the state of California (USA): "autonomous technology as the capability to drive a vehicle without the active physical control or monitoring by a

human operator." Fundamentally, an autonomous vehicle is defined primarily by the absence of human intervention. Inspiring from the definition of the state of California, as well as the one from Techopedia (2023), we choose to maintain the following definition for our work. We have also chosen to focus solely on passenger transport.

***An Autonomous Vehicle (AV) is a road vehicle that can transport passengers and operate without any human intervention.***

Please note that this question does not make any judgment on whether it is desirable or not to have a vehicle operating without any human intervention.

In literature, the term connected vehicle (CV) is often associated with autonomous vehicle (AV). However, the two have a different meaning. A connected vehicle is a car or any other vehicle that can communicate with other vehicles, infrastructure (for example, traffic lights or road signs), and external systems (such as cloud-based services or mobile applications). These vehicles are equipped with different sensors, processors, and communication technologies to enable data exchange. An autonomous vehicle is almost always a connected vehicle, but the reverse is not necessarily true (Shladover, 2018).

In addition, autonomous mobility is a broader concept that encompasses not only autonomous vehicles but also the entire ecosystem of transportation services and infrastructure that support on-demand and automated mobility.

In the upcoming sections, we provide a more detailed explanation of what we consider an autonomous vehicle, including our specific scope and positioning choices.

## **1.2.2. Levels of automation**

There are several levels of automation that can be distinguished between a non-autonomous vehicle and a fully autonomous one. The higher the level of autonomy, the less the human driver needs to intervene, until he/she no longer needs to intervene at all. For example, the lane-keeping function of some current vehicles corresponds to a low level of autonomy, because the driver still needs to press the pedals and pay attention to the road. We distinguish partial automation, which involves the user working together with the vehicle, and full automation, which requires no human intervention. Various organizations have attempted to classify these levels. The most widely used classification is the J30016 standard developed by the Society of Automotive Engineers (SAE International, 2021), a global professional association for the automotive and aerospace industries. This standard, which was adopted by the National Highway Traffic Safety Administration (NHTSA), a US federal agency

responsible for road safety, in 2016 (Herrmann et al., 2018), defines six levels of automation, ranging from level 0 (no automation) to level 5 (full automation), as depicted in Figure 3.

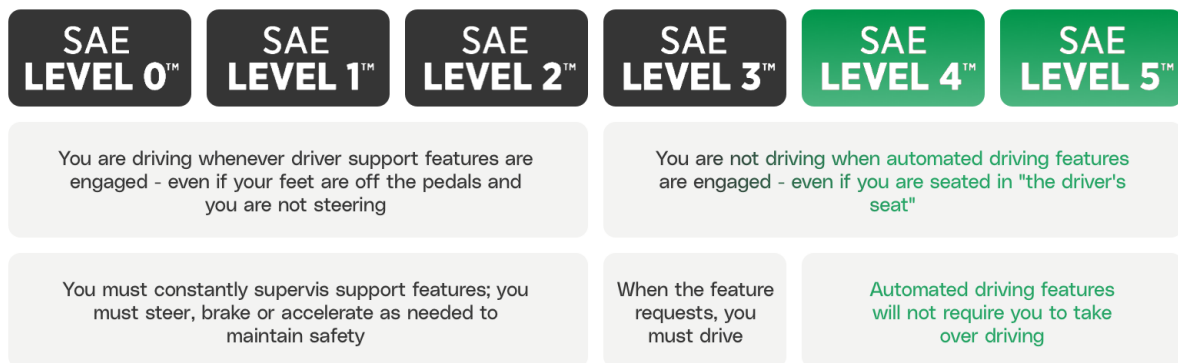


Figure 3. Levels of automation according to the J30016 standard developed by the Society of Automotive Engineers (SAE International, 2021).

At the lowest levels (1 to 3), one can find all the functions often grouped under the term ADAS, or Advanced Driver Assistance Systems. These are a set of technologies and systems that aim to improve vehicle safety and assist drivers by offering features beyond the traditional vehicle functions. Typically, ADAS provide warnings, alerts, and automated actions to help avoid accidents and make driving more convenient (*Car and Driver*, 2020).

In this work, we are specifically referring to autonomous vehicles that meet the automation levels 4 and 5 outlined in the J30016 standard (Figure 3, in green). This means that the vehicle is capable of full autonomy in driving. Level 4 operates in complete autonomy but with specific conditions, such as being limited to a particular city. In contrast, level 5 vehicles operate in complete autonomy without any constraints. To put it more simply, these vehicles may not have a steering wheel or any other controls that would allow a human to drive them.

### 1.2.3. Types of AVs

Autonomous vehicles can have various forms based on their intended use. The lack of a driver enables new kinds of designs in transportation, like the autonomous shuttle mentioned by Townsend (2020): “cozy inside but not claustrophobic, roomier than a car, but more intimate than a bus.” Therefore, before proceeding further, we created a scale of autonomous vehicle types designed for people transportation (Figure 4).

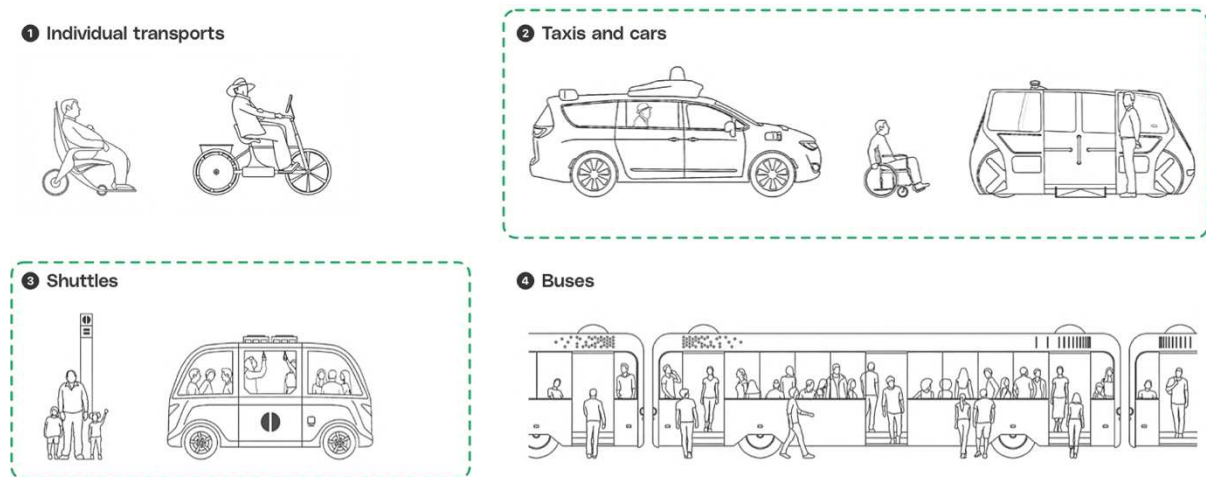


Figure 4. Scale of autonomous vehicle types intended for people transportation, with drawings taken from Townsend (2020).

We have identified four main types of autonomous vehicles that are capable of transporting people. The first type is individual transports, such as wheelchairs or tricycles, which are designed to carry a single passenger over short to medium distances. The second type is taxis and cars, which are like the cars we know today and can transport one to several people. For transportation of larger groups, the third type is autonomous shuttles, which are larger than cars but smaller than buses. Finally, for mass road transport, the fourth type is autonomous buses. Some vehicles may obviously fall into multiple categories, but we did not want to complicate our categorization, as it is sufficient for defining our scope. For more details, there are other categorizations available, such as the one provided by Liu (2016).

We chose to focus on the transportation of passengers in vehicles belonging to categories 2 and 3, with a maximum of 9 seats (corresponding to category M1 of the United Nations Economic Commission for Europe). Vehicles such as taxis, cars, and small shuttles (Figure 4, in green).

Today, there are two modes of car usage: private and shared. Private usage refers to a vehicle that is used only by its owner or a long-term renter. Shared usage refers to a vehicle that is shared among several people, which may or may not include the owner. Vehicle sharing, such as short-term rentals, and carpooling are different types of shared usage. Since the 2000s, vehicle sharing has experienced strong growth (see Figure 5 from Shaheen & Bouzaghrane, 2019).



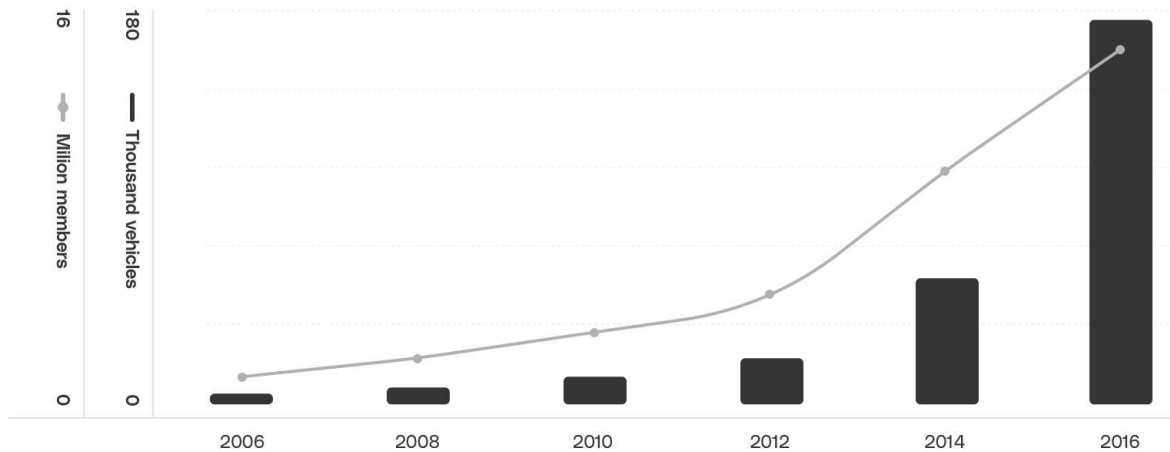


Figure 5. International growth of car-sharing between 2006 and 2016 by Shaheen & Bouzaghrane (2019).

The recent increase in transportation options has led to the development of new business models known as Mobility as a Service or MaaS (Mladenović, 2021; Smith, 2020). Unlike private modes of transportation, MaaS provides digital services to help people get from one place to another, regardless of how they choose to travel. The goal is to offer transportation solutions based on what users need. Examples of this include ride-sharing services like Uber or Bolt. This can also include multimodality, which means combining multiple modes of transportation to get somewhere, like taking a bus followed by a bike. With the introduction of self-driving cars, this trend is likely to continue growing because people will be able to order a vehicle anytime without the need for a driver and will not have to own a vehicle themselves. All these observations lead us to consider autonomous vehicles for both private and shared use.

Section 1.4 and Figure 17 summarize the scope of the thesis related to autonomous vehicles.

#### 1.2.4. Promises and criticisms

Advocates of autonomous vehicles argue that the benefits of this technology could be game-changing for transportation. AVs have the potential to reduce the number of road accidents, ease traffic congestion, save commuters time, and optimize routes to reduce congestion and delays. Distracted driving is a major safety concern, with drivers who use mobile phones being four times more likely to be in a collision (NHTSA, 2023). AVs could allow passengers to use distractions safely during transportation. In addition, AVs could free up 250 million hours of wasted commuting time annually in the most congested cities of the world by 2050 (Lanctot, 2017). Full vehicle automation could also enhance fuel efficiency and minimize carbon emissions by using lighter frames that no longer have to withstand the force of high-speed collisions. Smaller vehicles requiring less parking space could make better use of the road and free up space in cities. Furthermore, automation could improve accessibility for people with disabilities,

offering better mobility than ever before (Hawkins, 2023). Proponents of AVs envision the future as a driverless world where mobility is as simple as streaming music on your phone. They also believe that the aforementioned benefits could significantly improve the quality of life for millions of people worldwide.

On the other hand, critics of autonomous vehicles argue that they may cause more problems than they solve. This echoes criticisms that can be made about automation in general (Bainbridge, 1983). For instance, automated commutes could lead to a sedentary lifestyle and AVs for short-distance trips could disrupt walking, negatively impacting the health of people. Passengers being a captive audience could lead to a business model focused on monetizing their attention. The services developed for AV users, such as entertainment features, could make people more self-absorbed and less aware of their surroundings. While premium services can offer ad-free rest to the wealthy, using self-driving vehicles may mean submitting to be scanned, sorted, and solicited. Environmental promises may also not be kept, given that the number of vehicles and trips may significantly increase. Additionally, while the technology can remove human error, it could introduce technological ones, such as sensor error or vulnerability to hacking. The cost may also be higher than initially thought, for instance if remote human safety monitoring is deemed necessary. An analysis in the Harvard Business Review suggests that operating autonomous taxis may cost three times more than human-driven taxis (Nunes & Hernandez, 2019). Others argue that the market of AV may replace democratic deliberation in deciding who gets to travel, leading to increased inequalities. Moreover, certain groups, such as women and senior citizens, may have unique concerns about riding a bus with no uniformed crew.

The reality likely lies somewhere between these two points of view, but it is still difficult to predict which side the balance will favor. The thesis work will utilize models and tools to address the positioning of this reality and evaluate the contradictory elements discussed above in a scientific manner, considering the potential rebound effects.

### **1.3. History and current state of AVs**

AVs have evolved from being a concept from science fiction books to becoming a reality. The rise in the number of players and laws governing AVs demonstrates their potential to become widely used in the next few decades. Before discussing their future, it is important to understand their origins. This section provides a historical overview over the past century, highlighting significant projects and their contributions. It also presents how the usages of autonomous vehicles are anticipated and perceived over time. It then offers an outline of the current state of autonomous vehicles, identifying key players and their advancements, and finally, focuses on legal aspects.

### 1.3.1. History

To describe the main projects related to autonomous vehicles in chronological order, we distinguished three phases, represented in Figure 6. The first phase is characterized by a lack of concrete projects, but rather visions of the future of autonomous mobility. The second phase is defined by the appearance of the first experiments, which were more focused on infrastructure than on the vehicles themselves. Finally, the third stage marks a breakthrough with the emergence of the digital revolution, which allowed for the development of the first intelligent vehicles capable of adapting to their environment.

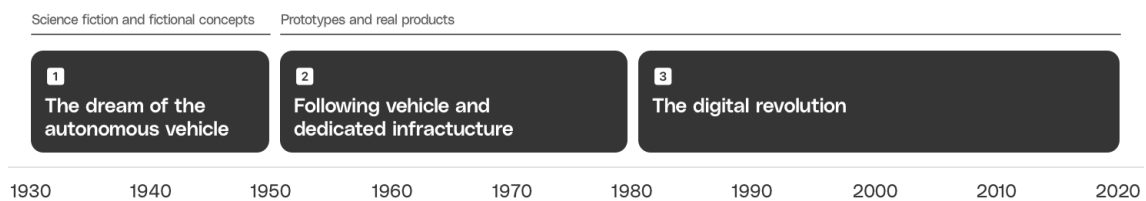


Figure 6. Simplified representation of three major phases of autonomous vehicles development.

The first phase began in the 1930s, when autonomous vehicles were only seen in science fiction. Without computers, it was hard to imagine AVs adapting to the road infrastructure. However, people still dreamed of a future with these vehicles reducing accidents, congestion, and freeing up city centers. New train technologies and the arrival of highways in Europe inspired the first ideas of AVs. The 1939 Futurama exhibit showcased a vision of automated highways with vehicles and infrastructure communicating (Figure 7, left). Until the 1950s, the representations were mostly fiction or conceptual ideas, with little focus on the technical aspect. Regarding the anticipated modes of use of AVs at that time, they were naturally associated with works of science fiction. During this period, many discussions about the impact of technology on society emerged, and AVs were no exception. For instance, in "Paradise and Iron" (Breuer, 1930), an idealized future city was depicted where everything, including vehicles, was automated. Isaac Asimov (1953) also imagined a story in which AVs have become mandatory (Figure 7, right).

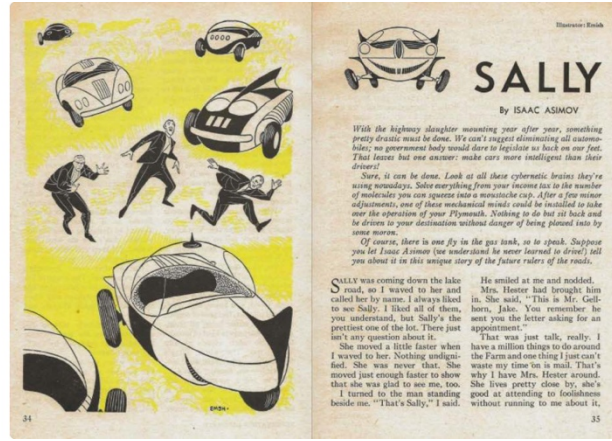


Figure 7. Left: General Motors Futurama exhibit, New York World's Fair, 1939. Right: Illustration of the story "Sally" by Isaac Asimov, 1953.

The second phase, which began in the 1950s, focused on vehicle and infrastructure development. Initial experiments involved the use of dedicated infrastructures to guide vehicles. Figure 8 (left) illustrates a test where an "autonomous" vehicle followed a steel cable embedded in the road by using a magnetic system. This example demonstrated that the car's behavior was more akin to a train than a true autonomous vehicle. Unfortunately, the emphasis on infrastructure rather than vehicle development failed to convince decision makers to invest in new roads. As Anthony Levandowski, the head of Google's robot car project in 2013, pointed out, "We don't have the money to fix potholes, why would we invest in putting wires in the road?" Consequently, this has resulted in further delays in the advancement of autonomous vehicles.

At that time, practical applications were beginning to be considered, going beyond the realm of science fiction. In an advertisement published in the American magazine *Life*, America's Independent Electric Light and Power Companies presented the autonomous vehicle as the next advancement in the electric revolution (after lighting). The advertisement showed a car where a family could play board games without having to pay attention to the road (see Figure 8, on the right). These presented applications, especially in advertisements, aimed to improve existing habits rather than disturb them. Promises of no traffic jams, accidents, or driver exhaustion were already being made.

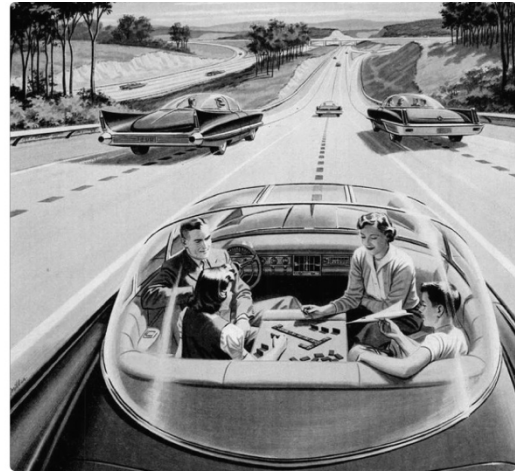


Figure 8. Left: Autonomous Highway System tests from General Motors (GM) and Radio Corporation of America (RCA), 1950. Right: "Electricity may be the driver" ad in the magazine Life in January 30, 1956.

The third phase, the digital revolution, began in the 1980s. In 1986, the Prometheus European project pioneered autonomous guidance systems and communication between vehicles and infrastructure or other vehicles (Vehicle to X, or V2X). The project tested prototypes like the VaMoRs Mercedes van, which could autonomously travel hundreds of kilometers on the highway (Figure 9, left). This project was the first to study the interaction between cars, infrastructure, and traffic. The Prometheus project faced limitations due to the high cost and large size of the required electronic components. It achieved remarkable results, including a 1000km autonomous drive on a French freeway in 1994. These achievements laid the foundation for other autonomous car projects like the *PATH* program from UC Berkeley, who developed platooning capabilities (Figure 9, right).



Figure 9. Left: VaMoRs Mercedes van project, Bundeswehr University Munich, 1986-2003. Right: Demonstration of platooning with lane change, PATH, 1997.

In 2004, the U.S. Defense Advanced Research Projects Administration launched the DARPA Challenge (Figure 10), a competition to design AVs before 2015. Participants raced their prototypes across a desert. The first race in 2004 was unsuccessful, with all participants losing quickly. The second race in 2005 was shorter and Stanford

University won the \$2 million prize. In 2007, the competition evolved into the DARPA Urban Challenge, which took place in an urban environment. At this stage, similar to other disruptive innovations, the military adopted them before the general public (e.g. internet or virtual reality). Mainly, it was not possible to create a feasible economic model due to the technology being in its early stages.



Figure 10. Left: The winning Stanley VW Touareg from Stanford Artificial Intelligence Laboratory (DARPA Grand Challenge of 2005). Right: The winning Chevy Tahoe "Boss" from Carnegie Mellon University and General Motors (DARPA Urban Challenge of 2007).

In 2008, Google invested in autonomous vehicles, and in 2010, they launched the Google car (Figure 11). They reused technologies from the DARPA Urban Challenge winner and managed to cover over 220,000 km autonomously. As Google grew more confident in their project, they began to promote it more. In 2012, an ad featuring a blind man using a Google Car went viral, showcasing the potential of the technology and the game changing usages it could bring. In 2016, the Google Car was renamed Waymo and became a standalone company under Alphabet Group. Waymo has covered over 2.5 million km between 2015 and 2017 with minimal repossessions (transitional phase between autonomous driving and human driving).



Figure 11. Left: Photo of a Google car (Toyota Prius) with the two Google founders Larry Page and Sergey Brin and the ex-CEO Eric Schmidt. Right: Screenshot of a video from Google showing a blind person using an autonomous Google Car, 2012 (see supplementary material 1). It has more than 10 million views on YouTube without counting the re-uploads on other platforms (assessed on January 28, 2022).

Since 2010, several projects for autonomous vehicles have been initiated. For example, the VisLab Intercontinental Autonomous Challenge aimed to test autonomous vehicles over a 13,000 km route from Italy to China to gather data and improve perception systems. BMW has been testing autonomous vehicles on German freeways since 2011 and showcased their capabilities at the 2014 Consumer Electronic Show. The Daimler Group developed a self-driving Mercedes S-Class limousine that traveled 103 km without human intervention, including urban, highway, and countryside areas. Tesla started developing autonomous car technology with Mobileye in 2013 and launched the "autopilot" function in its cars in 2015, which is actually an advanced driver assistance function (ADAS).

### 1.3.2. The AV today

Since the 2000s, the development of autonomous vehicles has gained momentum with projects like the DARPA Challenge or the Google Car. New sensors like LIDAR have made it possible to capture the 3D environment around the vehicle, and advances in data fusion and machine learning have inspired many companies to work on autonomous mobility. Waymo and Fiat Chrysler (now Stellantis) formed a partnership to implement level 4 self-driving technology across all their brands (Ohnsman, 2020). Hyundai has acquired Boston Dynamics to expand its future mobility concepts, including autonomous cars (Hyundai Motors, 2021). Several companies, including Mercedes-Benz (Lahee Lee, 2020), Jaguar Land Rover (Gooding, 2023), and Volkswagen (Dyble, 2020), have partnered with Nvidia, a graphical processing unit manufacturer, to develop artificial intelligence capabilities for their future autonomous vehicles.

More and more companies are making autonomous rides available to the public around the world. Waymo offers services in Phoenix and San Francisco (USA) (Bellan, 2022b; Roth, 2022b), Cruise in Phoenix, San Francisco, and Austin (USA) (Hawkins, 2022b; Figure 12, left), Baidu at Chongqing and Wuhan (China) (Bellan, 2022a), AutoX near Shenzhen (China) (Silver, 2021), and Pony.ai in Beijing (China) (Krolicki, 2022; Roth, 2022a). In total, there are over thirty cities worldwide, mainly in the United States and China, that provide autonomous mobility services. And this number is gradually increasing (Templeton, 2023a). However, autonomous mobility services are not as widely deployed in Europe, primarily due to regulations. One company, Easymile, has tested experimental shuttles in select countries (*Easy Mile*, 2021). Other organizations aim to provide autonomous mobility services in few years, such as the AV startup 42dot in South Korea (*42dot*, 2009), or the companies Perrone Robotics and May Mobility in the USA (*Perrone Robotics*, 2020; *Maymobility*, 2021). Motional and Uber have also partnered to introduce autonomous taxis throughout the United States (Abuelsamid, 2022).

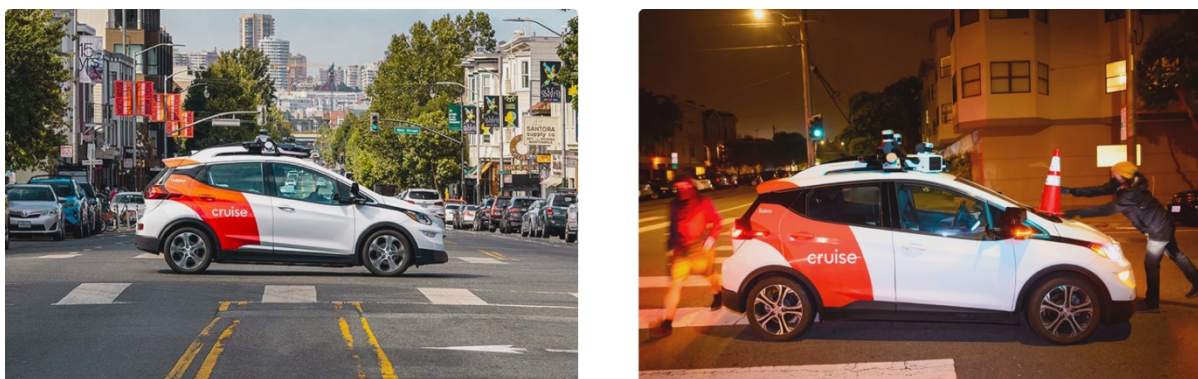


Figure 12. Left: A Cruise ride-sharing autonomous vehicle in normal operation in San Francisco. Right: A Cruise autonomous vehicle stopped by a protester using a traffic cone.

However, the deployment of autonomous vehicles has been considerably slowed down due to technical difficulties, costs, regulation issues, accidents-related scandals, slow infrastructure development and more recently public protestation (Topham, 2021). For example, at present, autonomous vehicles are much less dangerous than human drivers, but at the cost of being overly cautious, which results in the vehicles being too slow to be usable. It is not uncommon for Waymo or Cruise vehicles to remain stuck at an intersection for 40 minutes because the vehicle assesses crossing the intersection as "too risky". In 2023, local protesters used construction cones to block Cruise vehicles (Figure 12, right). Thus municipalities are requesting a slowdown in the deployment of autonomous taxis by Waymo and Cruise (Templeton, 2023). More generally, the hype around autonomous vehicles has gradually subsided since 2020 (Niedermeyer, 2023; Ovide, 2020; Robertson, 2023; Walters, 2021). Recent mergers, joint ventures, and acquisitions reflect this trend. Experts and investors alike are recognizing that the days of launching a startup with a few test vehicles and a vision for the future are over. Several promising projects, including Argo AI, a startup backed by Ford and Volkswagen, have ceased operations (Korosec, 2022; Hawkins, 2022a). Even Waymo acknowledged that the technology was becoming more and more difficult to improve (Coppola & Bergen, 2021). Consequently, a significant portion of the industry may redirect its attention to short-term profitable uses like logistics and industrial applications, instead of autonomous transportations. According to Raj Rajkumar, a robotics professor at Carnegie Mellon University, "The AV industry has promised too much for too long, and has delivered too little" (Hawkins, 2021). And as stated by Townsend (2020), "despite all the hassles, dangers, and drudgery of driving, [humans] remain the most cost-effective "technology" suited to the task".

The consulting firm Gartner publishes every year a graphic representation of expectations related to emerging technologies. In 2023, they placed autonomous vehicles in the "trough of disillusionment" category (Figure 13), estimating that companies would begin to enter a phase of consolidation and maturity in the next 5 to 10 years before finally developing and deploying autonomous vehicles.



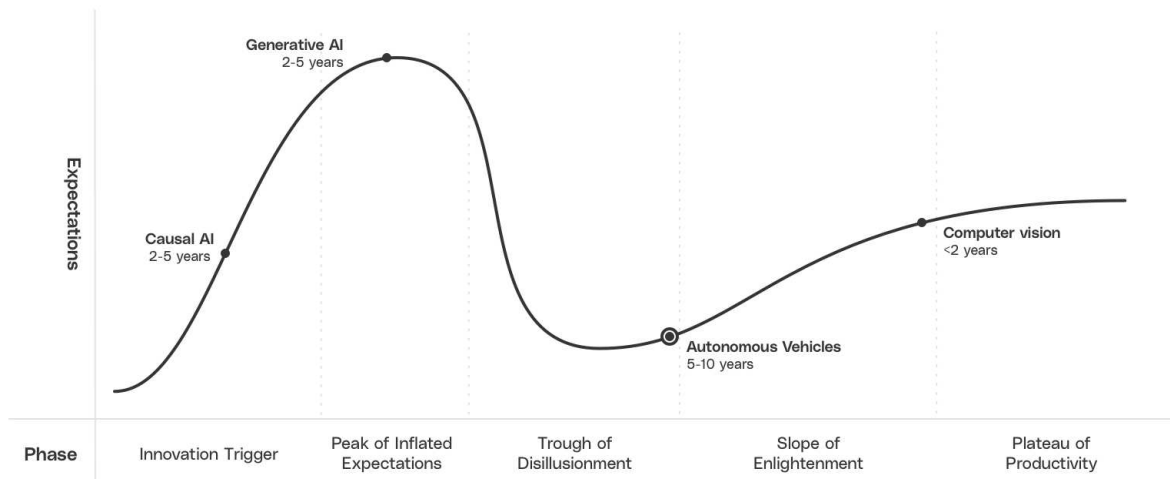


Figure 13. Hype Cycle for Artificial Intelligence from Gartner (Perri, 2023).

Autonomous vehicle development is currently headed in two main directions: autonomous taxis and commercial/logistics uses (Carey & Lienert, 2023). The pursuit of private autonomous vehicles has been put on hold by many companies due to concerns about economic viability (Templeton, 2023b). Only a couple, such as Tesla and Daimler (with Mercedes-Benz), are still actively working on private autonomous vehicle development. Tesla is aiming to make autonomous vehicles affordable, while Mercedes-Benz is focusing on creating luxury ones.

In parallel with these technical questionings, initiatives aiming to define guidelines or best practices for the deployment of truly beneficial autonomous vehicles to society have emerged. For example, the prospective workshop "The Robomobile Life", initiated by the French Ministry for Ecological and Solidary Transition in 2017, has been offering talks, analyses, and prospective work for several years to question the future of AVs from different perspectives and sensitivities. They have notably published a book compiling different alternative visions of a future with autonomous vehicles (Long et al., 2017). There are also diverse reflections, particularly those from industrial design firms like *uswto* and their book discussing the role that automation could and should play in our lives (Smith & Vardan, 2020). However, we have not found any significant public initiatives of this nature among the automotive manufacturers or tech giants mentioned earlier in this section. At this stage, it appears that they are either more focused on technical aspects or keeping their work internal. In Section 2, we try to investigate this further through an analysis of the car manufacturer Stellantis in relation to autonomous vehicles.

### 1.3.3. Legal aspect

AVs are in a special situation where regulations are being created before the technology is fully developed. As we discussed earlier, developing the technology takes time, so government agencies have had time to legislate.

At the international level, several attempts tried to reach agreements regarding autonomous vehicle standards. The Vienna Convention on Road Traffic, which was established in 1968 to govern traffic laws, was reformed in 2016 to allow for automated features (ADAS) in vehicles. An amendment pertaining to autonomous driving was accepted in 2022, to help the deployment of level 3 (United Nations, 2023). To date, the convention has been subscribed to by 83 countries worldwide. Meanwhile, the United Nations Economic Commission for Europe (UNECE) endorsed the World Forum for Harmonization of Vehicle Regulations to clarify worldwide regulations to deal with safety aspects related to automated, autonomous, and connected vehicles (Bowyer, 2020). In 2021, three regulations were published regarding cybersecurity, software updates, and automated lane-keeping systems. Since then, there have been several amendments (namely UN Regulations 155, 156 and 157). This regulation specifies the requirements for the use of these systems. These include areas, infrastructure, and speed. The regulation also outlines safety rules for maneuvers and transition requests, as well as mandatory equipment.

In Europe, The European Union (EU) has established regulations for approving automated and fully driverless vehicles, with specific requirements for different vehicle categories. These regulations were based on standardized procedures and technical specifications for the systems and other items, and they applied starting in 2022 under the name of Vehicle General Safety Regulation (Gospodinova & Miccoli, 2022). The United Kingdom (UK) has allowed testing of automated cars on public roads since 2013 and has passed legislation that permits self-driving automated lane-keeping systems up to 60 km/h (Maclean, 2021). France has allowed testing of automated cars on public roads since 2015 and has established a legal framework for the operation of automated vehicles that is claimed to be “the most complete legal framework in the G7 countries for the circulation of vehicles with driver delegation” (*National Strategy on Automated Vehicles*, 2023). The legislation of Germany was the first allowing autonomous vehicles to operate in specified areas on public roads, with provisions corresponding to Level 4 (Pingol, 2021). It also included requirements for handling dilemmatic situations (the AV has to choose between two difficult situations, see the trolley problem) and technical specifications for autonomous vehicles.

In the United States, a comprehensive regulatory structure has not yet been established at either the federal or state level. So, many states have created specific laws to clarify and regulate the legal status of AVs. Consequently, companies are allowed to build and deploy autonomous vehicles as long as they meet state standards. Currently, 40 states

(out of 50) have laws or executive orders related to autonomous vehicles, allowing testing on public roads (*Autonomous Vehicles State Bill Tracking Database, 2023*). Nevada was the first state to allow self-driving car testing in 2011 (Bishop, 2012), followed by Florida in 2012. California has been at the forefront of granting permission for autonomous vehicle testing and deployment, with two manufacturers recently licensed to deploy autonomous cars without a safety driver (namely, Cruise and Waymo).

Europe is developing a comprehensive framework of legislation to regulate autonomous vehicles (proactive approach), while the United States is taking a reactive approach by establishing legislation only when problems arise. Hence, the United States approach is more suitable for companies that want to innovate quickly in this field. (Houlé & Levy-Heidmann, 2018). However, Europe's approach could allow for a better framing, avoiding accidents and certain consequences. It is indeed an opposition between a techno-driven future (USA) and a normative one (Europe).

Since 2018, China has established regulations for testing autonomous cars, outlining requirements for testing and road use. This move aimed to promote the deployment of autonomous vehicles and compete with the United States (Reuters, 2018). In 2020, the "Strategy for Innovation and Development of Intelligent Vehicles" was published, outlining a roadmap plan until 2025 (Malleons, 2020). The goal was to boost the development of autonomous vehicles over the next thirty years. China is confident of its strengths in data, market, technology innovation, infrastructure, and environment for building a dominant autonomous car manufacturing industry.

## **1.4. Refining our positioning**

As stated in section 1.2.3, we focus on advanced automated self-driving vehicles (levels 4 and 5 on the SAE scale). These vehicles are designed for transporting people, whether for personal or shared use. This includes taxi-like vehicles, cars-shaped vehicles, or small shuttles (with a maximum capacity of 9 people). In this section, we propose to refine our positioning by adding temporal and spatial scales.

### **1.4.1. Time scope**

We consider AVs to be massively deployed if they make up more than 50% of the automobile market. To determine a realistic time frame, we examined the development trajectory established by the European Advisory Council (ERTRAC) in 2019. Figure 14 presents the development trajectory of different levels of automation over time but does not provide a clear timeline for levels 4 and 5 due to uncertainties (see Section 1.3.2).

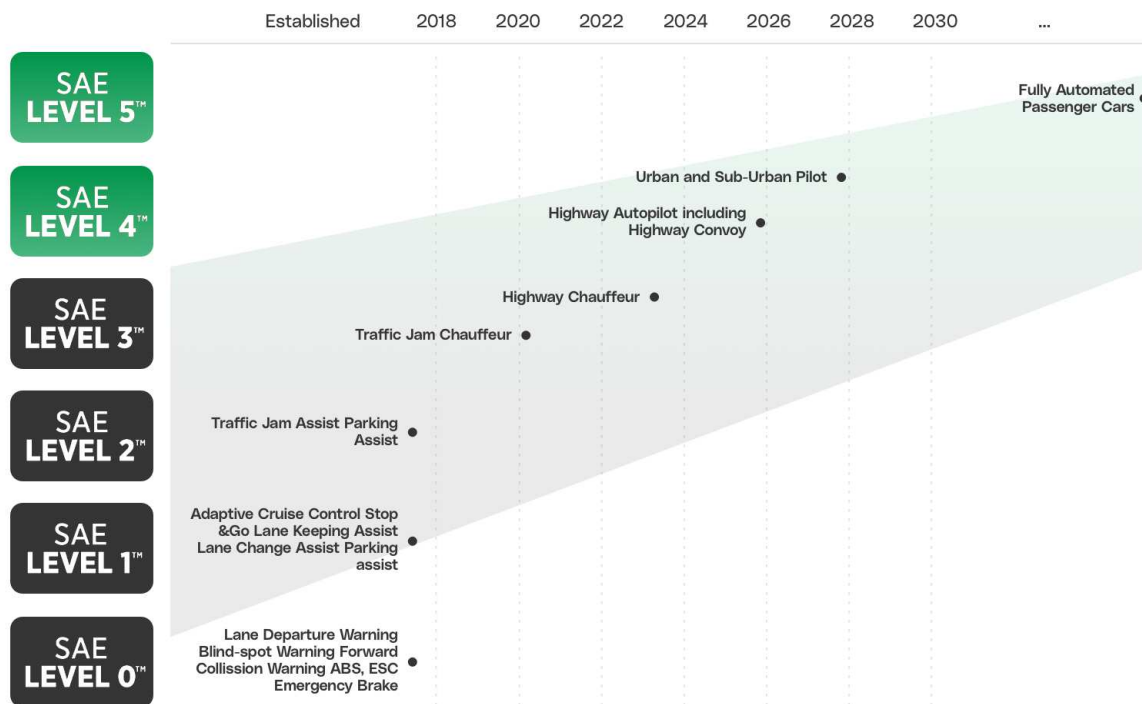


Figure 14. Development trajectory of autonomous driving for passenger cars by ERTRAC (2019).

According to insiders from the Stellantis automotive group, it typically takes about 20 years to replace an entire fleet of vehicles. In 2023, given that many countries are in the process of transitioning from combustion engine to electric vehicles, it is possible that the next transition to autonomous vehicles will take even longer to implement, particularly since the technology is not yet fully developed. One key driver could be the legislation, like for the transitioning phase to electric vehicles today.

By combining these elements with the Gartner hype cycle presented in section 1.3.2, we estimated an optimistic large-scale deployment around 2050, which is approximately 30 years from the time of this thesis. This is not a precise prediction of the future, but rather a reasonable time frame for our work. To ensure a relevant impact assessment, we avoided selecting a too-long period. The longer the deadline, the more likely our societies will change significantly and unpredictably (see Section 3.1 about futures studies). So we needed to limit the time horizon of our study as much as possible. We have reached a compromise between a deadline where the large-scale deployment of AVs would remain probable while limiting uncertainties.

### 1.4.2. Geographical / Spatial scope

We selected countries with a high human development index (greater than 0.700; Figure 15) because the richest countries are likely to be the first to adopt the technology. An indicator called AV readiness score, developed by confused.com, is calculated for each country based on its advances in regulation, number of patents, public interest,

road quality, and number of companies. This indicator confirms that the richest countries are most likely to adopt autonomous vehicles first (Figure 15). We also believe that developing countries have different mobility needs than those of developed countries.

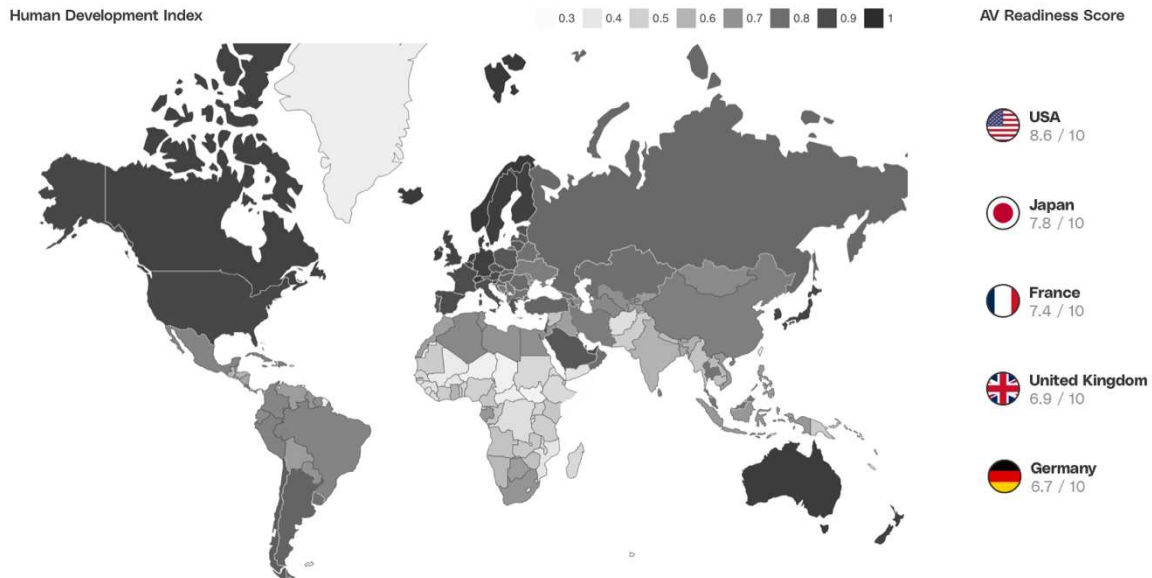


Figure 15. Categories of the Human Development Index (2019 data), extracted from the Human Development Report 2022 along with the top five countries ranked by the "AV readiness score" from confused.com (Doll, 2022).

We consider both rural and urban environments (see Figure 16). We also take into consideration specific areas, such as university campuses or businesses. However, some parts of our work may only be applicable to certain areas. In such cases, we make sure to specify it.

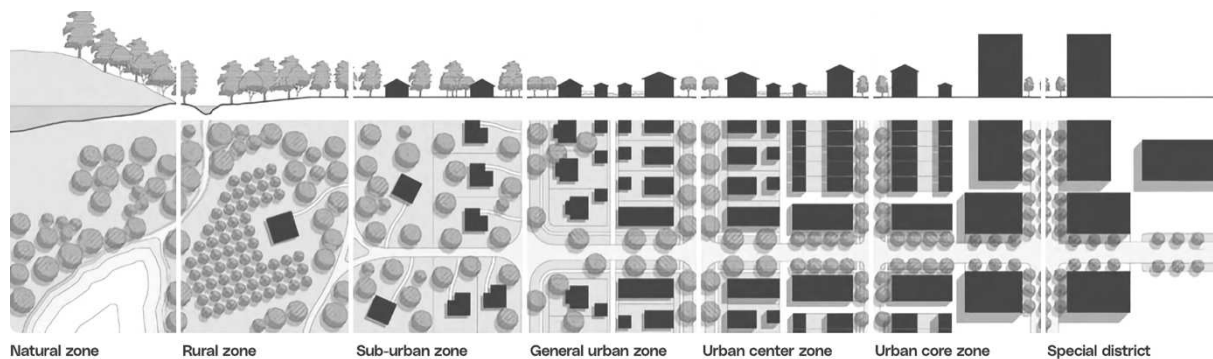


Figure 16. *The Urban Transect* by Duany (2002). We consider all zones in the thesis.

### 1.4.3. Positioning summary

The Figure 17 provides a visual summary of our positioning on autonomous vehicles.

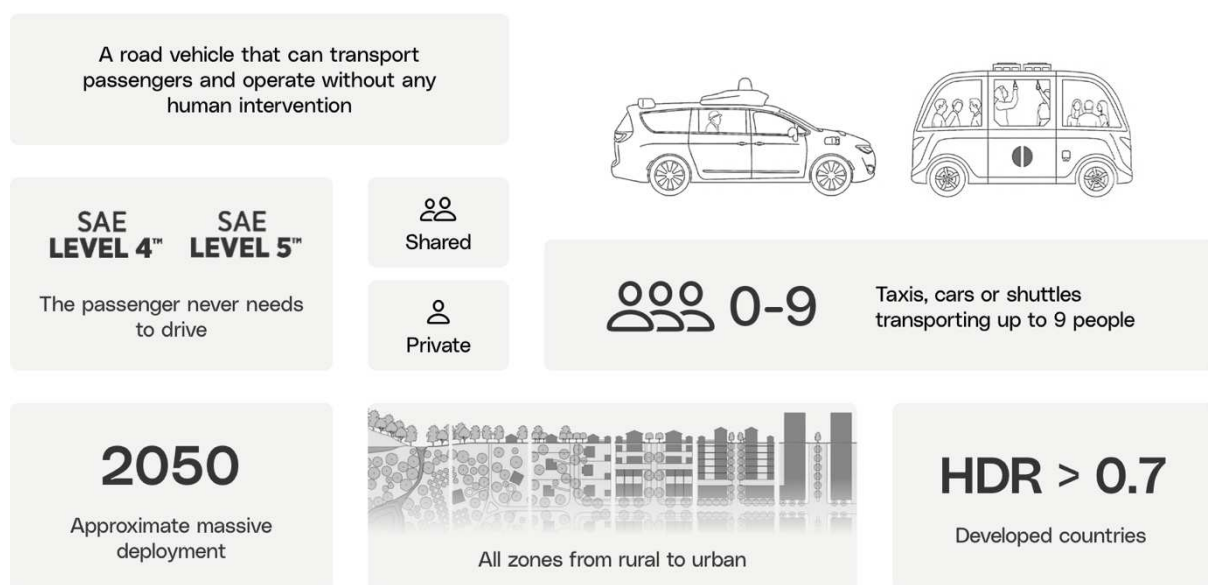


Figure 17. Summary of the characteristics of AVs considered in this thesis. Drawings taken from Townsend (2020).

## 2. Industrial context of Stellantis

This thesis is part of the CIFRE program (Industrial Agreements for Training through Research). It is a program in France that aims to promote collaboration between companies and public research laboratories within higher education institutions. The main objective of CIFRE is to promote research and development by enabling PhD students to carry out applied research work within a company. This collaboration brings two things: First, the opportunity to study a technological field internally. Second, the chance to conduct applied research and test it in the field.

This thesis is conducted in partnership with the automotive group Stellantis. To give industrial context, PSA Peugeot Citroën was a French automobile manufacturer built on the legacy of the historic French automobile companies Peugeot and Citroën, founded respectively in 1896 and 1919. Then, the manufacturer developed internationally by expanding its market to 160 different countries. In 2016, the company took the name PSA GROUP, then acquired the Opel and Vauxhall Motors brands from the General Motors group in 2017. In 2019, PSA GROUP announced jointly with Fiat Chrysler Automobiles (FCA) the merger of the two groups under the new name of Stellantis, which became the 6th largest automotive group in the world in 2020. For simplification purposes in the following sections, we refer to PSA Peugeot Citroën and PSA GROUP as PSA. We refer to ex-PSA to talk about parts of the Stellantis company that were previously from PSA.

Our work is part of the UXLAB (User eXperience LABoratory) entity of Stellantis, which is dedicated to user-centred innovation. This department is positioned in the early design phases of the innovation process, covering the initial idea to the formalization of a first concept. They notably work on vehicle cockpit interiors, bringing together professionals with different backgrounds, such as engineers, designers, and ergonomists.

## 2.1. Research methodology

We present the results of analyzing the Stellantis AVs-related work from 2010 to 2023. Our approach considers the company as a socio-technical system (Trist & Emery, 2006), considering strategic, organizational, and operational aspects, as well as social, cognitive, and cultural factors.

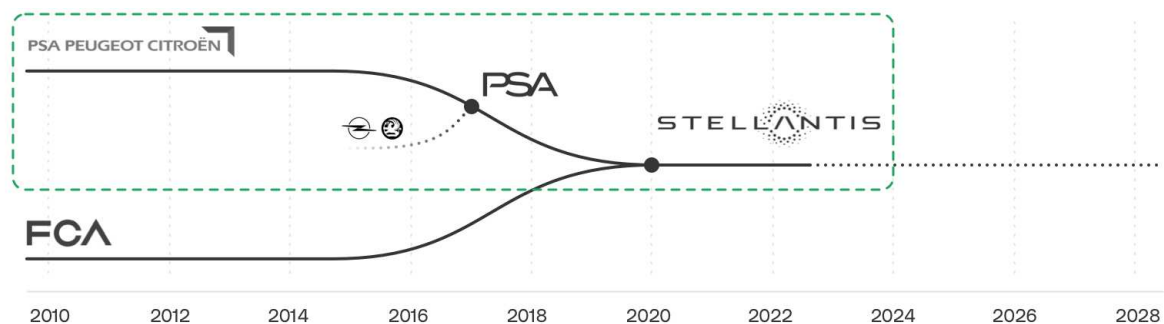


Figure 18. Evolution of the automotive groups that merged to form Stellantis.

We employed a multi-methods approach (Creswell & Clark, 2017; Creswell & Creswell, 2018) to gain diverse perspectives and validate our findings. Our research consisted of an external and internal analysis. The external analysis involved a review of the public communication and specialized news coverage of Stellantis to establish an extensive knowledge base. We collected data over various time periods to identify past, current, and future issues related to AVs. For the internal analysis, we conducted an ethnographic study of the ex-PSA part of the company in France between 2010 and 2023 (Atkinson, 2019; Elliott & Jankel-Elliott, 2003; Mariampolski, 1999). We chose this focus because the thesis originated in the PSA group and evolved within the context of a merger with the FCA group to officially form Stellantis in 2021 (Stellantis, 2021). Furthermore, the new organization was not fixed at the time of the field analysis, hence our preference to analyze the PSA part (Figure 18, in green). We supplemented our ethnographic approach with a collection of documents and materials to support our findings (Table 1). We investigated four levels: (a) the strategic level, (b) the organizational level, (c) the operational level, and (d) the cognitive and cultural level. We conducted twelve semi-structured interviews with collaborators and collected

approximately 50 documents. We talked with nine people in research and development, four were working on technical functions of autonomous vehicles or ADAS, five were working on user-oriented and innovation functions (interface, concepts, ergonomics), and one person was working on regulatory aspects. We also spoke with two people working on planning and strategy related to AVs for the group. Based on our findings, we proposed interpretations and recommendations. The complete protocol for this analysis is available in the supplementary material 2.

Table 1. Nature of captured resources.

Analysis	Nature	Description
External	Website (company)	We analyzed the different websites and communications from the company, including official documents, videos, and interviews about ADAS and autonomous mobility.
External	Website (articles)	We analyzed specialized press that covers autonomous mobility related to Stellantis.
Internal	Interview report	We conducted a series of 12 interviews within the company (via Microsoft Teams) and created detailed reports. To support these reports, we also made confidential audio recordings.
Internal	Company document	We retrieved several documents using intranet, internal contacts, or interviews.

We faced challenges in our research due to difficulties in obtaining interviews with some individuals and accessing key documents. Some collaborators were not available, while others did not respond to our requests. The Covid-19 context also limited our ability to conduct in-person interviews, requiring remote interviews instead. These factors surely posed a barrier to our socio-technical analysis.

## 2.2. Strategic level: The positioning history of Stellantis on AV

The term "strategic positioning" corresponds to the business strategy defined by the company regarding autonomous mobility. We have broken it down into three interdependent parts: (1) The economic part which concerns the envisaged business models, (2) the technical part which concerns the envisaged skills and technologies, and (3) the usage part which concerns the customers and how they will use the envisaged product or service.

This section describes the strategic positioning of PSA (and now Stellantis) on autonomous vehicles and how it has evolved since the 2010s. Based on the interviews, three phases regarding AVs were identified. The change in positioning is represented on the top of a Gartner-inspired hype cycle (Figure 19). A high level of ambition



corresponds to the implementation of significant financial, human, and material resources.

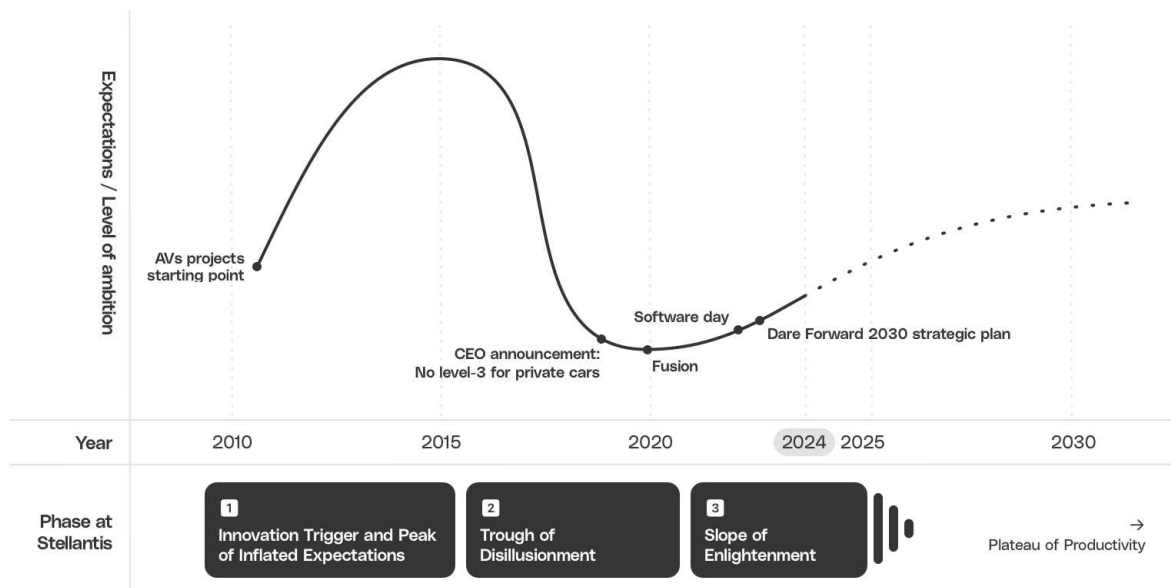


Figure 19. Diagram representing a qualitative estimation of PSA (and then Stellantis) level of ambition on autonomous vehicles over time. Based on field analysis and inspired by the hype cycle from Gartner (Figure 13).

## 2.2.1. Phase 1: Innovation Trigger and Peak of Inflated Expectations (2010-2015)

To stay competitive in the long run, it is crucial for a company to identify emerging technologies and master them quickly (Boly et al., 2016). This is what Stellantis did starting from phase 1, as the group became interested in autonomous vehicles and launched projects and experiments. This interest was in line with the trend among car manufacturers investing in autonomous vehicles. Promising initial projects like the Google car in 2010 and new technical enablers like data fusion or machine learning spurred this trend. Interviews revealed that the group was very enthusiastic about autonomous vehicles starting from 2011. They undertook numerous projects and experiments, and the company showcased their progress through videos that demonstrated the technologies they developed and their potential uses (see Figure 20 and supplementary material 1). The group was ambitious and driven to succeed.



Figure 20. Some screenshots of communication videos from PSA on autonomous vehicles between 2010 and 2015. See supplementary material 1 to access the videos.

### 2.2.2. Phase 2: Trough of Disillusionment (2015-2021)

The second phase corresponds to a decrease in ambition which led to the termination of many projects. This was due to encountering new technical and financial difficulties. This phase lasted from 2015 to 2021 and was notably marked by the public announcement of CEO Carlos Tavares expressing the abandonment of level 3 for personal vehicles. According to some experts, many technological obstacles gradually appeared. This is consistent with our general market analysis during this period (Section 1.3.2). Some of these obstacles include the evolution of roads (construction, deterioration, new signals), which require regular updates of maps and AI algorithms, and the reliability of systems that must be ensured for safety and legislation reasons (with the need to trace back the decision chain leading to a particular action of a vehicle). These factors have contributed to an increase in the technical complexity required for the design of a truly autonomous vehicle and have led to an accumulation of increasingly high costs.

We found a decreasing momentum for many projects, but we also discovered new experiments and communication operations. For instance, Peugeot e-LEGEND concept car was unveiled in 2018 and generated a lot of excitement due to its unique autonomous driving mode that made the steering wheel disappear. In addition, the first autonomous toll crossing in 2019 received significant media attention and demonstrated that good communication between infrastructure and vehicles allowed autonomous vehicles to effectively cross tolls in mixed traffic (see supplementary material 1). During the interviews, it was confirmed that only the projects with short or medium-term profitability were prioritized, specifically, ADAS technologies.

In 2019, PSA put on hold its plans for high-level automated vehicles (level 3 and above) due to the merger with FCA. This required the company to restructure and consolidate resources, leading to the development of a new group strategy. The emergence of the Covid-19 pandemic also played a role in this decision as PSA focused on the safest sources of revenue. CEO Carlos Tavares expressed his unwillingness to develop 100% autonomous driving technology for personal vehicles, as he believed there would be too high costs for both the customer and the manufacturer. PSA continued to work on highly automated shuttles, which they believed were more profitable. The group based its decision on a major internal strategic study carried out in 2018 that assessed the economic opportunities based on the state of technical skills on the subject. The study estimated that it was difficult to build a balanced business model based on the sale of private autonomous vehicles. In 2020, PSA stopped its remaining large autonomous vehicle projects. The Highway Chauffeur project, which corresponds to level 3 on highways, and the Traffic Jam Chauffeur project, which corresponds to level 3 in traffic

jams, were both abandoned. Only ADAS projects (level 2), intended for short-term commercialisation, were continued.

### 2.2.3. Phase 3. Slope of Enlightenment (2021-Today)

In the third phase, a new mature common strategy emerged, based on the previous knowledge and experimentation of both PSA and FCA groups. Two partnerships, with BMW and Waymo, support this strategy, with a respective focus on automation levels 2 and 3, and 4 and 5 starting in 2021.

Following the merger, the group identified three major trends that were likely to transform mobility: (1) electrification and alternative energy sources, (2) connected and autonomous vehicles, and (3) Mobility-as-a-Service (MaaS). To respond to these trends, especially trends 2 and 3, interviewees confirmed that Stellantis had decided to work on defining a new strategy for autonomous vehicles. The 2021 Corporate Social Responsibility reports even showed that the development of new mobility solutions (including autonomous vehicles) was part of the strategy of the company (Stellantis, 2021c; Figure 21).

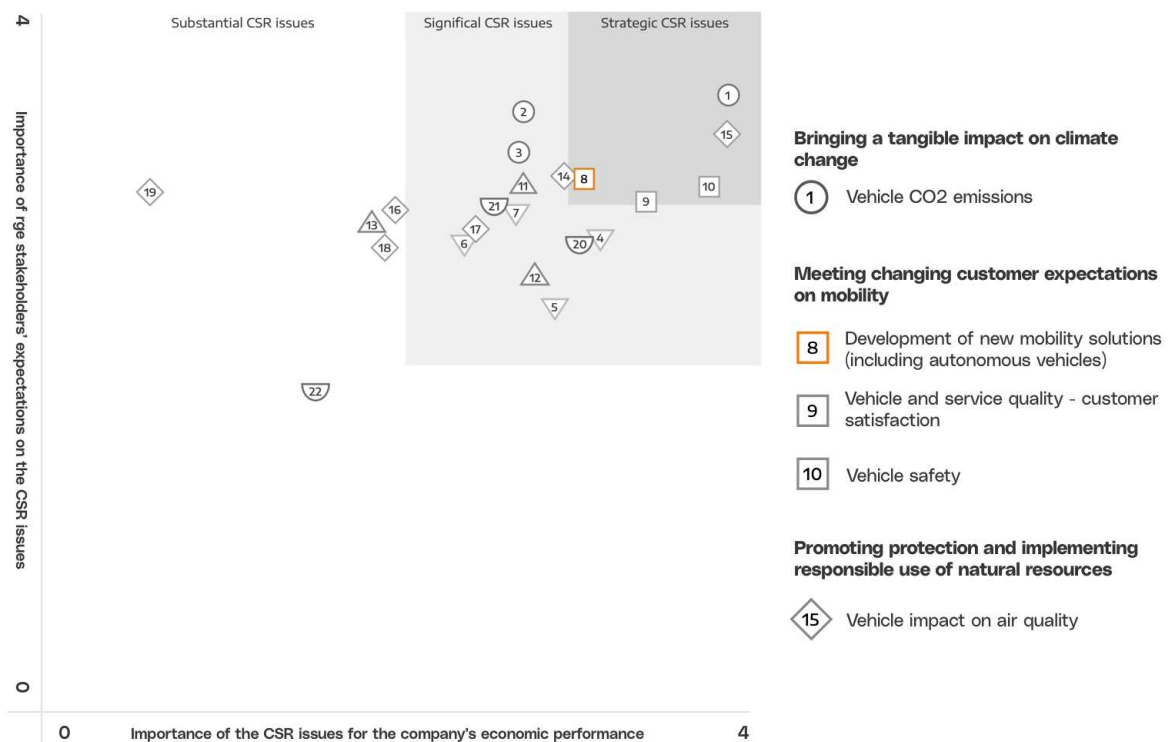


Figure 21. Materiality matrix of Stellantis presented in its 2021 Corporate Social Responsibility report (Stellantis, 2021c).

The arrival of MaaS is considered a risk by Stellantis. Mainly because the company is a supplier, and not an operator of mobility. The 2021 CSR report proposes two solutions to address this risk. First, develop mobility services with the brands Free2Move and Leasys to avoid gaps between the market and Stellantis commercial strategy. Second,

design "revolutionary" AVs as part of a multi-partner strategy. Based on interviews and documents, safety is considered as a major concern that automation (ADAS and AVs) can help address.

A Strategic Task Team (STT) led by ex-FCA established two axes to generate value from autonomous vehicles and develop expertise in the field, resulting in the unveiling of a new ambition and key partnerships for software and vehicle automation in late 2021 (Stellantis, 2021b). The strategy concentrates on two partnerships: "Project Thunder" with BMW, intending to incorporate new ADAS functions in the medium term, and with Waymo, aiming to create high-level autonomous taxis, public transportation, package and goods transportation, and industrial uses in the long term. Stellantis has emphasized the need to develop its own software expertise to avoid relying on partners and to minimize the "black box" effect of artificial intelligence.

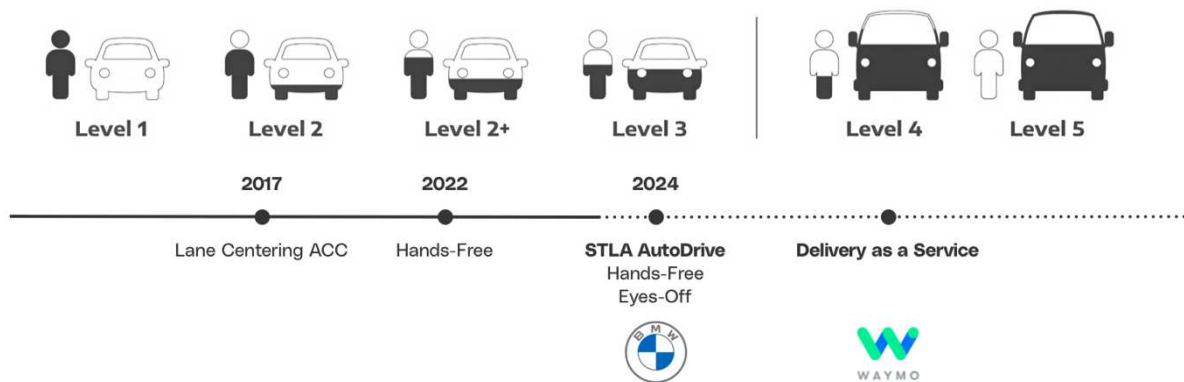


Figure 22. Automated driving cadence. Extracted from the "Dare Forward 2030" strategic plan (Stellantis, 2022).

In 2022, Stellantis introduced a new strategic plan titled "Dare Forward 2030" (Stellantis, 2022). The plan presented a new timeline for the advancement of AVs (see Figure 22). Stellantis affirmed its collaboration with BMW to attain Level 3 by 2024 and mentioned its partnership with Waymo for Levels 4 and 5, with no deadline. However, Stellantis has decided to concentrate exclusively on delivery-as-a-service for these last two levels and has abandoned its plans to create autonomous taxis. Therefore, it can be observed that by the end of 2022, the focus of this thesis was no longer part of the strategic plan of Stellantis.

## 2.2.4. Interpretations

According to AV experts at Stellantis, fluctuating ambition levels shown in Figure 19 are due to changes in technical confidence in vehicle automation. This can be associated with a bias known as the Dunning-Kruger effect, where individuals often overestimate their skills before realizing the actual difficulties due to acquiring new knowledge (Duignan, 2023). During Phase 1 (Figure 19), Stellantis may have overestimated its skills in autonomous technologies, similarly to some competitors, and then scaled back its

ambition as it faced technical and economic challenges in Phase 2. Momentum in Phase 1 could have come from other manufacturers' influence, such as BMW and Daimler, who had started developing AVs earlier. Deploying large-scale autonomous driving beta versions is particularly challenging due to safety requirements, especially in Europe. This is why Stellantis formed partnerships with BMW and Waymo, who have already started and now have technologically superior autonomous vehicles (AVs).

## 2.3. Organisational level: The company organisation regarding AV

This section concerns the organizational level of PSA. Its purpose is to identify the actors and competencies. Here, we describe the organization as it was in 2021 on the PSA side, during the merger period.

### 2.3.1. Organization around AVs

We identified that the AV was mainly present in two divisions: Research and Development (R&D) and Strategy. These are presented in the simplified information flow diagram (Figure 23) explained subsequently. For privacy and simplification reasons, the names of the services have been changed.

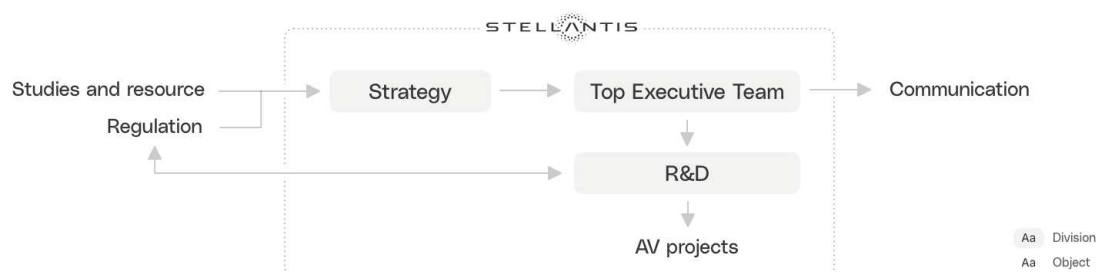


Figure 23. Simplified macroscopic diagram of information flows leading to autonomous vehicle projects (based on our research and interviews conducted in 2021, on the ex-PSA side).

The R&D division has two entities that deal with specific aspects of autonomous vehicles. One is focused on autonomous vehicles but interacts with many other parts of the company such as transversal projects teams (working on technologies to be implemented into different products within the group), and cockpit, body and vehicle teams, which focus on ADAS issues, safety, scenario validation, new mobility concepts, and user experience. The second R&D entity is responsible for regulation, homologation, and standards. They work at the interface between the group strategy and the regulation. We spoke with someone from this entity who dealt with issues related to autonomous vehicles and ADAS at national, European, and global levels. Regulation is an important factor in designing autonomous vehicles as it can facilitate or block innovation choices (a level 2 project proposed by PSA was blocked for safety

reasons). However, regulations can also be influenced through legislative discussions between the group and the regulators (for example, the UN regulation text ECE 157 about level 3 function).

The global corporate planning division focuses on the strategic level. They provide informed opinions to the top executive teams. Their opinions revolve around project groups called Strategic Task Teams (STT), which consider potential business models, possible partnerships, and identify opportunities for value creation. These STTs then support making strategic directions. For example, a 2020 STT conducted on the ex-FCA side allowed Stellantis to define its economic and technical positioning on autonomous vehicles in 2021. These project groups have a business approach and are largely based on consulting studies to support their conclusions.

### **2.3.2. Key skills and weaknesses of the company**

Regarding AV technologies, the strengths of PSA lie in the areas where they have the most experience, such as safety, comfort, and vehicle behavior. Stellantis is fully committed to safety and has been active in standardization issues, particularly in the context of AV and ADAS. Stellantis teams have joined forces with a global ecosystem of 34 partners, including suppliers, research institutes, road authorities, and other equipment manufacturers, to collect automated driving data to evaluate level 3 automated driving functions as a safe and efficient means of transportation on public roads. Therefore, Stellantis led into defining ISO 21448 safety standards. In addition, skills related to transport ergonomics and user experience are also quite developed (especially within UXCT division), and numerous experiments have gradually consolidated them (for example, user studies on shuttles). With the arrival of sensors, lidars, and cameras, the company is now quite advanced in areas involving data fusion, redundancy, mapping, or obstacle detection. Stellantis is also committed to cybersecurity (Auto-ISAC). Several autonomous vehicle automation-focused technical training courses are available for collaborators, including Autonomous Driving, Sensors, Control System, CAN Network, and Architecture trend. Some skills still need to be consolidated, such as the traceability of decisions made by artificial intelligence algorithms (explainable AI), as it is essential to ensure proof of decision, especially for rights and insurance issues. Artificial intelligence-based autopilot technologies are also lagging behind players like Waymo, Cruise, or Daimler for example. An autonomous vehicle expert confirmed that Stellantis planned to increase its expertise in artificial intelligence to avoid depending on external players and to try to master the decision chains of AIs. To increase skills, scientific partnerships on artificial intelligence (PRAIRIE Institute, FRANCE 3 AI initiative, Joint Research Laboratory with Valeo and SAFRAN) and on connected and autonomous vehicles (VEDECOM) have been launched.

One of the weaknesses of the group concerns its skills in deploying autonomous vehicles within an infrastructure. This results in a poor understanding of the possible interactions between users, buildings, and other vehicles (despite some experiments). Remote supervision, i.e. remote control of the vehicle, is also a weakness, despite having a driving simulation center and a virtual reality center. To address this weakness, research activities on "Vehicle to X" and 5G technologies are underway. Finally, according to our interviews, skills in forecasting and futurology, which allow for establishing common contextualisation of what could be the future of mobility, are virtually non-existent or diluted within the different teams. This last point will be detailed in the following sections. The partnerships with BMW and Waymo announced in late 2021 aim to answer to Stellantis' weaknesses. Sharing knowledge between the companies should also lead to complementarity and faster development of automation technologies.

### **2.3.3. Interpretations**

Various departments within the company are involved in vehicle automation at different levels, but communication on the subject could be improved, according to some interviewees. Different departments have different levels of access to information, especially those not directly involved with autonomous vehicles. Concept cars for autonomous vehicles showed capabilities that are not yet possible with current technology (e.g. the Peugeot e-Legend). It is common practice to keep some information confidential to prevent leaks, particularly since autonomous vehicles play a crucial role in the strategy. However, the illusion that the group was competent in every aspect of the field probably hindered progress. The company is strong in areas such as vehicle behavior, safety, and user experience, but needs to improve in areas such as interactions between vehicles, infrastructure, and users.

## **2.4. Operational level: Projects and experiments**

### **2.4.1. Projects and experiments**

We have analysed 15 notable PSA and Stellantis AV experiments and projects spanning from 2011 to 2021. We distinguished between experiments and projects. An experiment helps the company refine its skills by testing prototypes, conducting surveys, studies, or observations. A project, on the other hand, has a commercial objective. We identified 8 experiments that mainly focused on user experience (acceptability, emotions) and technical validation (tests in complex environments). These experiments covered different levels of automation, up to level 5. We identified 7 projects that were multidisciplinary and focused on lower levels of automation due to their short-term commercial positioning. Two major level 3 projects (Traffic Jam Chauffeur and Highway

Chauffeur) were abandoned, while level 2 projects (improvement of ADAS) were preserved, in line with the evolution of strategic positioning.

Stellantis' projects and experiments have helped identify problems related to human factors and technology. For example, some participants strongly opposed autonomous technologies, and some passengers felt unsafe using an autonomous shuttle without a driver, leading to refusals to use the vehicle. Also, the speed limit and imposed schedules of an autonomous shuttle tested in Vélizy, a technical center in France, often led to longer journeys than walking, resulting in very little usage. The risk of stopped cars and traffic jams was also raised several times, caused by the detection of false obstacles, sensor failure, or over-cautiousness. This raised the question of the compromise between speed and safety, which is still a central technical issue today. The group achieved functional level 2 in China and level 2+ in the USA, along with improving level 2 in various vehicles and advancing active safety features such as autonomous emergency braking and lane keeping. In total, the group developed 30 autonomous vehicles (with or without partners) and crossed the milestone of 1 million kilometers in autonomous mode (according to the 2021 CSR report, see Stellantis 2021).

## 2.4.2. Interpretations

We believe that the experiments and projects conducted by PSA and Stellantis since 2010 have played a crucial role in the deployment of ADAS currently used in the group's vehicles. However, these experiences have also made Stellantis realize the challenges of developing a highly automated autonomous vehicle. As a result, the level 3 projects (namely, *Traffic Jam Chauffeur* and *Highway Chauffeur*) were terminated, and there was a general decline in ambition observed between 2015 and 2020 (refer to Figure 19, phase 2). Nonetheless, the knowledge gained during the experiments allowed for the development of a more mature strategy starting in 2021 (refer to Figure 19, phase 3).

## 2.5. Cognitive and cultural level: Imagination and representations of autonomous mobility

### 2.5.1. Imagination and contextualization of the future

We surveyed individuals working on the strategy and found that they regularly consider big-picture trends in their decisions. This includes using studies from consulting firms and partnerships, as well as keeping an eye on competitors like Toyota, Baidu, and Hyundai, who frequently share their plans for future mobility. For example, Toyota e-palette (see supplementary material 1) is a modular AV that can serve various purposes. Stellantis also considers regulations at national and international levels to predict future mobility trends. These trends directly impact the group's strategy for the future



of mobility. For instance, in 2019, an internal document outlining the 10-year vision for mobility showed seven mega trends (see Figure 24) that express the ambitions of PSA and inform both the public and internal projects. These trends also allowed strategic teams to create internal scenarios. One of them is called "double squeeze," and imagines a future in which the company must face both economic and environmental constraints. But these scenarios have a business-oriented focus and do not emphasize future mobility usages.

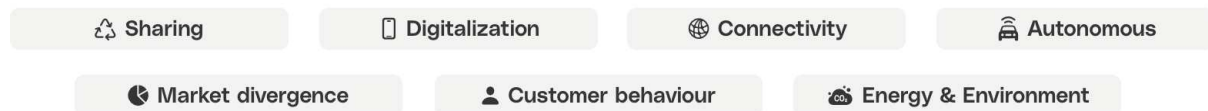


Figure 24. The seven mega trends identified by PSA in 2019.

We have been unable to find a comprehensive knowledge base that could serve as a shared foundation for designers working on AVs. For example, we have identified a lack of internal activities, such as conferences or workshops, focusing on future transport sociology, anthropology, future mobility usage, futurology, or prospective analysis. We believe such activities could have facilitated a common understanding of AVs issues and possible usages at a group level, and thus ensure the development of coherent AV projects. As a result, we listed usage scenarios – that script ways of using autonomous vehicles – with conflicting choices, and with heterogeneous justifications from one project to another. It appears that these scenarios were created independently by designers with varying levels of knowledge about autonomous vehicles.

Some collaborators identified this problem as early as 2019, which notably led to the initiation of this thesis project. It was also inspired by the mega-trends "Autonomous" and "Customer behaviour" (Figure 24).

### 2.5.2. Representations and maturity levels of AVs

During various projects, experiments, and works, different representations of autonomous vehicles (levels 3 and above) have been generated. To characterize the nature of these objects, we have constructed a two-dimensional taxonomy illustrated by examples captured during our analysis. To characterize the different representation spaces, we were inspired by the typology of intermediate design objects from Bassereau et al. (2015), which links modes of representation to cognitive-perceptive representation spaces. We defined three representation spaces:

1. **Product.** Model, prototype.
2. **Graphic and sensory.** Drawings, comics, sketches, nomenclature, roughs, perspective (3D represented), technical drawing, video.
3. **Linguistic and semantic.** Descriptive, specifications, interview, brief, written history.

Then we used the Technology Readiness Levels (TRL) scale (CEA, 2014) as a guide to determine the maturity level of each AV representation. Since high-level autonomous vehicle technology is not fully developed, we only considered the first three levels of the TRL scale, which we slightly modified for our case study:

1. **Observation and exploration.** Exploration and discovery of principles.
2. **Conceptualization.** Defining a concept based on previous observations and explorations.
3. **Proof of concept.** Testing the concept under experimental conditions.

At project level, these three stages might not happen one after the other. Figure 25 shows the classification of 15 representations according to our system. We chose the representations that were mentioned by the collaborators (those who have had an influence on their imagination of autonomous vehicles). A summary database, as well as three detailed examples, with varying degrees of maturity, are available in supplementary material 3.

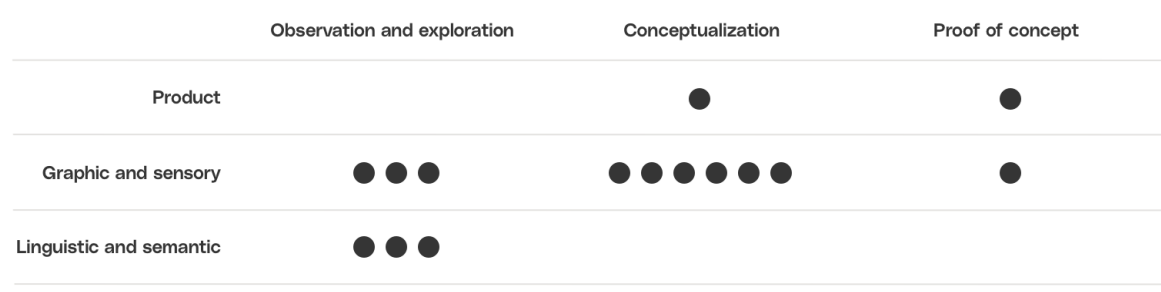


Figure 25. Representations of autonomous vehicles at Stellantis distributed in our classification system.

### 2.5.3. Interpretations

Collaborators in an innovation project may have varying perspectives on the future context, which can have an impact on the final product. By combining these perspectives, it is possible to develop innovative products. However, it is important to strike a balance between external influences and internal influences from the company. Failing to do so may result in separate projects that do not align with a long-term plan, potentially leading to project abandonment. We schematized this phenomenon in Figure 26.

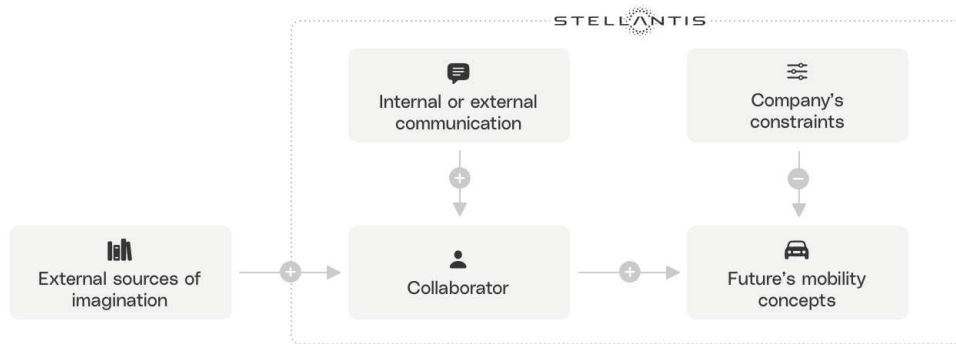


Figure 26. Simplified diagram of the influence flows leading to future mobility imaginaries used for projects. The nature of our analysis (qualitative) does not allow us to know the proportion of these flows but simply to represent some influences at play.

Some collaborators admitted that there was not enough effort and communication within the group regarding knowledge about the future of transportation in the long term. Specifically, they noted the absence of a clear, engaging, and common strategy on AVs. This issue is seen as a significant factor in the cancellation of projects. External communication also seems to be inconsistent and struggles to represent desirable futures towards which the group wishes to move. For example, the concept presentation videos, displayed in supplementary material 1, are technical demonstrations rather than presentations of potential future usages for the customer. The Stellantis Dare Forward 2030 strategic plan presented in 2022 confirms this point, as it considers automation as a technical advancement and does not mention its benefits, both for the users, the environment, or the society in general (Stellantis, 2022). Analyzing the 15 internal representations (Figure 25), there was no homogeneous context about the future usages of AVs among them. This confirms that the group seems to be more focused on the "what" (the technology and its capabilities) than the "why" (the profound reasons and motivations behind its development) (Sinek, 2011). This issue is confirmed by the frequent changes in ambition for high levels of automation (see Section 2.2).

## 2.6. Summary of issues identified

This socio-technical analysis of Stellantis' AV ambitions identifies three phases between 2010 and 2021, correlated with the hype cycle from Gartner (Figure 19). We identified three main issues based on our observations:

### **Issue 1: A lack of expertise that contributed to falling behind on the AV**

Since 2010, Stellantis —like other historical constructors— has been unable to develop fully autonomous vehicles independently. The group has recognized the challenge of this task and acknowledges that it lacks the necessary expertise to compete with other companies. So, the company formed strong technical partnerships with Waymo and BMW in 2021.

**Issue 2: A lack of internal communication about AV**

We observed that employees from various teams, were not sharing knowledge about AVs within the company. This led to information being kept within their own groups and we believe that it contributed to slower technology development. An inter-departmental information sharing between technical, strategic, and design teams about AVs should be beneficial.

**Issue 3: No strategy for the future of mobility and AVs**

We have noticed that the strategy of the company on AVs in the long run has not been clear both internally and externally. Firstly, the ambition for AVs has been unstable since 2010, as shown in Figure 19. Public communications have been inconsistent and did not offer a desirable future to the public in terms of substance and form. Within the group, we found a very limited number of shared representations (usage scenarios, universes) of the long-term future of mobility, resulting in a lack of coherence between projects. To tackle this issue, we encourage the company to continue supplementing its economic and technical strategy on AVs with a clearer strategy on future usages (what Stellantis started to do with the Dare Forward plan). This could help define autonomous mobility services, generate common internal representations of AVs, and communicate consistently and desirably to the public.

**2.7. Limits to our analysis**

We chose to focus on PSA and Stellantis, but not FCA. Our limited knowledge of FCA may have prevented us from fully understanding and interpreting certain elements related to Stellantis. Moreover, we conducted internal analysis from the perspective of PSA in France, and more specifically from the employees of the Vélizy technical center. We also faced difficulties in obtaining interviews and documents, which was a major limitation of our study. In addition to the Covid-19 context, some people took several months to find an hour slot to participate in an interview, others did not respond or could not provide certain documents that could have been essential to understanding certain strategic choices or projects. The question of confidentiality also prevented us from reading important documents.

**2.8. Industrial positioning**

We have identified that Stellantis' delay in developing autonomous vehicles has been amplified by two factors: uneven knowledge sharing among different teams within the group, and a lack of a clear strategy for the future of mobility (until 2022). This has resulted in an open-loop design for several projects which, as a result, have been abandoned. This has also resulted in confusion within the company and inconsistent and unclear messaging to the public.

The purpose of this thesis is to address this issue. Even though Stellantis' objectives for 2022 no longer align with our case study, the work remains relevant due to the potential evolution of automation technologies. The work aims to contribute to the dissemination of knowledge within the group, so it should be shared among the group members and not tailored to a single entity. Ultimately, it could help to highlight flaws and qualities of one technology, enabling designers to take a step back and consider broader changes (i.e. rethinking the concept of mobility). Therefore, it needs to be flexible enough to be applicable in different design processes and with various types of employees in the company. This should help the company determine the future usages of AVs to be prioritized, ultimately guiding the group in shaping the future of mobility.

## 3. Research context

### 3.1. Futures studies

Autonomous vehicles are expected to be deployed in the coming decades. Therefore, it is important to understand how science approaches the future and the methods used to discuss it. Futures studies is a systematic, interdisciplinary, and holistic approach to exploring how we will live in the future. It is also known as futures research, futurism, strategic foresight, futuristics, futures thinking, futuring, or futurology. The goal of this field is to understand how the future may unfold by examining various factors, including technological advancements, social changes, economic developments, environmental shifts, and political decisions. By analyzing possible future scenarios and trends, one can make more informed decisions in the present, anticipate potential challenges and opportunities, and plan for a better future. However, some authors criticize the field for lacking scientific robustness and not experiencing many theoretical improvements in recent years (Chermack, 2007; Fergnani, 2019).

Three factors generally distinguish this field from other research disciplines (Bishop & Hines, 2012): (1) Examination of trends to identify the possible, the probable, and to identify preferable futures. (2) Attempt to have a holistic and systemic vision based on information from several disciplines (e.g. social, technical, economic, environmental, political). (3) Challenge and analysis of possible future hypotheses, including dominant visions, by highlighting contradictions.

Amara (1981), in *The futures field: Searching for definitions and boundaries* defines the concept of future with three characteristics: (i) The future is not predetermined. (ii) The future is not predictable, meaning that even if it were predetermined, it would be impossible to obtain enough information to describe it. (iii) What will happen in the future can be influenced by our actions today. Many futures studies experts and researchers (Bishop & Hines, 2012; Dator, 2011; Voros, 2017; Boulding, 1990; Slaughter,

2003; Hurley et al., 2008) insist that the future must be pluralized into alternative futures. The main reason being that attempts to predict the future are generally false, and reality often lies in a combination of several alternatives. Most models are based on five classes of futures (Casti, 2013, and Figure 27):

- **Possible futures.** All imaginable futures, including those that may involve currently unknown knowledge or technology.
- **Plausible futures.** Feasible futures that are not excluded by our current knowledge.
- **Probable futures.** Likely outcomes that align with current trends but acknowledging that trends can shift.
- **Preferable futures.** Normative futures desired by individuals or organizations, which can influence present actions and knowledge to increase their plausibility or probability (e.g. climate change advocacy groups).
- **Wild cards.** Low-probability, high-impact events that occur too quickly for social systems to respond effectively. Examples include the September 11 attacks and the damage caused by Hurricane Katrina (Hiltunen, 2006 and Figure 27).

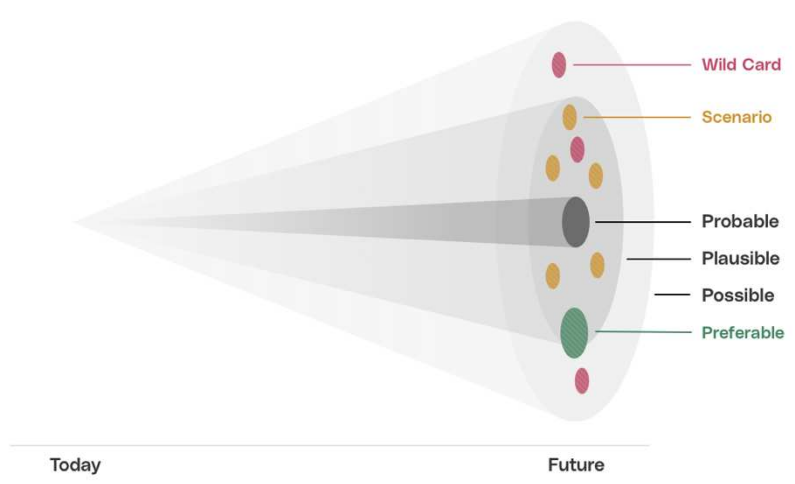


Figure 27. The Futures Cone adapted from Hancock & Bezold (1994), Henchley, (1978) and Gall et al. (2022). Also known as the three Ps and a W model (Possible, Plausible, Probable and Wild Card).

Hines and Bishop (2007) summarize the process for conducting a futures study into three main steps: selecting the area of study, examining trends to establish baselines, and constructing scenarios to explore alternative futures. Inayatullah (2013) outlines six key aspects: Mapping, Anticipation, Timing, Deepening, Creating Alternatives, and Transforming. Mapping involves contextualization to understand the past and present. Anticipation looks towards the future by identifying trends, opportunities, or weak signals. Timing involves identifying patterns of change to formulate hypotheses about future behaviors. Deepening futures involves using specific techniques to evaluate

probabilities more accurately. Creating Alternatives involves generating several alternative futures. Finally, Transforming aims to transform the present to prioritize a desirable future or prepare for future problems. It includes specific techniques like visioning (bring stakeholder together around a desirable future that is inspiring), backcasting (define the actions to be taken backward to reach the desired future), and transcending (intelligently combine multiple alternative scenarios to construct a new scenario considered better). For example, the University of Toronto conducted a comprehensive study for the city of Toronto in 2015, which envisioned three potential scenarios for the future of autonomous vehicles. These scenarios included one where most AVs were privately owned, another where most were used as taxis, and a third where ownership was split between private and commercial use (Laidlaw et al., 2016). Another example showing four alternative scenarios about the future of urban mobility is showed in Figure 28.

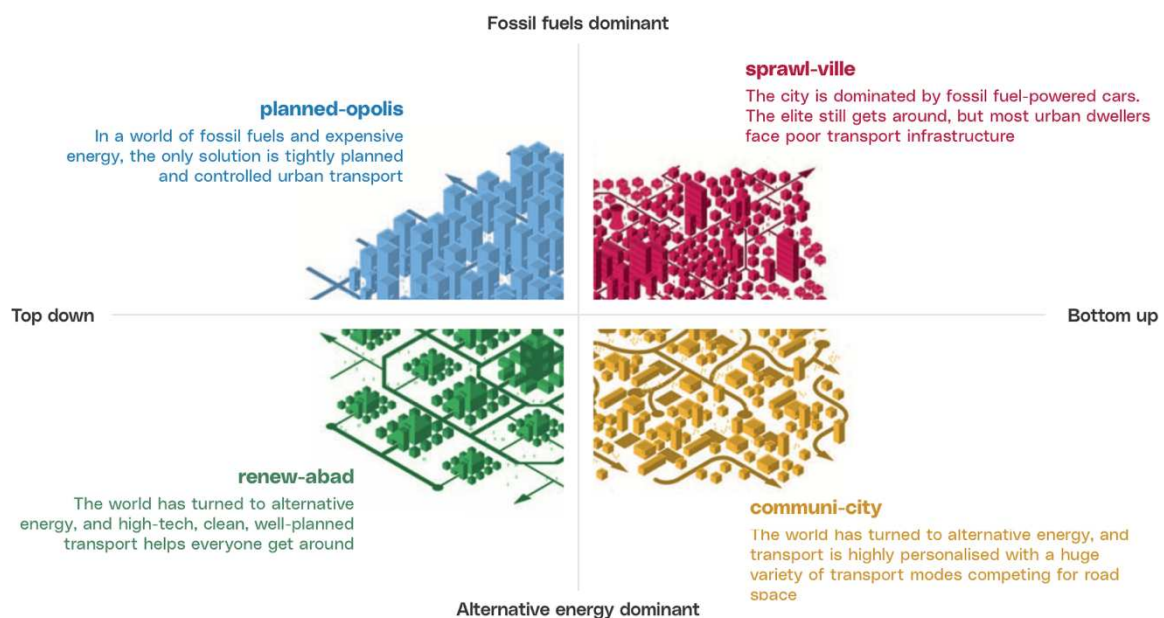


Figure 28. Example of four alternative scenarios for urban mobility in 2040 from Schlaikjer (2010). The y-axis is about the dominant energy mix and the x-axis is about the global governance framework.

There are two main types of futures studies research: exploratory and normative. Exploratory research identifies possible or probable futures by extrapolating trends, while normative research proposes desirable futures. Both approaches are helpful and complement each other. Probable/credible scenarios are useful because they allow to explore futures that rely on extrapolations of trends (business as usual) and/or weak signals. Desirable scenarios, on the other hand, are beneficial because they can influence future directions and the collective imagination by defining normative scenarios that should be achieved (backcasting). These two approaches are complementary.

The Futures Research Methodology is the most comprehensive set of research methods reviewed by experts (Glenn & Gordon, 2009). The latest version (V3) includes 37

methods. Salminen (2017) also lists methods in his book: *How do we explore our futures?: Methods of futures research*. These methods help to add substance, realism, or credibility to scenarios. For instance, *ethnographic experiential future* immerses participants in imaginary futuristic scenarios and evaluates their emotions (Candy & Potter, 2019; Garduño & Gaziulusoy, 2021). *Science-fiction prototyping* proposes to use the principles of science fiction as a tool for exploration (Johnson, 2009, 2011; Lombardo, 2005). Additionally, *causal layered analysis* helps build multi-layered scenarios to ensure the coherence of imagined futures (Inayatullah, 1998, 2013, 2017).

Futures studies is an interdisciplinary field that aims to investigate potential, likely, and desirable futures. It facilitates decision-making, prepares for possible challenges and opportunities, and strategizes for an improved future. The discipline integrates diverse methods and approaches from other fields and questions probable future hypotheses. Concerning autonomous vehicle, Townsend (2020) explains that exploring alternative futures “can help develop skills that will reduce our shock and help us recognize the future we eventually do face. By thinking through the possibilities, we can also take actions that prepare us for many different scenarios, not just one.” However, futures studies are not specifically adapted to developing new products. Thus, half of the work presented in this thesis aligns with this discipline and employs some of its methods, while the other half pertains to product design, which we discuss in the next section.

## 3.2. Design

Now that we have covered the discipline that concentrates on the study of futures, we shift our focus to product design and the responsibility of designers in their decision-making.

According to Papalambros (2015), design is “a way for humans to intentionally change the world.” The dedicated scientific field for this is called design science. It “studies the creation of artifacts and their embedding in our physical, psychological, economic, social, and virtual environments.” This interdisciplinary research field focuses on both products and processes, aiming to disseminate design research knowledge as much as possible. Papalambros claims it relies on two principles: good design improves lives, while bad design ruins them. The Design Research Methodology (DRM) is the leading methodology developed to practice design science in a rigorous and organized way. For that purpose, seven design research types are proposed (Blessing & Chakrabarti, 2009).

Within the product development process, we can distinguish two complementary disciplines: *engineering design* and *industrial design*. Engineering design, described in section 3.2.1, focuses more on the technical aspects and functionality of a product, while industrial design, described in section 3.2.2, focuses more on form and user experience (Freddi & Salmon, 2019). Note that engineering design and industrial design overlap and complement each-other (Figure 29).



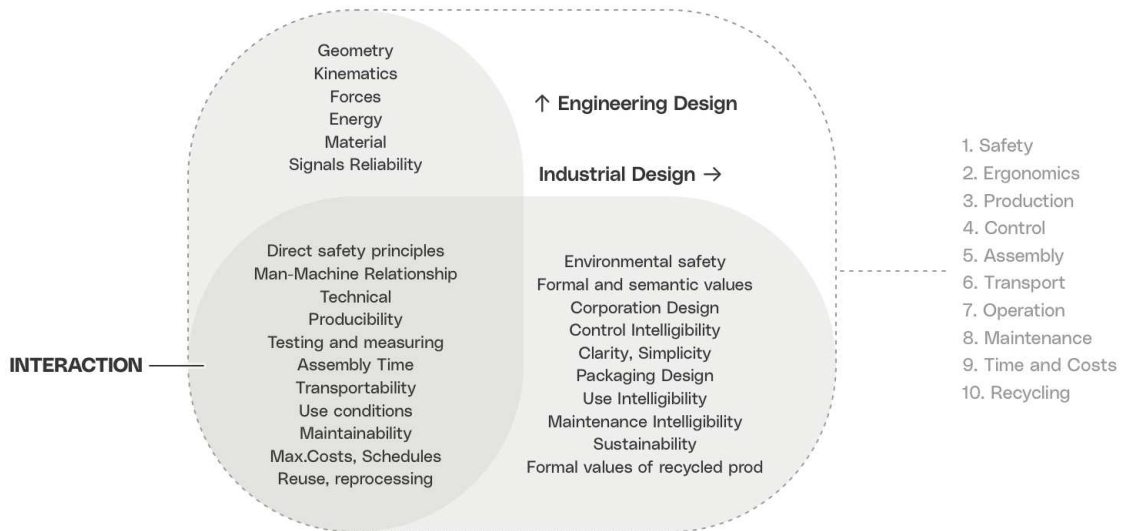


Figure 29. Engineering and industrial design interaction. Adapted from Freddi & Salmon (2019).

To clarify next sections, a product can be a physical object, consumable, industrial artifact, software, or intangible goods like know-how and patents. It can also include public services, theaters, healthcare facilities, and materials. A system is a collection of interconnected parts that together form a complex whole. This can include mechanisms, networks, or organized methods and schemes (Freddi & Salmon, 2019).

### 3.2.1. Engineering design

Engineering design is a decision-making process that often involves iteration. It applies basic sciences, mathematics, and engineering sciences to optimize resource use and achieve specific objectives (ABET, 2000; Pahl et al., 2007). The design process comprises establishing objectives and criteria, synthesizing, analyzing, constructing, testing, and evaluating. It also considers various realistic constraints, including economic factors, safety, reliability, aesthetics, ethics, and social impact. According to Herbert Simon, an economist known for his contribution to design science, engineering design aims to achieve the best possible outcome within the constraints of rational decision-making.

The following are some well-known prescriptive methods of engineering design:

- Design Thinking (Razzouk & Shute, 2012) is an approach to problem-solving that emphasizes user-centered innovation, desirability, iterations, feedback loops, failing fast, and collective intelligence. It originated in California and was initially developed by Rolf Faste at Stanford University. However, the method has received some criticism.

- The Double Diamond (Design Council, 2005) is a process theorized by the UK Design Council in 2005 that shows the two stages of problem setting and problem solving with for each a divergence and an convergence stage.
- The V-model (Mathur & Malik, 2010) is a visual representation of a system's development lifecycle used for creating precise development models and project management models for computerized system validation.
- The Dependency Structure Modeling (Eppinger & Browning, 2012), or DSM, is a modeling technique that uses matrix representations to design and manage complex systems. It provides network modeling tools that allow for assessing design complexity, modularization, reliability, risks, maintenance, and product family issues.
- The Stage-Gate model (Edgett, 2022) is a project management technique commonly used in large companies worldwide. It focuses on the innovation process and involves several stages.

These methods emphasize important aspects of engineering design, such as considering the whole system rather than just the product. Simulations can identify potential issues, while clear specifications and requirements ensure that the final product meets necessary standards. Moreover, prioritizing robustness, safety, reliability, sustainability, inclusivity, and user feedback can result in products that are durable, secure, dependable, sustainable, and easy to use.

A product like an autonomous vehicle, which is not yet clearly defined and will take a long time to implement, is positioned in the upstream phase of design. During this phase, ideas must be generated and then selected based on various criteria. This involves both ideation by designers and strategic decision-making by executives to determine the direction and position of a company regarding the technology. For example, should the company develop a vehicle for delivery or focus on private cars? While many methods discussed in this section can help reduce uncertainties and facilitate strategic decision-making, they may have limitations when the time scales extend beyond several decades, as is the case for autonomous vehicles. This observation is particularly problematic because the autonomous vehicle is a product that does not yet exist, making it nearly impossible to apply some of the methods described above (Lecomte et al., 2023).

### **3.2.2. Industrial design**

Industrial design emerged as a professional practice in the early 19th century, linked to the industrial revolution and mass production for consumers (IDSA, 2019; Heskett, 1980). French and Italian definitions of design, initially coming from "industrial arts", usually relate to object, service, or interface design, where the aesthetic component is

essential and can even outweigh usage. In Anglo-American culture, the definition of design mainly comes from engineering, the Bauhaus, and the common meaning of the word focuses more on the process of creation within a usage context and can refer to any application domain, including math or ideas (it is closer to engineering design). Nowadays, these two tendencies tend to merge due to globalization. This shift has had a lasting impact on business and society.

Today, industrial designers focus use a practical, user-centered approach to design products (Icsid, 2015). They provide clear and concise recommendations through drawings, models, and descriptions (IDSA, 2009) to create products that improve people's lives. As Auger et al. (2019) describe, industrial design plays a role in shaping consumer desire. It is a field that requires creativity and artistic skills, with designers often using their imagination to develop appealing product concepts. The output of industrial design includes concept sketches, 3D renderings, physical or digital prototypes, and mockups that highlight the visual and user experience aspects.

Industrial design is often seen as a discipline that creates beautiful products to increase customer desire and thus improve its financial value (Løwy & Cendrars, 1990). But its role goes beyond marketing reasons, as it carries the responsibility of deeply questioning the direction in which society is heading. As Auger & Hanna (2019) point out, "In the future, we must enlist design in the fight to bring our desires more closely in line with our needs." This normative aspect of design is aligned with what can be found in futures studies (Section 3.1). Here, it is the responsibility of industrial designers to propose a desirable future while acknowledging that any new technology introduced into the world will inevitably bring negative consequences. Auger & Hanna (2019) explain that it is important to explore these possibilities in detail. For example, in their work, they demonstrate the severe environmental and social consequences of our unquestioned energy usage. The role of the designer is thus to guide us away from these patterns of fossil-based consumption by proposing desirable and responsible alternatives. This implies an understanding of the nature of energy and the implications of its use. Figure 30 depicts a proposed concept that explores this aspect.

In addition, speculative design is an approach that focuses on exploring and envisioning possible futures. It involves creating design artifacts, scenarios, and prototypes to help envision responsible products in the future. Speculative design goes beyond conventional problem-solving or functional design. Instead, its aim is to provoke thought, stimulate discussions, and challenge existing assumptions about the future.

Speculative design is a creative and imaginative process that is not primarily concerned with practical or immediate solutions. Instead, it explores alternative, provocative, and sometimes dystopian or utopian visions of what the future could be (e.g. design fiction). Our research is situated within this framework, combining speculative design principles with a systematic engineering approach in a project-centered design.



Figure 30. Gravity Battery from Auger et al. (2019). It uses a combination of natural and cultural materials to generate and store energy, thus helping to raise awareness about our current unquestioned energy consumption.

## 4. General question

We have demonstrated that the concept of autonomous vehicles was a human fantasy that began to be seriously developed in the 1980s. Since then, it has progressed rapidly both technically and legislatively. Along the way, numerous technical complexities have caused delays in its development, however, there is no doubt that the technology will emerge in the decades to come. Moreover, we discovered that the consequences of the technology on the society have not been studied as thoroughly as the technical and legislative aspects, which is already causing issues today.

From the industrial side, we analyzed Stellantis, an automotive group, and found that they have been developing autonomous vehicle concepts since 2010. However, it seems that they have prioritized technical aspects before attempting to answer the question: What future mobility do we want to bring? This is evidenced by a lack of investigation and knowledge sharing about the potential usages of autonomous vehicles. In combination with new technical challenges faced by the entire industry, this contributed to significant delays and several projects stops. This has even led to regular shifts in the group's strategy regarding AVs. This aligns with a phenomenon well summarized by Roy Amara, from the Institute for the Future: "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."

From the research side, we have found that futures studies can be valuable for exploring long-term futures. In addition to futures studies, we have investigated engineering design because it offers methodologies and techniques widely used in business for designing products and services. However, we have concerns about the effectiveness of these methods for designing products that will be deployed over an extended period. We have also discussed how industrial design can bring empathy (ability to see the world through other people's eyes) into the product design process, not only to adapt to

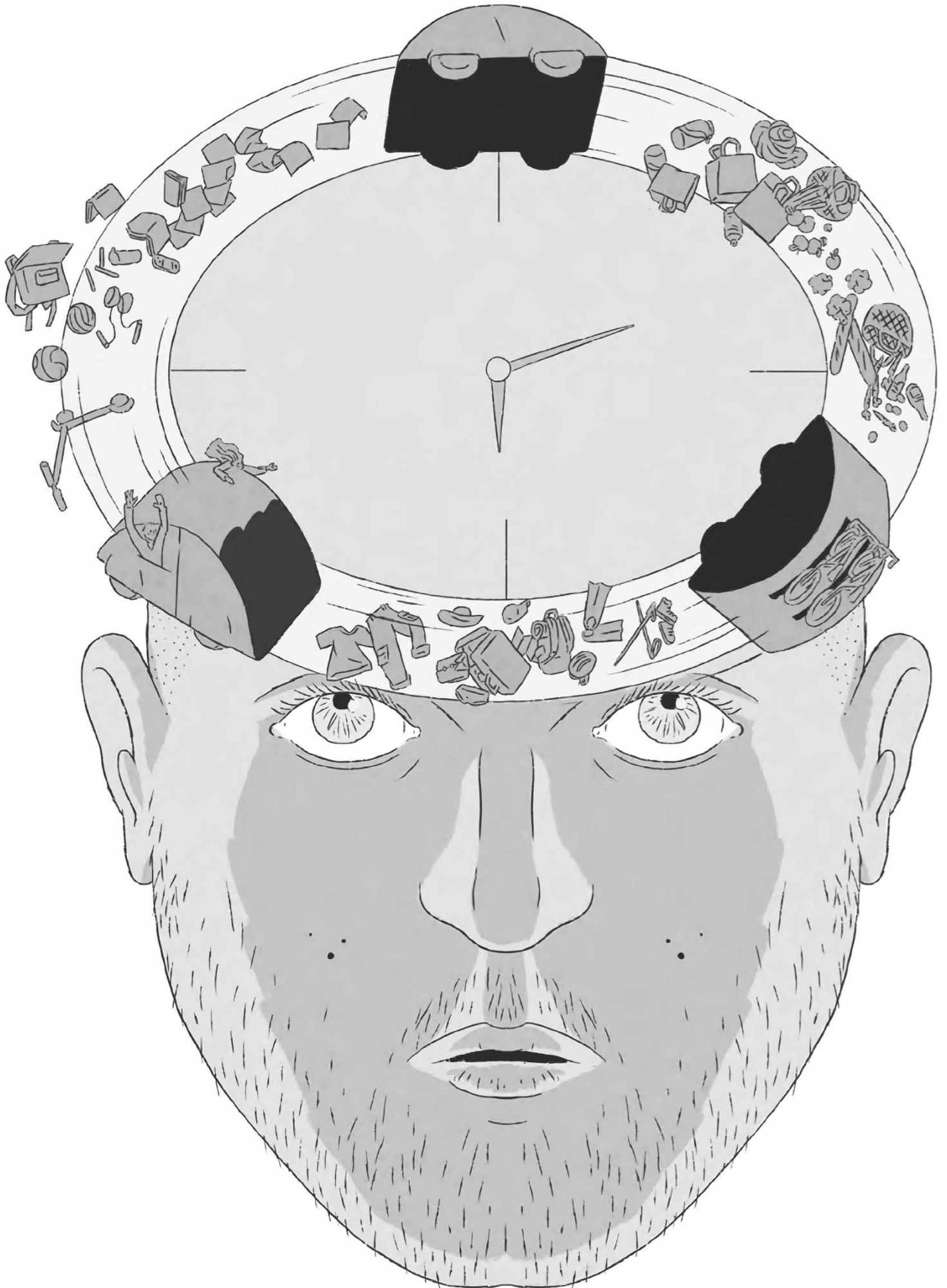
user needs but also to propose and create an attractive and responsible future for society. The combination of the three disciplines seems promising to studying the deployment of a potentially disruptive technology and clarifying the responsibility of designers for its impact on alternative futures.

This leads us to the following general question.

**General Question:** How can a company understand the unforeseen consequences of a design, like the autonomous vehicle, that does not yet exist but will undoubtedly cause significant disruptions?

The following chapter presents a state of the art of methods that could allow anticipating the long-term consequences of such a product, focusing naturally on the case of autonomous vehicles. It is particularly interested in the limitations of these methods. It describes the general methodology used and breaks down the general question into three research questions, which we attempt to answer in chapters 3 to 7.







CHAPTER 2

# Literature Review, research questions and methodology

In this second chapter, we summarize three literature reviews from chapters 3, 4, and 5. We also provide details on our general methodology, including the different research questions, and the validation steps.



# 1. Literature review summary and research questions

In this section, we first define the notion of impact. Then, we summarize three literature reviews conducted in chapters 3, 4, and 5 to highlight specific gaps and propose three specific research questions.

## 1.1. Definition of an impact

To adopt a responsible approach in the development of a product that will be deployed over several decades, it is essential to understand the potential long-term effects that the product could have on people and on society. To capture notable changes or consequences related to the arrival of autonomous vehicles, we chose the word "impact" which emphasizes the ability of an event to produce significant change. We believe it is important to consider these impacts as early as possible to avoid path dependency that can lead to irreversible consequences (Garud & Karnøe, 2001). As an example of path dependency, the "QWERTY" keyboard layout was not designed for practicality or ergonomic reasons, but rather to prevent the hammers on typewriters from getting tangled. Despite advances in typewriter technology, "QWERTY" remains the standard due to usage habits (Wagner et al., 2003). The Cambridge dictionary defines impact as "a powerful effect that something, especially something new, has on a situation or person." As a result, the term carries a negative meaning and is frequently linked with adverse outcomes such as climate change. When referring to positive outcomes, the term "effect" is often used instead. Even if we use the term "impact," we view "impact" and "effect" as interchangeable, as stated in the Regulations of the US National Environmental Policy Act. In design, we generally use the terms "property" or "performance" to qualify future consequences of a product. Performance is a comparison between a measured effect and a goal or reference point (Bourguignon, 1997). On a long-term basis, it can be difficult to define a quantified objective as the context can change considerably. Moreover, an objective is linked to interests for a given actor at a given moment. This is why we have opted for a neutral and long-term adaptable approach by choosing the term "impact".

Regarding AVs, we define "impact" as a quantified evolution of an indicator caused by the advent of autonomous vehicles to a given system. An impact can be characterized by different levels of precision and can be quantitative or qualitative. With a very long-term deployment of AVs, we mainly consider possible and plausible impacts, which refer respectively to all imaginable futures, including those that may involve currently unknown knowledge or technology and to feasible futures that are not excluded by our current knowledge (Casti, 2013). In the rest of the thesis, we use the term "possible impacts" (as explained in the cone of futures in Chapter 1).

In conducting an initial review of literature to map the state of knowledge on the impacts of autonomous vehicles, we have identified two categories of impacts: (1) studied impacts, for which there already exists quantified knowledge within the literature, and (2) unstudied impacts, for which knowledge is virtually non-existent.

In the first category, we found quantitative impacts that extend on a large spatial scale. This means that they extend over macroscopic geographical areas (city, country, continent, planet). Examples include the evolution of urban parking space requirements for vehicles or the evolution of energy consumption. We have classified these impacts as socio-economic and environmental. They are further detailed in section 1.2 and chapter 3.

On the other hand, we have found virtually no impacts at the individual or community level. For example, no study addresses the evolution of family ties or the health status of individuals who will use autonomous vehicles. Therefore, we have defined the second category at smaller scales (person, relationships). We have classified these impacts as social impacts. They are further detailed in section 1.3 and chapter 4.

It is important to note that in reality, these two categories of impacts are not completely separate, and our differentiation mainly reflects the dichotomy that exists in the existing (or non-existing) knowledge. It should also be noted that these two categories cover long time scales, ranging from a few years (e.g., health evolution) to several decades (e.g., energy consumption evolution). Figure 31 graphically represents these two categories based on the knowledge found and the geographical scale.

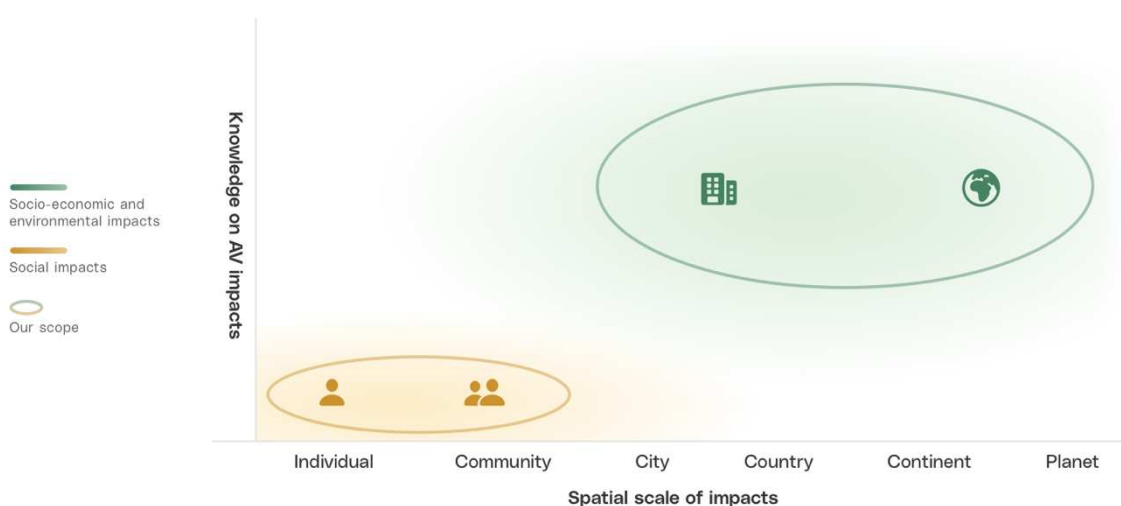


Figure 31. Schematic representation of the spatial scale and the level of knowledge found in literature about the two types of impacts.

The following two sections present these two types of impacts and summarize their respective state of the art concerning autonomous vehicles.

## 1.2. Socio-economic and environmental impacts of AVs

Our literature review revealed numerous studies and meta-analyses that examine the socio-economic and environmental impacts of autonomous vehicles. In fact, we have highlighted that there has been increasing scientific research on this topic during the next decade (Gandia et al., 2019). To determine the magnitude of these impacts, various techniques such as surveys (Zhang et al., 2018), numerical simulation (Childress et al., 2015; Fagnant & Kockelman, 2014), analytical methods (Greenblatt & Saxena, 2015) and optimisation models are used (Asadi & Vahidi, 2011). These impacts are mainly quantitative and can include metrics such as the total number of vehicles in an area, the average travel time per vehicle or person, and the amount of CO<sub>2</sub> emissions from a vehicle fleet.

If the abundance of these studies is good news for anticipating this type of impact, it can also make information retrieval difficult, especially for a designer or decision maker who needs to quickly form a reliable opinion on the matter. For example, they may not necessarily have the tools to quickly synthesize the results of different studies corresponding to a shared autonomous vehicle used in rural areas. It is therefore not only important to provide access to correct and understandable information, but above all, it is necessary to be able to adapt to the needs of designers, who need to address complex questions about the possible impacts of certain choices (we talk of complex queries).

To sum up, there are many studies on the socio-economic and environmental impacts of AVs, but it can be challenging for decision-makers or designers of autonomous vehicles to access the information. As we discussed at the end of Chapter 1, it seems essential for designers to take responsibility for the usages and ways of life that their products will bring in the future. Therefore, it is crucial for them to familiarize themselves with scientific findings, when available, on the possible consequences of autonomous vehicles. As explained by Berman (2009), designers "have a professional duty to make sure that [their] inventions are not just clever, but that they are wise; that [they] don't just create cool things, but that [they] are in alignment with a sustainable future." These observations led us to formulate research question No. 1.

**Research question No. 1:** How to allow non-experts to obtain high-quality information on the socio-economic and environmental impacts of autonomous vehicles, based on complex queries?

You can find the full literature review about socio-economic and environmental impacts in the chapter 3.

### 1.3. Social impacts of AVs

While socio-economic and environmental impacts have been extensively studied using specific models and simulations, social impacts of AVs are barely present in scientific literature. This is mainly because predicting social phenomena in the long term cannot be simulated through specific models due to their subjective and human-centered nature. For example, simulating the impact that autonomous vehicles (AVs) could have on the mental health of regular users is challenging. Will they experience improved well-being due to the elimination of driving stress? Or will they feel stressed by the idea of having to work while in their vehicle? Social impacts consider individuals and communities of people who use the vehicle or are affected in their daily lives by its presence (Burdge, 2015). Examples of social impacts include employment, family relationships, individual health status, well-being, conflict, crimes, among others (Rainock et al., 2018). Moreover, as we focus on long-term impacts, we do not consider impacts related to user experience or ergonomics, as they are not applicable to not-yet-defined products and have more immediate effects on users.

Companies typically rely on product evaluation methods from the engineering design field (Brown, 2008 ; ISO, 2018). However, these methods are not suitable for assessing a product's long-term social impacts. This is because these methods are primarily designed for well-defined products that will be launched in the short term. Short-term deployment allows the product to be tested with representative samples of future customers, something that is not feasible over the long term as the future population is still uncertain.

Impact assessment methods, such as Environmental Impact Assessment, Social Impact Assessment, Societal Impact Assessment, and Technology Assessment (Banta, 2009; Becker, 2001; Morgan, 2012; Vanclay, 2003) are designed to evaluate the consequences of significant interventions, such as policy measures or new technologies on people and society. Although they have the potential to anticipate social impacts, they are not tailored for specific products. Moreover, they are most relevant when planned actions are well defined or already engaged and when the targeted population is known.

To sum up, the scientific literature does not address the social impacts of autonomous vehicles because the methods used to evaluate impacts are not appropriate for products or technologies that will be massively deployed in a long time. But this does not absolve the responsibility of the designers who will propose autonomous vehicles. This observation led us to formulate research question No. 2.

**Research question No. 2: How to allow designers anticipate the possible long-term social impacts of autonomous vehicles?**

You can find the full literature review about social impacts in the chapter 4.

## 1.4. Existing solutions

Currently, companies use various solutions - or tools - to position their products in the market and societal context. However, most of these solutions focus on the company's interests rather than the product's impact on society. To give some examples, SWOT analysis studies a business's market position, the Five Forces Model defends a market position, and PEST analysis examines political, economic, social, and technological factors (Ifediora et al., 2014; Johnson et al., 2009; Porter, 2008). These tools do not provide a comprehensive view of a product's impact on society. Moreover, during our investigation at Stellantis, we confirmed that no approach was being taken to evaluate the long-term impacts of AVs (see Chapter 1).

However, some methods exist to evaluate the long-term impacts of a technology within an industrial framework such as technology assessment (Banta, 2009). Strategic foresight is another process that can be used by companies to identify potential opportunities or threats in the future (Godet & Durance, 2011). Moreover, companies often rely on external providers or internal experts to carry out impact analyses. But these approaches can be time-consuming, difficult to implement, and limited in scope. As a result, in the context of iterative innovation for AVs, companies would need to conduct a new study for each new concept idea, which is unrealistic. Few tools exist, such as the method proposal from Lecomte & Jean (2022) or the *Ethical OS* (2018) toolkit which aims to help companies prevent harmful technology use. However, these types of tools are not common and far from being effectively used.

To sum up, Stellantis and similar companies lack integrated methods in their design process that can foresee the long-term impacts of products like autonomous vehicles. This observation led us to formulate research question No. 3. This question focuses on the design process, distinguishing it from questions No. 1 and 2, which are more general and can be used by non-experts who are not designers.

**Research question No. 3:** How to leverage knowledge on the impacts of autonomous vehicles within a corporate design process framework, so automotive companies can make informed choices and prevent negative outcomes?

You can find the full literature review about existing tools in the chapter 5.

## 2. General methodology

To formulate the three research questions and be able to answer them, we followed the general research methodology described in this section and illustrated in Figure 32. This methodology adopts the principles of the Design Research Methodology framework of Blessing and Chakrabarti (2009). Within this framework, our work aligns with a type 5 research approach.

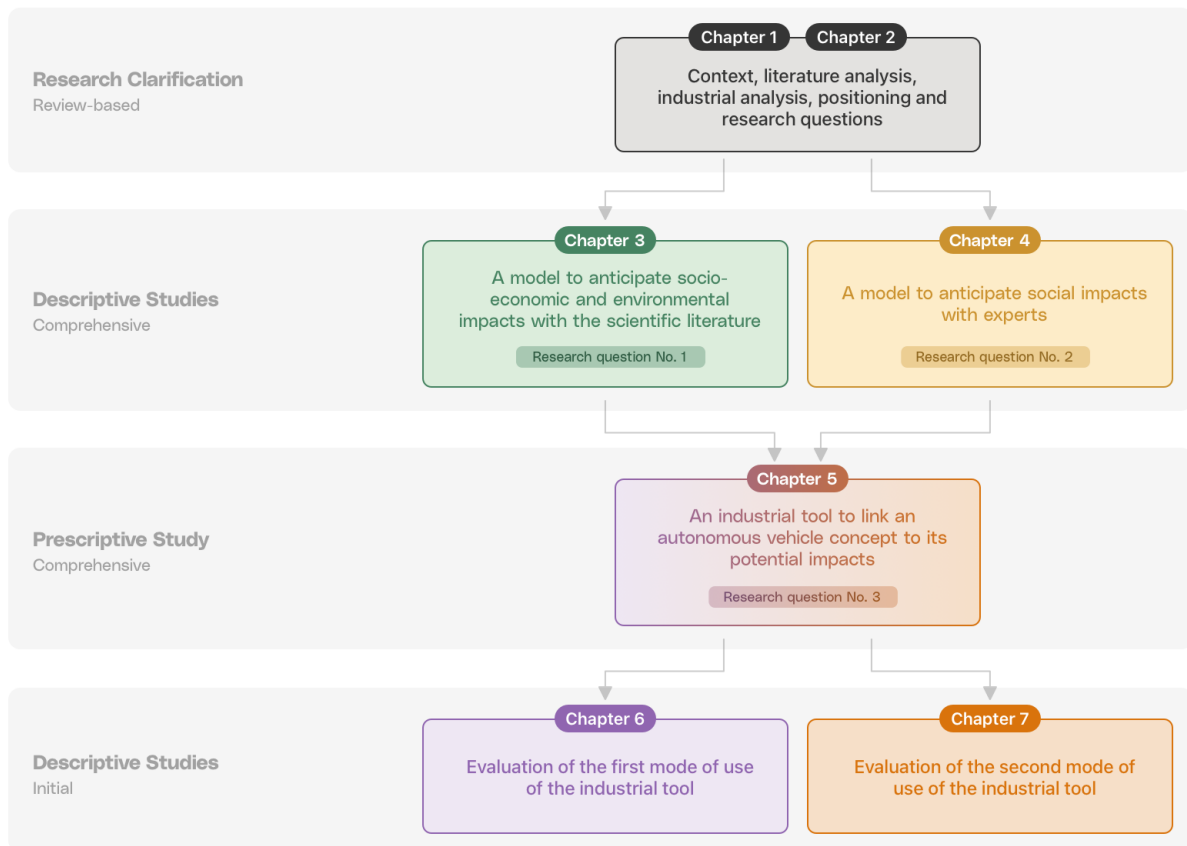


Figure 32. Methodological process of the thesis and the different chapters (after Blessing and Chakrabarti’s DRM, 2009).

The chapters 3, 4, and 5 can be read independently of each other, without any particular order. However, it is recommended to have read chapter 5 before reading chapters 6 and 7.

In the following four sections, we detail each phase of our research methodology and their correspondence with the different chapters of the thesis.

### 2.1. Research clarification

The research clarification phase of this thesis involves a literature review and an industrial analysis of the Stellantis company.

Our first goal is to position our work, which is covered in chapter 1. We start by examining the context of autonomous vehicles, including their history and related issues. Then, we place our work in the industrial context of Stellantis. Finally, we situate our work in relation to the scientific fields of futures studies and design science.

The second objective is to define the thesis goals by formulating three research questions that address the gaps identified in both the literature and the company. This pertains to the current chapter 2, but the literature reviews are further detailed in chapters 3, 4, and 5.

## **2.2. Two descriptive studies to better understand AV impacts (research questions 1 and 2)**

To better understand the potential impacts of autonomous vehicles, we conduct two descriptive studies for both types of impacts: (i) socio-economic and environmental, and (ii) social. These two studies correspond to chapters 3 and 4, and respectively attempt to answer the first two research questions. Each chapter includes a literature review, an original model proposition, and an analysis of its results.

Chapter 3 presents the Study-Method-Impact (SMI) model, which concentrates on the socio-economic and environmental impacts of autonomous vehicles. The model is based on scientific literature and is designed to help non-experts ask precise questions and access scientific knowledge related to this type of impact.

Chapter 4 presents the Representation-Usage-Impact (RUI) model, which focuses on the social impacts of autonomous vehicles. It is based on interviews with experts like sociologists or urban planners and aims to address the lack of knowledge on long-term social impacts in the scientific literature on AVs.

## **2.3. A prescriptive study introducing a new industrial tool (research question 3)**

After gaining a better understanding of how the long-term impacts of autonomous vehicles can be captured through the two previous studies, we propose a solution to address research question No. 3. This phase corresponds to chapter 5 and details the construction of an industrial tool aimed at decision-makers or autonomous vehicle designers. The original tool (named AutoVision) is based on a brief review of existing tools, as well as the two previous impact models. We build it in stages by getting feedback from people at Stellantis along the way.

AutoVision has two distinct modes of use:

- The Impact Guesser mode takes autonomous vehicle characteristics like its usages or geographic deployment area as input and outputs a list of weighted possible impacts.
- The Advisor mode enables the input of desired or undesired impacts (such as wanting to reduce CO2 emissions) and offers suggestions for corresponding autonomous vehicle characteristics.

The distinction between Chapters 3/4 and Chapter 5 is that Chapters 3/4 focus on the models to analyze knowledge (the main subject), while Chapter 5 focuses on the AutoVision platform as the subject. This is why they were characterized by descriptive studies.

## **2.4. Two descriptive studies to evaluate the tool (research question 3)**

The final phase proposes an initial evaluation of the tool in answering research question No. 3. This evaluation is split into chapters 6 and 7, which evaluate the two modes of the tool respectively. Through experiments conducted in both laboratory and industrial settings, we investigate the relevance of the tool within two different use cases.

Chapter 6 assesses the ability of the Impact Guesser mode to assist decision-makers in defining a concept of AV with desired impacts. An experiment is conducted with 28 participants in both a corporate and laboratory setting to assess four hypotheses.

Chapter 7 evaluates the ability of the Advisor mode to propose a concept of autonomous vehicle perceived as responsible by decision-makers. An exploratory experiment is conducted with 8 participants in a corporate setting to assess three hypotheses.

The experiments in this final phase involve a total of forty participants. The various results are discussed in the eighth and final chapter of the thesis, as well as prospects for improving the tool and conducting additional evaluations.



Impact variable refined (IVR)	Value	Trend	VDC - Case study location	VDC - Mode of use	VDC - Penetration rate	VDC - Technologies	Study
Intersection capacity	+150%	↑				Autonomous Vehicle (AV) / Connected AV	Clement (2004)
Intersection capacity	+94%	↑				Vehicle-Intersection Coordination Scheme (VICS)	Kamal (2015)
Intersection capacity	+93%	↑				Vehicle-Intersection Coordination Scheme (VICS)	Kamal (2015)
Intersection capacity	+76%	↑				Vehicle-Intersection Coordination Scheme (VICS)	Kamal (2015)
Intersection capacity	-4% to -21%	↓				Autonomous Vehicle (AV) / Connected AV	Le Vine (2015)
Intersection capacity	-18% to -53%	↓				Autonomous Vehicle (AV) / Connected AV	Le Vine (2015)

Impact variable refined (IVR)	Value	Trend	VDC - Case study location	VDC - Mode of use	VDC - Penetration rate	VDC - Technologies	Study
Intersection delay	-	↓				Autonomous Vehicle (AV) / Connected AV	Dresner (2008)
Intersection delay	-	↓			100%	Autonomous Vehicle (AV) / Connected AV	Fajardo (2012)
Intersection delay	up to -60%	↓			0% to 60%	Connected Vehicles (CV)	Ilgin Guler (2016)
Intersection delay	up to -7%	↓				Autonomous Vehicle (AV) / Connected AV	Ilgin Guler (2016)
Intersection delay	-	↓	Austin - USA			Autonomous Vehicle (AV) / Connected AV	Levin (2018)
Intersection delay	-	↓				Autonomous Vehicle (AV) / Connected AV	Li (2013)
Intersection delay	-90%	↓				Advanced cruise control (ACC-CACC-ICC-PCC-CFC)	Zohdy (2016)

Impact variable refined (IVR)	Value	Trend	VDC - Case study location	VDC - Mode of use	VDC - Penetration rate	VDC - Technologies	Study
Intersection capacity	-2%	↓				Autonomous Vehicle (AV) / Connected AV	Hall (2001)
Intersection capacity	-40% to -60%	↓				Autonomous Vehicle (AV) / Connected AV	Hall (2001)

Impact variable refined (IVR)	Value	Trend	VDC - Case study location	VDC - Mode of use	VDC - Penetration rate	VDC - Technologies	Study
Spaces needed	-58%	↓	Melbourne - Australia	Private (PAV) / Shared (SAV)	100%	Autonomous Vehicle (AV) / Connected AV	Dia (2016)
Spaces needed	-83%	↓	Melbourne - Australia	Shared (SAV)	100%	Autonomous Vehicle (AV) / Connected AV	Fagnano (2016)
Spaces needed	-92%	↓	Austin - USA	Shared (SAV)	100%	Autonomous Vehicle (AV) / Connected AV	Friedman (2016)
Spaces needed	-	↓	Austin - USA	Shared (SAV) - Carsharing / Taxis		Autonomous Vehicle (AV) / Connected AV	Friedman (2016)
Spaces needed	-75.9% to -80.9%	↓	Stuttgart - Germany	Shared (SAV) - Ridesharing		Autonomous Vehicle (AV) / Connected AV	Gruber (2016)
Spaces needed	-90.8% to -92.8%	↓	Stuttgart - Germany	Shared (SAV)	100%	Autonomous Vehicle (AV) / Connected AV	International Forum (2016)
Spaces needed	-	↓	Lisbon - Portugal	Shared (SAV) - Carsharing / Taxis	100%	Autonomous Vehicle (AV) / Connected AV	International Forum (2016)
Spaces needed	-84.0% to -89.3%	↓	Lisbon - Portugal	Shared (SAV) - Ridesharing	100%	Autonomous Vehicle (AV) / Connected AV	International Forum (2016)
Spaces needed	-92.8% to -94.4%	↓	Lisbon - Portugal	Shared (SAV) - Carsharing / Taxis / Private (PAV)	100%	Autonomous Vehicle (AV) / Connected AV	International Forum (2016)
Spaces needed	-22.2% to +3.8%	-	Lisbon - Portugal	Shared (SAV) - Ridesharing / Private (PAV)	100%	Autonomous Vehicle (AV) / Connected AV	Kumar (2016)
Spaces needed	-0.6% to -24.2%	↓	USA	Shared (SAV)	66% to 100%	Autonomous Vehicle (AV) / Connected AV	Kumar (2016)
Spaces needed	-80%	↓	Singapore	Shared (SAV)	100%	Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-50%	↓	Boston - USA	Shared (SAV)		Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-48%	↓	Singapore	Shared (SAV)		Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-	↓	Amsterdam - Netherlands	Shared (SAV) - Carsharing / Taxis / Shared (SAV) - Ridesharing	2%	Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-80%	↓		Shared (SAV) - Carsharing / Taxis	2%	Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-91%	↓		Shared (SAV) - Carsharing / Taxis / Shared (SAV) - Ridesharing	2%	Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-90%	↓		Shared (SAV) - Carsharing / Taxis / Shared (SAV) - Ridesharing	5%	Autonomous Vehicle (AV) / Connected AV	Li (2016)
Spaces needed	-92% to -93%	↓	Atlanta - USA	Shared (SAV) - Ridesharing		Autonomous Vehicle (AV) / Connected AV	Li (2016)

Extract of the SMI database

VDC - Mode of use >40% VDC - Penetration rate VDC - Technologies Advanced cruise control (ACC-CACC-ICC-PCC-CFC)



## CHAPTER 3

# The Study-Method-Impact model

The Study-Method-Impact (SMI) model is introduced to simulate the long-term socio-economic and environmental impacts of autonomous vehicles. By centralizing and structuring data from scientific literature, the model provides accessible and detailed results to non-experts.

# 1. Introduction

As shown in Chapter 1, car manufacturers are investing in partnerships to develop autonomous vehicles (AVs), but deployment plans are frequently delayed due to technical difficulties. The long-term impacts on society are often overlooked, so it is important to anticipate and provide decision-makers with insights on the consequences of AV technologies.

Our work revolves around the concept of impact. In Chapter 2, we distinguished between socio-economic and environmental impacts, and social impacts. This chapter focuses on the former, which has been the subject of increasing scientific research in recent years. As previously discussed in Chapter 2, there are various techniques used to determine impact magnitude, including surveys, numerical simulation, analytical methods, and optimization models. These techniques have demonstrated their relevance on numerous quantitative indicators, such as the total number of vehicles in a given area, the average travel time per vehicle or person, and the amount of CO<sub>2</sub> emissions from a vehicle fleet. To determine the impacts of autonomous vehicles, we need to analyze how these indicators have changed over time and compare them to current data.

Some existing comprehensive impact assessment methods are often used in the automotive industry. For example, the Social Life Cycle Assessment (S-LCA) attempts to analyze the potential social and socio-economic impacts over the entire life cycle of a product or service (Benoît & Mazijn, 2009). However, unlike these methods, speculation about the advent of autonomous vehicles is currently highly theoretical since the technology is still far from being fully developed (the future of self-driving cars is uncertain, as some companies still use cars with steering wheels and it is difficult to make assumptions about their long-term progress). It is still unknown what the costs, business models, and life cycles of autonomous vehicles will be, and market acceptance is not entirely predictable. Therefore, the use of these impact assessment methods and the databases on which they rely are no longer appropriate. The scientific literature related to AVs has increased significantly since the early 2000s (see Figure 33). This increase has also led to more and more studies on non-technical aspects. The bibliometrics analysis of Gandia et al. (2019) shows a rise since 2015 in the categories of “social sciences, management, philosophy, business and economics, law, and urban studies, among others.” Within these fields, some studies concern socio-economic and environmental impacts of AVs. Some synthesis reviews have then emerged from analyzing these studies and beginning to see trends in the likely consequences AVs massive deployment. However, some reviews may be limited to specific characteristics or impacts of AVs. For example, the review by Narayanan et al. (2020) examines shared autonomous vehicles (SAVs), the reviews by Kopelias et al. (2020) and Taiebat et al. (2018) only cover energy and environmental considerations, while Tafidis et al. (2022)

focus on safety. Harb et al. (2021) focuses on travel-related behavior impacts. On the other hand, some reviews that try to take everything into account can remain quite generic and lack quantitative analysis (Faisal et al., 2019 ; Milakis et al., 2017). In this context, automotive manufacturers seeking information on the potential impacts of autonomous vehicles (AVs) may struggle to find quick, comprehensive, and reliable information that meets their specific needs. And comprehensive impact assessment methods typically used in the automotive industry may not be applicable to AVs due to their highly theoretical nature. While automotive decision-makers may lack the time or skills to find, analyze, and draw conclusions by themselves from scientific literature — even if they can provide a detailed analysis of possible impacts. This observation brings up the first research question:

**Research question No. 1:** How to allow non-experts to obtain high-quality information on the socio-economic and environmental impacts of autonomous vehicles, based on complex queries?

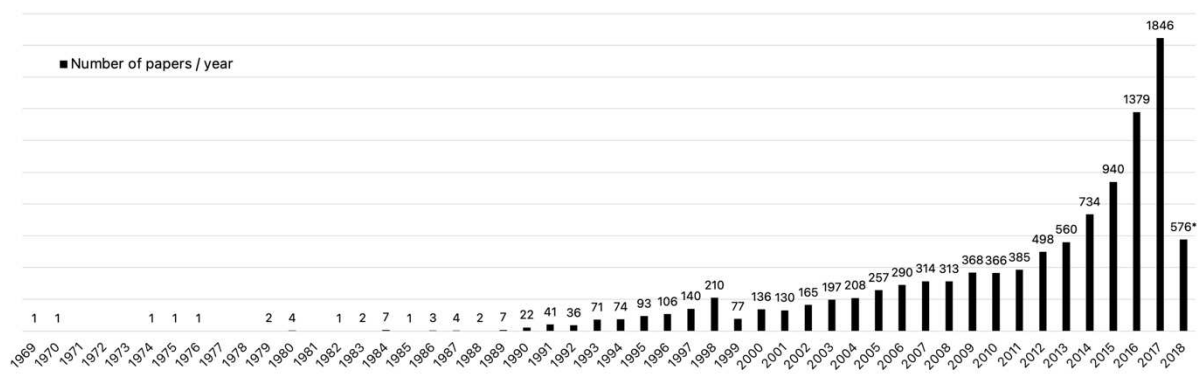


Figure 33. The number of publications per year on autonomous vehicles (Gandia et al, 2019). \*Research conducted in 2018.

This chapter presents the Study-Method-Impact (SMI) model, which can assist automotive decision makers in understanding the current state of the art regarding the socio-economic and environmental impacts of autonomous vehicles. The goal is to create a bridge between scientific knowledge and designers while enabling regular updates. It can be seen as an expert system, as defined by Feigenbaum (Stanford University). The model uses a custom database of scientific literature about AV impacts and provides automated and structured analysis of the knowledge contained in the literature from specific queries made by a non-expert. It can answer simple questions such as "Will the number of kilometers traveled increase with the advent of autonomous vehicles?" or "What are the most common methods used in the literature to determine the energy impacts of autonomous vehicles?" It can also answer more complex questions that combine many parameters, such as: "For a fully autonomous shared car evolving in European road infrastructure, is the evolution of the number of kilometers traveled per vehicle constant for all anticipation methods used?" The model centralizes and structures information that is typically scattered throughout scientific literature

and enables regular updates. Additionally, it presents results in a format that non-experts can understand. But this leads to the question of accuracy. To evaluate if the model conserves accurate information from the studies until it presents the results to the user, we compare its outcomes with two recent synthesis reviews. Our research focus is to determine if it is feasible to create a model for non-experts that can predict the socio-economic and environmental impacts of autonomous vehicles while ensuring accurate information comparable to the results of scientific literature reviews.

We begin by creating the Study-Method-Impact (SMI) model. First, we conduct a systematic search for synthesis reviews related to autonomous vehicles to help us build the structure of the model (Section 2.1). Then, we establish the four interconnected databases that make up the model (Section 2.2). We describe the data addition protocol (Section 2.3) and demonstrate how the model works for non-experts (Section 2.4). In the next section, we explain our model evaluation protocol (Section 3). We present the evaluation results, along with a specific example of how the model can be used, in Section 4. The final two sections consist of a discussion of the results (Section 5) and a conclusion about the ability of the model to address the problems identified in this introduction and its potential (Section 6).

## 2. The SMI model

Here we present the original Study-Method-Impact (SMI) model, which consists of listing quantitative socio-economic and environmental impacts based on existing studies. The model is made up of four interconnected databases: The first database, *STUDY*, is used to store all sources that provide data on impacts. The second database, *METHOD*, is a knowledge base detailing the methods used to calculate each impact. The third database, *INDICATOR*, describes existing impact indicators. The last and central database, *IMPACT*, includes raw data about autonomous vehicle impacts from the studies (Figure 34).

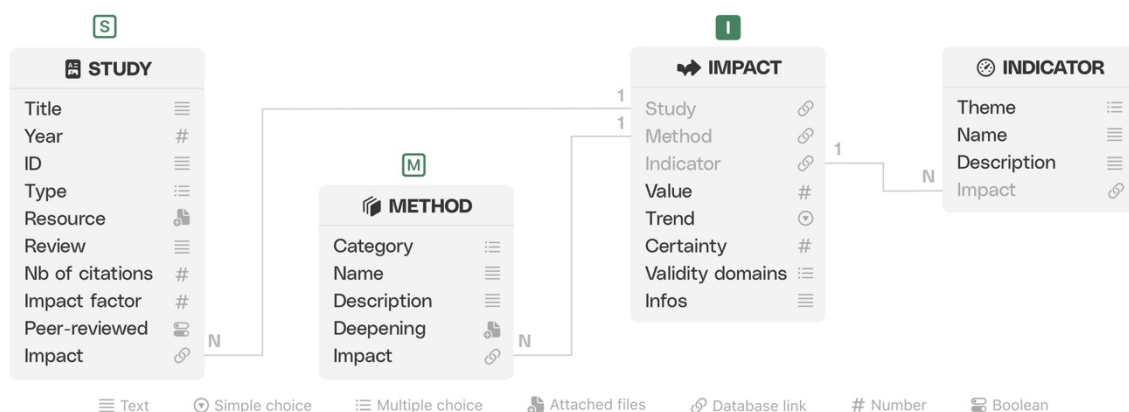


Figure 34. Databases and links. The study database is not filled by synthesis reviews, but with original studies.

## 2.1. Searching for existing synthesis reviews

To build the SMI model, we searched for existing methods used by researchers to synthesize the impacts of autonomous vehicles. Our objective is twofold: first, to draw inspiration from existing classification methods, and secondly, to provide our model with an initial list of studies.

We conducted a systematic search inspired by Tranfield et al. (2003). We limited our search to synthesis reviews published exclusively in the English language between January 2010 and June 2021 using Google Scholar and Scopus. We considered peer-reviewed papers only. The search fields have been filled in accordance with the specific features offered by each search engine. The Google Scholar search conducted in June 2021 was: “*allintitle: autonomous OR automated OR self OR driverless vehicle OR vehicles OR car OR cars OR driving OR transport OR transports review*” and the Scopus search also conducted in June 2021 was: “*TITLE((autonomous OR automated OR self OR driverless) PRE/O (vehicle OR vehicles OR car OR cars OR driving OR transport) AND (Review)).*” This first phase of research is displayed in the Figure 35. The query is limited to papers that have the word "review" in their title to avoid having to manually review too many articles. While this approach may not provide a complete view, it was considered acceptable as the objective was not to achieve completeness.



Figure 35. Literature search process and the number (n) of articles kept for each phase.

We then reduced the number of results with two additional phases: Reading titles and abstracts (phase 2), and full reading (phase 3). Four criteria were used (see Figure 35). Phase 2 criteria were re-used in phase 3. Ultimately, we selected six synthesis reviews to help us build the foundations for our model (see Table 2).

Table 2. List of synthesis reviews selected.

ID	Reference	Title
Review 1	Narayanan et al. (2020)	<i>Shared autonomous vehicle services: A comprehensive review</i>
Review 2	Milakis et al. (2017)	<i>Policy and society related implications of automated driving: a review of literature and directions for future research</i>

ID	Reference	Title
Review 3	Golbabaee et al. (2021)	<i>The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature</i>
Review 4	Acheampong (2018)	<i>Literature review on the social challenges of autonomous transport</i>
Review 5	Soteropoulos et al. (2019)	<i>Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies</i>
Review 6	Faisal et al. (2019)	<i>Understanding autonomous vehicles: A systematic literature review on capability, impact, planning and policy</i>

The six synthesis reviews selected searched for studies on the internet with the help of different search engines. Review 1 (Narayanan et al., 2020) searched Scopus using 13 keywords, selecting relevant studies, and adding more from references. Review 2 (Milakis et al., 2017) searched for peer-reviewed literature on Web of Science and Scopus. Reviews 3 (Golbabaee et al., 2021), 4 (Acheampong, 2018), and 6 (Faisal et al., 2019) used systematic review approaches and searched up to 393 databases. Review 5 (Soteropoulos et al., 2019) provided a comprehensive review of AV impact modelling studies, searching Scopus, Google, and Google Scholar with keywords. All six reviews adopted the SAE taxonomy to define levels of automation. Review 4 (Acheampong, 2018) was the only one not listing impacts in table form.

Phase 2 reviews are described in supplementary material 4, as well as the rejection reasons for seven of them (Sun et al., 2017; Gandia et al., 2019; Duarte & Ratti, 2018; Stead & Vaddadi, 2019; Becker & Axhausen, 2017; Gkartzonikas & Gkritza, 2019; Kopelias et al., 2019).

All selected reviews used a categorization system to distinguish between different impacts. We found 32 categories and made our own system using them. The cumulative impacts identified by the reviews amount to 391, from 184 distinct studies. Half of the impact indicators were mentioned in at least two reviews, while another half of the impact indicators were mentioned in at least four studies. Additionally, 16% of the impacts were found to be common to multiple reviews.

## 2.2. Databases construction

Drawing mainly on the methodologies used in the selected synthesis reviews, we defined specific attributes for the three databases. This subsection describes and justifies each of these attributes.

### 2.2.1. STUDY database

To list studies in the database, we have defined a total of seven attributes (Table 3).

Table 3. List of attributes for the database *STUDY*.

Name	Description	Modalities
<i>Title</i>	Study title.	Text
<i>Year</i>	Publication year.	Number
<i>ID</i>	Unique identifier to locate the study.	DOI or ISBN number
<i>Type</i>	Document type.	Select among a list
<i>Resource</i>	Downloadable file(s).	Files
<i>Review</i>	Synthesis review in which the study is referenced (in the form of a citation).	Text
<i>Number-of-citations</i> (N)	Number of citations.	Number
<i>Impact-factor</i> (JIF)	The impact factor of the journal in which the study is published, if it is a journal article.	Number
<i>Peer-reviews</i> (P)	Peer-reviewed or not.	Boolean

The first four attributes are used to identify the study. These attributes include *Title*, *Year*, and *ID*, which respectively refer to the title of the publication, its year of publication, and its unique identifier in the form of a DOI or ISBN (if one exists). *Type* allows characterizing the nature of the study as one of the following: Article, Conference paper, Conference slides, Research Report, Book chapter, Book, Thesis, Working paper, Preprint, Data, Workshop paper, Forum paper, Letter, or Notes. This last attribute can be useful for specific queries, such as for a user who wants to display results from articles-only. The next attribute is called *Resource* and allows listing one or multiple files related to the study, typically the PDF document of the study. This is a way to minimize the difficulty for the user to verify the sources of each data present in the database. We have also added the possibility to reference a synthesis review from which the study has been found (typically, one of the six reviews selected in section 2.1). The corresponding attribute is noted *Review*. The last three attributes are data related to the study and are used to weigh the impacts. For more details, see Section 2.2.4.

### 2.2.2. *METHOD* database

The *METHOD* database enables the listing, description, and referencing of various methods used in studies to calculate socio-economic and environmental impacts (Table 4). It was inspired by reviews 1 (Narayanan et al., 2020), 5 (Soteropoulos et al., 2019), and 6 (Faisal et al., 2019) and consists of four attributes.

Table 4. List of attributes for the database "Method".

Name	Description	Modalities
<i>Category</i>	The category of the method: (1) Simulation, (2) Survey / Workshop, (3) Optimisation, (4) Analytical.	Select among a list
<i>Name</i>	The name of the method.	Text
<i>Description</i>	An explanation of the method principles and objectives.	Text



Name	Description	Modalities
<i>Deepening</i>	Specific resources to get more informations.	Files and links

For the category attribute, four macro-categories were defined, inspired by the work of Narayanan et al. (2020).

1. **Simulation.** Simulation of the movement of one or more vehicles in a given environment. This category contains Microsimulation, Agent-based, Travel demand, Activity-based, Macrosimulation, Discrete-time, Multi-agent, Vehicle simulator, and Simulation – Others.
2. **Survey / Workshop.** Realization of surveys, studies, workshops on participants to capture preferences/desires/fears. This category contains Stated preference survey, Conjoint analysis, and Survey / Workshop – Others.
3. **Optimization.** Development of control algorithms to optimize certain parameters (e.g., intelligent rebalancing of vehicles to limit the number of kilometers traveled). This category contains Adaptive / Predictive / Intelligent cruise control, Intersection control, Rebalancing algorithm, Energy modeling system, and Optimization – Others.
4. **Analytical.** Use of analytical principles to determine impacts (e.g., use data from an existing transportation network as a basis for reasoning). This category contains Data-based, Life cycle assessment, and Analytical – Others.

The *Name* attribute contains the name of the method used after merging data from synthesis reviews and the study. A *Description* allows describing the method so that someone who is not an expert can get an idea of it and be able to identify it in a study. The last attribute is called *Deepening* and contains specific links and references to help access trusted resources about the method.

### 2.2.3. INDICATOR database

The *INDICATOR* database references all the indicators considered by the SMI model. Three attributes are distinguished (Table 5).

Table 5. List of attributes for the database “Indicator”.

Name	Description	Modalities
<i>Theme</i>	The theme of the impact.	Select among a list
<i>Name</i>	The name of the indicator.	Text
<i>Description</i>	A detailed description of the indicator.	Text

The first attribute is the *Theme*. Due to the potentially large number of impacts, it is important to be able to classify them into representative categories to make them easier to find. We were inspired by the 32 impact categories extracted from the six selected review articles in section 2.1. The next attribute is the *Name*. It must correspond to a

quantified variable that is likely to change with the advent of autonomous mobility. Each indicator is associated with a detailed *Description*.

### 2.2.4. *IMPACT* database

This section discusses the links between the three databases mentioned earlier. This is the most crucial part of the SMI model because it is where most of the data is referenced (Table 6).

Table 6. List of attributes for the database “Impact”.

Name	Description	Modalities
<i>Study</i>	/	Link to the database Study
<i>Method</i>	/	Link to the database Method
<i>Indicator</i>	/	Link to the database Indicators
<i>Trend</i>	Evolution of the indicator (↑ = Increase, ↓ = Decrease, → = Unchanged, – = Uncertain/Limited evidence)	Select among a list
<i>Value</i>	Change rate of the indicator compared to today.	Number
<i>Certainty (study-related)</i>	Approximate level of confidence given to the impact (calculation based on the number of citations, impact factor, and whether each study underwent peer-review).	Number
<i>Location (validity domain)</i>	The place where the simulation/experiment took place.	Select among a list
<i>Mode-of-use (validity domain)</i>	How the vehicle is used (shared, private).	Select among a list
<i>Penetration-rate (validity domain)</i>	The percentage of vehicles on the road that are equipped with autonomous driving capabilities.	Number

An impact is characterized by the combination of an *Indicator* and a *Value*, obtained from a *Study* using a *Method*. The *Value* is a number or interval between -1 and 1, representing the change of the indicator between today and the effective deployment of autonomous vehicles. The *Trend* is calculated from the value and represents the evolution of the indicator (↑ = Increase; ↓ = Decrease; → = Unchanged; – = Uncertain/Limited evidence). It is important to note that certain studies only provide trends and not numerical values. As a result, the value can remain unspecified.

To be able to give more weight to the most reliable data, we have developed a quality coefficient related to the *Study* from where the data comes from (*Quality*, noted *q*) based on 3 criteria:

- Average number of citations per year (noted *N* – assessed on Google Scholar)
- Last Impact factor of the journal (noted *JIF* – assessed on the website of the journal)
- Peer-reviewed (boolean noted *P*)

We borrowed these three criteria from Anjana & Choudhuri (2018), who demonstrated their relevance in assessing the quality of a study. We defined the coefficient as relative so that the study with the most citations (on average per year), that is peer-reviewed, and from the journal with the highest impact factor would receive a quality score of 1, while the worst would receive a score of 0. The number of citations accounts for half of the score, whereas the peer-review and impact factor criteria combined account for the other half. This arbitrary weighting aims to give more weight to the direct influence of a study (i.e., its number of citations) and avoid assigning too low a value to studies that are considered references in the field but are not published in peer-reviewed scientific journals. It is important to note that this calculation is based on the strong assumption that citations are positive, meaning they are not referencing the study to critique it. The *Quality* coefficient is defined by formula (1).

$$q = \frac{1}{2} \left( \frac{N}{N_{\max}} + \frac{1}{2} \left( \frac{JIF}{JIF_{\max}} + 1 \right) P \right) \quad (1)$$

With  $N$  the average number of citations per year ( $\in \mathbb{R}^+$ ),  $JIF$  the last impact factor of the journal ( $\in \mathbb{R}^+$ ) and  $P$  the peer-review indicator (boolean).  $N_{\max}$  and  $JIF_{\max}$  are respectively the maximum average number of citations per year and the maximum impact factor value of the database among the last impact factors published.

This database also has three validity domains as attributes, which are the assumptions made in the studies that condition the data. It is possible to add other attributes related to these validity domains.

- *Location*: This concerns the place where the study or simulation was conducted. It can be a city, a region, a country, or a continent.
- *Mode-of-use*: This concerns the mode of use of the vehicle, ranging from private to shared.
- *Penetration-rate*: This corresponds to the ratio between the number of autonomous vehicles and conventional vehicles.

Since assessing the impact can require some interpretation, we included an attribute called *Infos* that allows to retain the "raw" data from the study. If needed, this attribute can provide the following information in plain text: the name of the indicator used in the study, the description of the indicator, details on validity domains, and any assumptions or information provided by the authors to explain the results. In general, any important information from the study that may be useful for interpreting the data in the database should be included within this attribute.

## 2.3. Adding data

### 2.3.1. Protocol to add data

The data addition protocol must be easy to help update the databases while respecting rules to ensure data quality. Eligibility criteria shown below are defined to select the values to be included in the databases. By order of priority:

- The referenced impact is socio-economic or environmental.
- The referenced impact concerns autonomous vehicles or autonomous mobility.
- The full study is accessible.
- The data is quantitative (or based on quantitative data).
- The study itself does not refer to another study for its results (e.g. the study is a literature review).
- The method used is sufficiently described in the study (it is identifiable and classifiable in the *METHOD* database).

Figure 36 shows the process for adding new impacts to the databases.

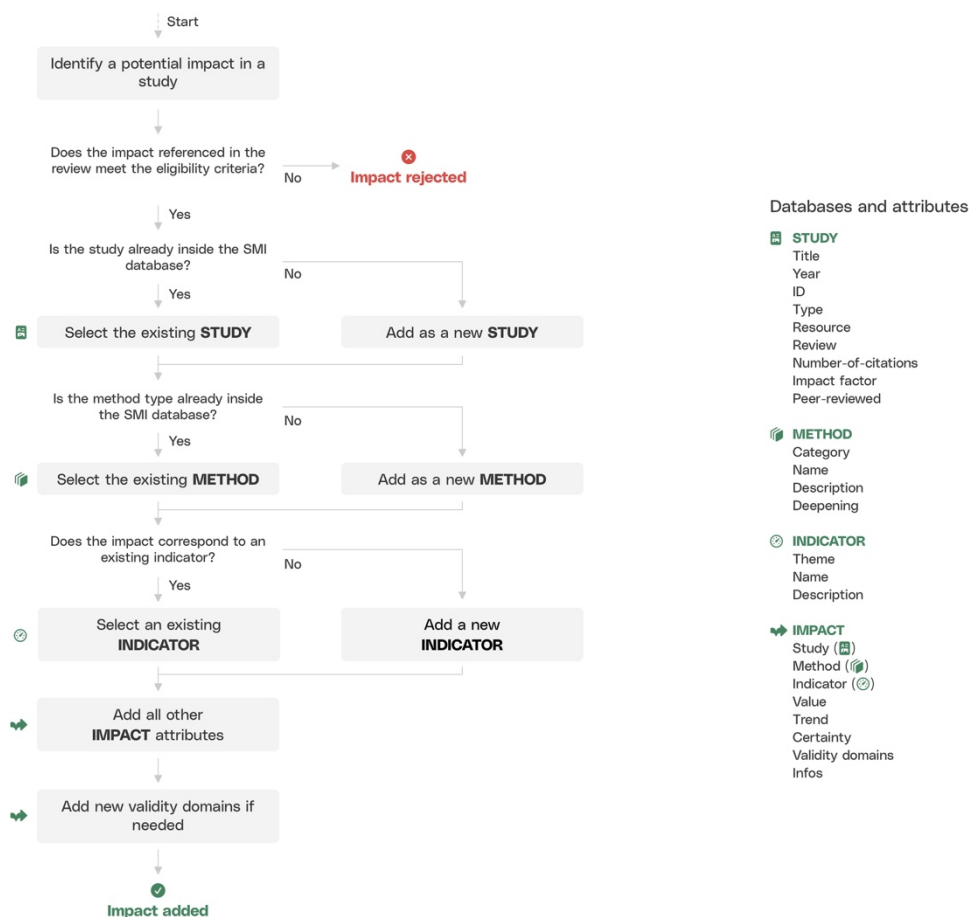


Figure 36. Flowchart for adding new data to the SMI model.

This protocol is designed to be accessible to non-experts. Its goal is to enable easy database updates while minimizing friction and ensuring high coding quality.

### 2.3.2. Adding first data

As explained in Section 2.1, we manually scanned six synthesis reviews. We extracted 391 impacts, resulting in 62 distinct indicators. However, before adding these impacts to the database, we needed to conduct a manual check of the original studies (as per the protocol mentioned in Figure 36). To limit the number of time-consuming manual source checks, we selected only the ten indicators with the most impacts. This also prioritized indicators with the most data for better statistical insight. These ten indicators belong to 57% of the 184 initial references (see Figure 37). It is probable that the 10 most significant indicators are the ones that people are most familiar with. However, it is still crucial to keep them because designers may not be aware of their importance (as we demonstrated in Chapter 7).

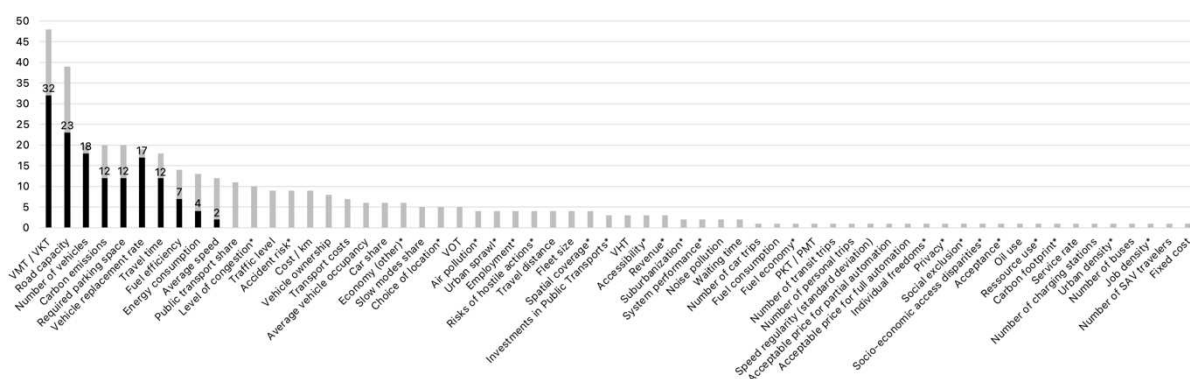


Figure 37. Number of references per indicator extracted from the six selected synthesis reviews; grey: original impacts from the reviews; black: remaining impacts after a manual check (among the first ten).

To ensure the quality of the data incorporated into the database, we conducted a careful reading phase of the original studies (105) with the help of five exclusion criteria. We kept 139 impacts out of 223. Thanks to a manual check of studies, we then divided the ten *Indicators* into 18 new ones, which were better defined and more precise. The 18 *Indicators*, along with their respective definitions, are presented in supplementary material 5. These *Indicators* are divided into 8 themes:

- **Parking**
- **Transport share**
- **Distance**
- **Speed**
- **Environment**
- **Energy**
- **Time**
- **Traffic**

## 2.4. Using the model

In the previous sections, we described the impact model built by populating an *IMPACT* database with its linked *METHOD* database. As the nature and quantity of the collected data are extensive, we now describe how to exploit them. To use the same wording as in the introduction, the goal is to help a non-expert who wants to know about the likely impacts of autonomous vehicles to quickly obtain comprehensive and reliable information based on existing knowledge. The query tool prototype we developed provides an interface that allows users to easily formulate their questions for querying the databases (query wizard). We first defined a theoretical framework for interrogating the databases. We then defined the query tool with three discrete elements to be filled in: *Indicator* (1) and *Refinement* (0-∞) as input, and *Visual output* (1-∞) as output. For the latter, we defined several views in the form of graphs or figures to best represent the output values of the model. A query tool prototype is shown in Figure 38.

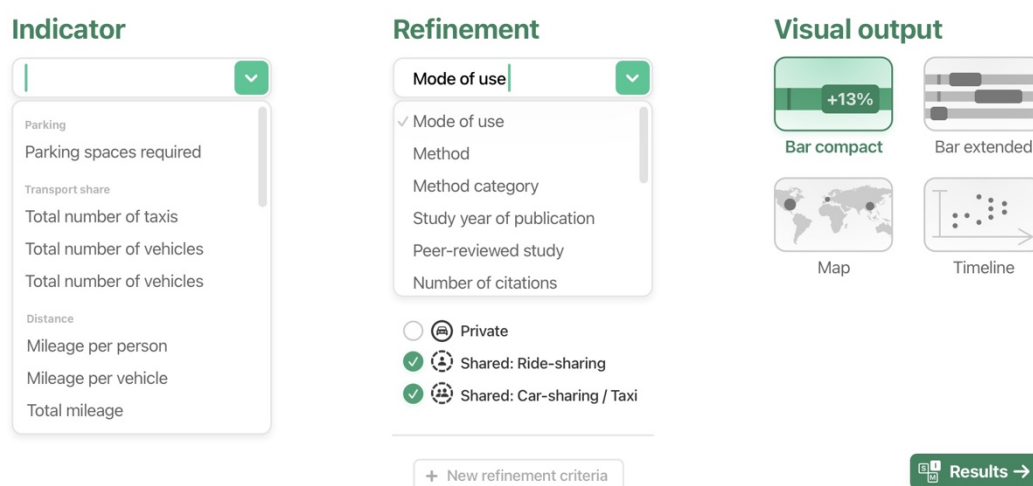


Figure 38. Query tool prototype for non-expert to exploit the SMI model. In the *Visual output* section, you can choose how the results will be presented. "Compact bar" displays the average on a horizontal axis. "Extended bar" breaks down each data point. "Map" displays the data based on where the studies were conducted. "Timeline" displays the data based on the publication date of each study.

The query tool can also compare multiple elements. For instance, you can compare the average speed between shared and private modes of use.

## 3. Validation protocol

The construction of the SMI model was inspired by synthesis reviews published between 2010 and 2021. Since then, additional synthesis reviews have been published. To evaluate the capacity of the model to deliver accurate information, we compared the results obtained by querying it with these recent reviews.

The first step involves conducting a systematic search for synthesis reviews (Section 3.1). In the second step, we aim to identify statements from these synthesis reviews that correspond to some of the 18 indicators of the SMI model (Section 3.2). Then, we formulate a list of specific queries adapted to the model, which enables us to compare review statements with model outputs (Section 3.3).

### 3.1. Conducting the search

To find new synthesis reviews on the impact of autonomous vehicles, we followed the same systematic queries as described in Section 2.1. However, this time we restricted our search to reviews published from 2022 onwards (the previous search was conducted between 2010 and 2021). We used both Google Scholar and Scopus, limiting ourselves to reviews written in English. We found a total of 202 documents across both tools (156 on Google Scholar and 46 on Scopus). We narrowed down the selection to two reviews by applying the same four criteria presented in Figure 35. These two reviews are referred to as Review 7 and Review 8 (see Table 7).

Table 7. List of synthesis reviews from 2022 selected for the validation protocol.

ID	Reference	Title
Review 7	Othman (2022)	<i>Exploring the implications of autonomous vehicles: a comprehensive review</i>
Review 8	Silva et al. (2022)	<i>Environmental impacts of autonomous vehicles: A review of the scientific literature</i>

Review 7 (Othman, 2022) provides a broad overview of impacts, while Review 8 (Silva et al., 2022) specifically addresses environmental impacts. These two papers are now the control synthesis reviews that we want to compare our results with.

### 3.2. Identifying common indicators

After carefully reading the results of the two reviews, we identified a total of eight statements that involve one or more common indicators with the SMI model. All of these statements are displayed in supplementary material 6, as well as all the 18 indicators.

### 3.3. Formulating specific queries

By reading the two synthesis reviews of 2022, we have identified all the statements (8) that could be compared with the model. It is from these statements that we formulated exhaustively 13 queries to interrogate the model (identified by letters from "a" to "m") involving nine different indicators out of 18.

- a. Evolution of the indicator "GHG emissions" if vehicles are shared only.
- b. Evolution of the indicator "CO2 emissions" if vehicles are shared only.

- c. Evolution of the indicator "Total VMT / VKT" if vehicles are shared only.
- d. Evolution of the indicator "Energy consumption" if vehicles are shared only.
- e. Evolution of the indicator "GHG emissions".
- f. Evolution of the indicator "CO2 emissions".
- g. Evolution of the indicator "Total VMT / VKT".
- h. Evolution of the indicator "Energy consumption".
- i. Evolution of the indicator "Road capacity".
- j. Evolution of the indicator "Intersection capacity".
- k. Evolution of the indicator "Total PKT / PMT".
- l. Evolution of the indicator "Parking spaces needed".
- m. Evolution of the indicator "Total number of vehicles".

## 4. Results

This section presents the raw results from the SMI model (Section 4.1) and compares them with the statements from control synthesis reviews (Section 4.2). An additional section provides an example of a more realistic usage of SMI by an industrial decision-maker (Section 4.3).

### 4.1. Raw results from the model

We used the thirteen simple queries described in section 3.3 to inquire about the SMI model. For each question, we presented the average value and its corresponding 95% confidence interval. These values were averaged using the *Quality* indicator  $q$  as a weighting factor. The results are displayed in Table 8.

Table 8. All queries' results from the model.

Query ID	Indicator	Condition	Average value	95% confidence interval	Number of data points processed (from the databases)	Average quality indicator
a	GHG emissions	Shared vehicles	-44%	[-127%; +39%]	2	76%
b	CO2 emissions	Shared vehicles	-25%	[-49%; -1%]	3	18%
c	Total VMT / VKT	Shared vehicles	+9%	[+5%; +13%]	32	32%
d	Energy consumption	Shared vehicles	-55%	[-71%; -39%]	5	48%
e	GHG emissions		-44%	[-127%; +39%]	2	76%
f	CO2 emissions		-20%	[-31%; -8%]	11	26%
g	Total VMT / VKT		+8%	[+4%; +12%]	58	31%
h	Energy consumption		-56%	[-70%; -41%]	6	40%
i	Road capacity		+62%	[+22%; +103%]	38	34%
j	Intersection capacity		+54%	[-2%; +111%]	6	41%



Query ID	Indicator	Condition	Average value	95% confidence interval	Number of data points processed (from the databases)	Average quality indicator
k	Total PKT / PMT		+17%	[+11%; +23%]	1	37%
l	Parking spaces needed		-75%	[-88%; -62%]	17	24%
m	Total number of vehicles		-81%	[-86%; -77%]	50	38%

It is important to note that these results are aggregated, and some of them combine different validity domains. Some studies presented a range instead of a single value, which we averaged. Other studies simply stated whether the indicator increased or decreased without providing a numerical value, so we excluded them from the calculation (they were very few). Therefore, it is crucial to consider all of these approximations when interpreting the results. The last three columns can help to evaluate the confidence that can be placed in the results. The confidence interval, combined with the number of data points processed, informs about the dispersion of the data and their quantity. The average *Quality* indicator can help identify whether data is extracted from reliable sources. This can be particularly useful when the number of data points is low.

## 4.2. Comparing results

After extracting values from the SMI model using specific queries, it is possible to compare them to the eight statements extracted from the control synthesis reviews (reviews 7 and 8 — see Section 3.2 and supplementary material 6). This section reviews each of these statements and assigns a correspondence label with our model results. The four correspondence labels are: (1) Agree, (2) Agree but uncertain data, (3) Disagree but uncertain data, and (4) Disagree. We have subjectively assigned these labels in the paragraphs below. We have provided justification for each assignment.

**Statement 1.** Review 8 authors claimed that shared autonomous vehicles are likely to reduce emissions. Querying the model using (a) and (b) resulted in a decrease in greenhouse gas emissions (-44%) and CO<sub>2</sub> (-25%). However, confidence intervals were wide, and the number of processed data points was low. Therefore, we assigned the correspondence label *No.2: Agree but uncertain data*.

**Statement 2.** Review 8 authors claimed that improved traffic flow, improved safety, increased road capacity and reduced congestion lead to a reduction in emissions. Before comparing emission evolution, we verified if our model predicted an increase in road capacity and intersection capacity. Results of queries (i) and (j) showed a clear increase of road capacity (+62%) and a mildly uncertain increase of intersection capacity (+54%). Therefore, we could make the request on emissions. Using the results of query (f), our model predicted a decrease in CO<sub>2</sub> emissions (-20%) with a narrow

confidence interval and a substantial amount of data. Query (e) suggested a decrease in greenhouse gas emissions (-44%), but the confidence interval was wide, and the number of data points was insufficient for a conclusion. Considering only CO<sub>2</sub> emissions, we got enough data to assign the label *No.1: Agree*. Considering greenhouse gas emissions, we assigned the label *No.2: Agree but uncertain data*.

**Statement 3.** According to review 8, an increase in distance traveled is likely to lead to an increase in CO<sub>2</sub> emissions. Before comparing emission trends, we verified whether our model predicted an increase in total vehicle miles / kilometers traveled. The results of the query (g) indicated that the total miles / kilometers traveled by vehicles were likely to increase slightly by 8%. The high number of data points (58) and the narrow confidence interval allowed us to have a high degree of confidence in this result. Therefore, we could make the request on emissions. The results have already been presented in the previous paragraph: A decrease in CO<sub>2</sub> emissions (-20%) with a good confidence, and a decrease in greenhouse gas emissions (-44%) with a bad confidence. Considering only CO<sub>2</sub> emissions, we got enough data to assign the label *No.4: Disagree*. Considering greenhouse gas emissions, we assigned the label *No.3: Disagree but uncertain data*.

**Statement 4.** The authors of review 7 indicated that a shared use mode of autonomous vehicles could lead to an increase in vehicle miles/kilometers traveled, emissions, and energy used. Concerning emissions, querying the model using (a) and (b) resulted in a decrease in greenhouse gas emissions (-44%) and CO<sub>2</sub> (-25%) but with a bad confidence. The results of the query (c) indicated that the total miles / kilometers traveled by vehicles were likely to increase slightly by 9% with a good confidence. The query (d) results showed a decrease in energy consumption (-55%). A relatively low confidence interval allowed us to have a decent confidence in the results. Considering emissions (CO<sub>2</sub> and GHG), we assigned the label *No.2: Agree but uncertain data*. For vehicle miles/kilometers traveled and energy consumption, we assigned the label *No.1: Agree*.

**Statement 5.** This statement is similar to statement 4 but with a different condition: An increase of distance traveled by people could lead to an increase in vehicle miles/kilometers traveled, emissions, and energy used. Results of query (k) shows that total people miles/kilometers traveled is likely to increase (but with only one data point). Considering this result was sufficient to validate the condition, we still examined the queries. GHG emissions are likely to decrease but with a bad confidence (query e). CO<sub>2</sub> emissions are likely to decrease, total VMT/VKT is likely to increase, and energy consumption is likely to decrease with a good confidence (queries f, g and h respectively). Considering only greenhouse gas emissions, we assigned the label *No.2: Agree but uncertain data*. Considering CO<sub>2</sub> emissions, total VMT/VKT and energy consumption, we got enough data to assign the label *No.1: Agree*.

**Statement 6.** The authors of review 7 indicated that autonomous vehicles have the potential to significantly reduce parking demand by 80 to 90%. The results of query (l) indicated a decrease in the number of required parking spaces by 75% across 17 data points, with a confidence interval ranging from 62% to 88%. This result validated the label *No.1: Agree*.

**Statement 7.** In review 7, the authors observed a reduction in congestion caused by vehicles searching for parking spaces. Query (l) showed a significant reduction in required parking spaces (-75%) with good confidence, validating the condition stated. Query (i) indicated an increase in road capacity (+62%). Although the associated confidence interval was quite large, the increase in capacity was confirmed by many data points (35). This result validated the label *No.1: Agree*.

**Statement 8.** This statement is taken from review 7 and suggests that reducing the required fleet size could lead to a decrease in emissions and energy consumption. However, the required fleet size indicator is not present in the SMI model. Therefore, we approximated it by using the total number of vehicles. The query (m) shows a significant decrease (-81%) in the number of vehicles with a good confidence. We assume that this result confirms the condition for reducing the required fleet size. According to results of queries (e), (f) and (h), we obtained a reduction of GHG (-44%) with a bad confidence, a reduction in CO<sub>2</sub> emissions (-20%) with a good confidence, and a reduction in energy consumption (-56%) with a good confidence too. Considering only greenhouse gas emissions, we assigned the label *No.2: Agree but uncertain data*. Considering CO<sub>2</sub> emissions and energy consumption, we assigned the label *No.1: Agree*.

Overall, we assigned the label (1) *Agree* to 10 indicators and the label (2) *Agree but uncertain data* to 6 indicators. We also assigned the labels (3) *Disagree but uncertain data* and (4) *Disagree* to one indicator each. In total, there are 16 "agree" labels and only 2 "disagree" when comparing results of our model with two recent synthesis reviews.

### 4.3. Getting more details

The SMI allows for the formalization of complex queries, but it is impossible to present all possible results due to the vast number of variables and parameters involved. With 18 impact indicators, 20 anticipation methods, and various declinations of each area of validity (such as each location of each experiment or simulation, or each mode of use), years of publication, and more, the number of possible queries grows exponentially. Furthermore, the model presented in this chapter is still incomplete and is expected to incorporate much more data in the future, while also considering additional areas of validity. Considering only one refinement criterion, the order of magnitude calculated with the current model is over 100,000 different queries. In this subsection, we offer a concrete use-case from the perspective of a decision-maker at an automotive company (Figure 39).

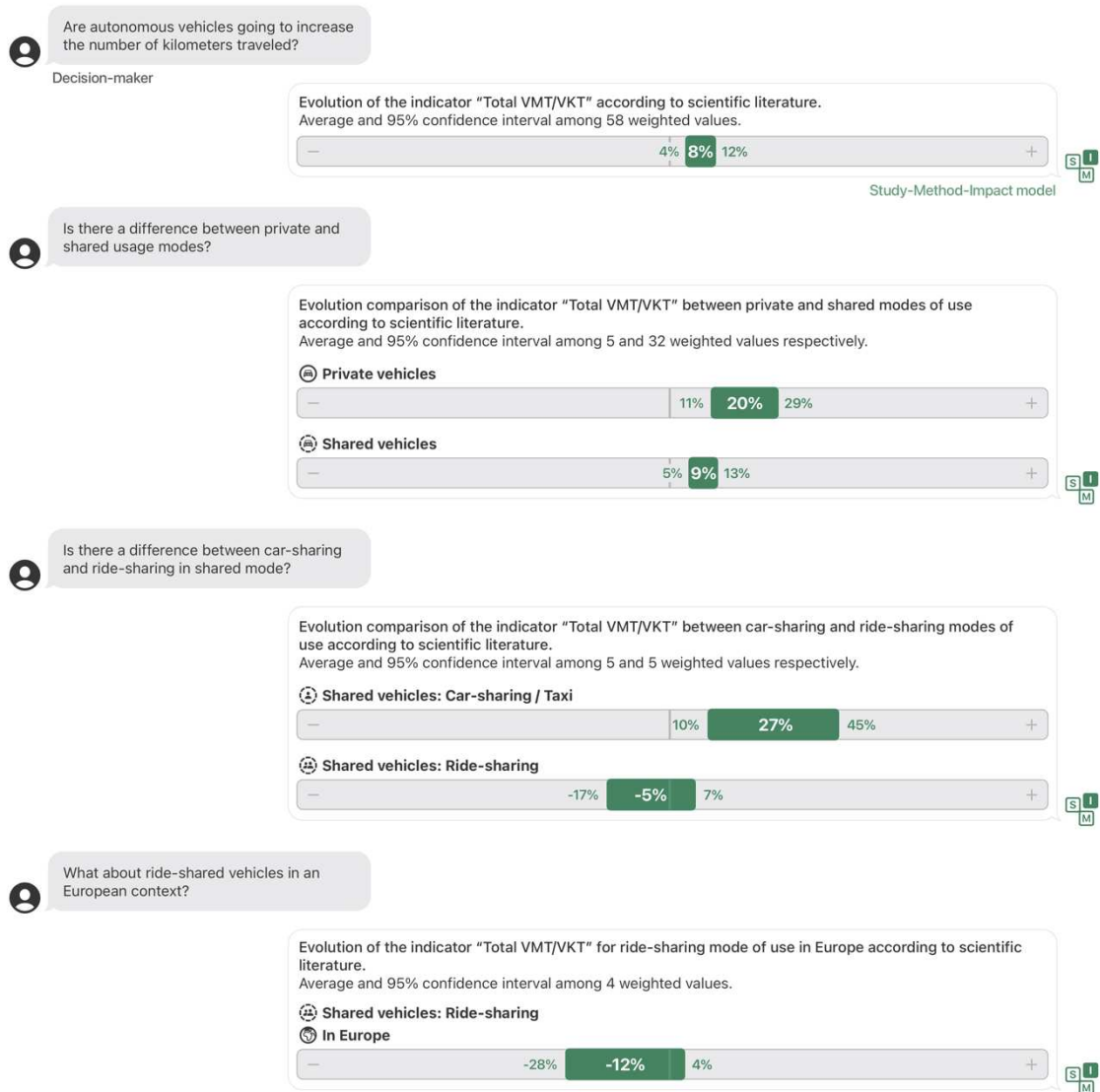


Figure 39. Example questions that a decision maker might ask (on the left) and SMI model responses to the corresponding query (on the right). They are displayed in conversational format for the example only to better illustrate a use case scenario. A user would use queries resembling those of Figure 38 (there is no language processing).

In Figure 39, an automotive group decision maker is interested in the potential impact of autonomous vehicles on distance traveled, compared to current conditions. The person formulates different questions in natural language on the left side of the figure (assuming that the natural questions are translated into queries, the real input of the model). The SMI model answers these questions on the right side by providing a data visualization. Using all information displayed by SMI, the decision maker can decide to explore ride-sharing options, which appear to generate fewer traveled kilometers and thus may be more environmentally friendly. The user can then ask the model about energy consumption or CO2 emissions and make new comparisons to refine its knowledge and guide its strategic choices. He could also create more complex queries

by refining, for example, the methods used to gather data (see Figure 38 for examples of queries).

A recommendation for use would be to start from the general (aggregated results) and then go to the specific (complex queries). Users can ultimately access the most relevant studies is needed.

## 5. Discussion

The SMI model was compared to the results presented in two control synthesis reviews (Section 4.2). The comparison indicated that the SMI model seems to accurately aggregate the scientific data on which it is based. Out of 18 indicators presented in the control synthesis reviews, the SMI model corroborates 16 of them, representing a success rate of about 90%. However, the lack of data on some indicators calls for nuance, as 7 out of 18 results lacked sufficient data to definitively conclude on the trend. As these databases are very young, it is obvious that new versions will have to be developed to add new content. However, among the 11 with enough data to assert that there is a likely consensus in the data literature, 10 of them corresponded to the predictions of the control synthesis reviews. It is important to note that some data from the SMI model may come from the same studies as those listed by the two control synthesis reviews. But this does not weaken what we wanted to test: the ability of the model to present accurate aggregated results. In other words, the SMI model seems to successfully aggregate data to provide users with results worthy of a synthesis review published in a peer-reviewed journal.

Despite this promising result, the aggregation provided by the SMI model is not without faults, and it is important to re-contextualize the results it may propose. It should be noted that the model does not claim to provide absolute truth to users. As mentioned in the introduction of this chapter, autonomous vehicles are still highly theoretical, and impact studies lack sufficient input data to provide accurate results. Therefore, it is crucial to explain to users that while the model can provide trends and help simulate impacts of AV concepts, it is not a crystal ball that can predict the future with certainty. Furthermore, it is possible that the model could mislead users. It may inherit problems found in the literature, such as many low-quality studies that may counterbalance the results of a few good studies. Additionally, the quality of aggregation could deteriorate, and misinterpretations could emerge due to various biases that the data coder may be subject to. The absence of some validity domains could also lead to a decrease in the quality of aggregation. Each study has a varying number of validity domains, some of which are very specific. To avoid complicating the use of the model, we only considered general validity domains like mode of use or penetration rate. Nevertheless, it aligns with our choice to build a model that is accessible to non-scholars. Furthermore, the

impacts of a technology on society are in reality part of a complex causal network. An increase in miles traveled increases CO<sub>2</sub> emissions, which in turn increases global warming, which disrupts biodiversity, and so on. In 2016, Gruel & Stanford attempted to represent these interdependent impacts using causal loop diagrams. We chose not to include them in our model because the links between impacts and their effects are still too heterogeneous and uncertain to expect satisfactory quantitative weighting. Nevertheless, it seems important to keep this simplification in mind when using the model.

We showed in section 4.3 an example of using the model to answer specific questions from a decision-maker's point of view. This example illustrates the possibilities offered by the model to finely question the results of scientific literature and to propose precise and easy-to-understand data visualization. It would have been interesting to test this point by submitting a prototype of the model to non-scholar users. We could have quantified the ease of use and understanding (ensuring that users do not make nonsense of results). From an improvement perspective, integrating the SMI model into a multicriteria decision-making tool — such as a software platform — could be an obvious next step (see Chapter 5). For example, it could indicate the usage mode that minimizes both CO<sub>2</sub> emissions and parking space requirements. It would be even more relevant to test the ease of use and understanding of users directly on this type of tool.

Concerning results, the SMI model showed us some interesting trends for autonomous vehicles impacts. Some of them are discussed here: First, an increase in the number of kilometers traveled by vehicles ("Total VMT / VKT") which is around +8% with a small confidence interval. Some studies explain this phenomenon by increasing the number of empty trips (without passengers). The result for the total number of vehicles is even more surprising, with an average reduction of 81% with a small confidence interval. Nevertheless, this can be explained because most studies on the subject focus on shared AVs. This results in fewer vehicles per person and per trip. Concerning road capacity, the trend is upwards, but the confidence interval is very large as it ranges from +22% to +103%. This variability can be explained by a significant disparity in the penetration rates of autonomous vehicles between studies (ranging from 20% to 100%). Several studies explain that autonomous vehicles can significantly increase road capacity when they are not mixed too much with conventional cars. Finally, the reduction in car parks by about -75% is very high. It is explained in the studies by the fact that vehicles (1) no longer need to park in front of their destination and (2) need less space because they can park more precisely than if humans drove them. The model we have developed allowed us to easily go into detail when a result seemed inconsistent or surprising (e.g. total number of vehicles and road capacity).

## 6. Conclusion

In this chapter, we developed an impact model by combining four databases to rigorously reference the socio-economic and environmental impacts of autonomous vehicles (AVs) found in the literature. These databases were inspired by six existing literature reviews, which we populated using more than a hundred studies. We placed emphasis on the flexibility of the databases to accommodate a wide range of impacts of different kinds while allowing for accurate, simple, and straightforward exploitation of the data. Finally, we proposed a process for feeding the databases, which would enable the model to evolve with the arrival of new studies. Our objective was to provide non-scholars, such as decision-makers in the automotive industry, accessibility and visibility to existing knowledge on AVs' impacts.

We tested the validity of the results proposed by our model by comparing it to two recent synthesis reviews. The comparison of 18 statements showed a success rate of 90% for our model, demonstrating that its results can be comparable to those of a synthesis review published in a peer-reviewed journal. However, we also found that the model lacked sufficient data to identify real consensus on certain indicators. To address this issue, we proposed to update the model regularly following the protocol presented in Section 2.3. The discussion section addresses some biases related to this evaluation. Therefore, it should be necessary to consolidate the evaluation when the model will get more data.

By building the SMI model, we aimed to address several gaps in the literature: (1) There are a great number of scientific studies that use different methods to calculate the impacts of AVs, which can be difficult for non-experts to comprehend, and (2) synthesis reviews are often limited to specific validity domains (Narayanan et al., 2020; Kopelias et al., 2020), or are too generic to be quantitatively exploited (Faisal et al., 2019; Milakis et al. 2017). From a non-scholar perspective, such as a decision maker working in the automotive industry, these two aspects make it very difficult to find and trust data in the literature. This can result in a lack of consideration of scientific knowledge or their misuse. In addition to providing results of a quality comparable to that of a synthesis review, the SMI model brings several unprecedented advantages: It provides non-experts with advanced and specific query possibilities. It is more accessible than synthesis reviews, and more extensive, meaning it is not limited to specific validity domains (e.g. only private vehicles, or only the United States for some reviews). Unlike a synthesis review, it is dynamic and can be regularly updated by non-experts. We have also added new descriptive elements for impacts such as a quality coefficient, or even a precise categorization of impacts. For advanced use, the fine information encoded in the database (e.g. specific attributes like *Infos*) can provide keys to understand and interpret data. The model systematically lists and describes the methods used to

achieve each result. This allows users to see how impacts were assessed and identify common or distinct methods.

Furthermore, by reviewing studies in the synthesis reviews, we found that the reviews selection process was not rigorous. Out of 139 studies, only 97 met our criteria, resulting in a 29% rejection rate due to inaccessibility of data or referring to another study for results. One advantage of our approach is that it adds a strong and systematic verification layer compared to existing reviews.

Some interesting results emerged from the study, such as the fact that AVs may drastically reduce the number of parking spaces or increase the average distance travelled by vehicles. If we consider that the six selected synthesis reviews used in our model are representative of the literature, this work has also highlighted the heterogeneity of the research on AVs societal impacts. For example, we can see that the distance travelled, the number of vehicles and road capacity are very well studied, whereas noise pollution and privacy are likely not (for AVs). This indicates that there are still many grey areas and the benefits of this new mobility paradigm still await answers. Hence, there is still an urgent need to conduct more studies on the likely impacts of the autonomous vehicle on the scale of our society, hence the proposal of another model for social impacts in Chapter 4. A complete tool is also proposed in Chapter 5 to adapt to industrial needs — incorporating SMI and the new model about social impacts. Then, a rigorous field test could help evaluate and thus validate the relevance of models such as SMI to effectively influence industrials and have a positive impact on choices about AVs (Chapters 6 and 7).

The SMI model was developed to assess the impacts of autonomous vehicles, but the method used to create, enhance, and explore the impact model can be applied to other areas of scientific research. For instance, in the medical field, this approach could be combined with existing meta-analysis tools to create a collaborative platform that accelerates research on a new drug. Such a platform could also bridge the gap between scientific knowledge and non-experts by providing simple query and visualization tools like those in our approach. Future work could focus on formalizing a general guide that allows researchers from various fields to apply and contribute to this approach.





CAFE ON WHEELS

Spaces on Wheels: Exploring a Driverless Future by SPACE10 and f'am Studio (extracted from the RUI model)



## CHAPTER 4

# The Representation-Usage-Impact model

The Representation-Usage-Impact (RUI) model is introduced to anticipate the social impacts of disruptive products. By combining expert knowledge from sociology and other fields, the model explores possible future scenarios and contextualizes product usage to frame its impacts effectively. Social science experts were able to identify a wide range of potential long-term social impacts of autonomous vehicles.

# 1. Introduction

Companies should consider the social consequences of their products before launching them, especially when a product is anticipated to disrupt people's lives. In the long term, the product could have significant effects on well-being, social relationships, or even health. It should therefore not be taken lightly. Responsible innovation involves anticipating the impacts of a product early on to avoid negative consequences on people and society (De Saille, 2015). However, forecasting social phenomena on large time scales is a challenge due to the high level of uncertainty. For example, the smartphone caused long-term social impacts, such as attention deterioration among young people (van Velthoven et al., 2018) or addiction problems (*Financial Times*, 2018). Early anticipation during development could have prevented or lessened this issue. However, it is likely that designers did not have the will nor reliable methods to anticipate these impacts. This leads us to the question of how to characterize the possible social impacts of a disruptive product that does not yet exist on the market. As described in Chapter 1, we specifically focused on social impacts as defined by Burdge (2015): "The influence of a product on the day-to-day quality of life of persons." We considered individuals, groups, and the entire population (multi-stakeholder approach).

We identified two main research fields that focus on evaluating future technologies: Engineering design, at the product level, and Impact Assessment, at societal scales. In the field of design science, there are evaluation methods that can predict the social impact of a new product. A simplified design process can be divided into three main steps: Discover, Design, and Evaluate (e.g. Design Thinking (Brown, 2008) and V-cycle (ISO, 2018)). The purpose of the Evaluate step is to measure the performance of the product. It can be carried out by a company to test performance, usability, acceptability, market acceptance in advance or to determine whether a specification or regulation is met (quality requirements or standards imposed by governments as part of approval, for example). There are various methods used in the industry to evaluate the product and ensure that it will have the intended effect when it is launched. One category is User Acceptance Testing (UAT). Its purpose is to validate the relevance of the product to the user. For example, verify that a new product effectively improves the practice of an activity. Evaluation methods involving users are common and assess the effective use of the product, understanding, and contribution. Because, according to Jørgensen (1990), "Users' knowledge is different from designers' knowledge." Therefore, it is important to go through this step which allows limiting the different biases and fixations of designers towards the actual usage of the product. Evaluating a new product is a process that takes place throughout its design and typically involves five stages: concept testing, prototype testing, pretest market, test market, and launch (Ozer, 1999; Mahajan & Wind, 1988). Some examples of methods are analogies (Davis, 1985;

*Startup Cemetery*, 2022), focus groups (McQuarrie & McIntyre, 1986), heuristic evaluation (Nielsen & Molich, 1990), usability tests (Dumas et al., 1999), multi-attribute models (Green & Srinivasan, 1990), purchase intention, A/B Testing and experts opinion. Most of the methods mentioned assume that test participants are end-users, meaning that the group of volunteers for testing is considered representative of actual users. This bias is recognized and often limited during user testing by specific techniques. However, when the launch window for a product is far from the time of testing (few decades), changes in habits, culture, and mindset become both significant and unpredictable. At this scale, it is no longer possible to have access to participants representative of end-users. Even if some design approaches, such as Radical Innovation Design (Yannou, 2015; Yannou et al., 2018), try to consider this aspect, product evaluation remains unsuitable for characterizing or assessing long-term social impacts.

On a larger scale, the impact assessment methods aim to assess the overall effects of large-scale interventions such as policy measures or the deployment of new technologies (Becker, 2001). They are often used in policymaking to assess impacts on themes such as environment, people, communities, social well-being, culture, economy, or health. Vanclay (2003) identifies two objectives for impact assessment: To improve decision-making about interventions and their implementation, and to implement measures that minimize damage and maximize benefits. The success of an impact assessment study lies in its analysis of multiple alternatives, and in its ability to propose recommendations that can be sustained to limit or avoid negative impacts and maximize positive effects. For example, the Intergovernmental Panel on Climate Change (IPCC) reports are considered as impact assessment reports. Thus, one of its most common uses is within the *Environmental Impact Assessment (EIA)* (Morgan, 2012), which is currently required in most countries around the world to validate bills or policies (the term has been internationally recognized since 1992 — United Nations, 1992). Regarding social aspects, the Social Impact Assessment (SIA) focuses on individuals, organizations, and social systems (Becker, 2001). Its main objective is to achieve a more sustainable and equitable environment. The SIA community considers all questions that affect individuals, directly or indirectly, relevant for evaluating social impact. SIA methods help identify the future social consequences of an intervention to achieve a more sustainable and equitable environment. Kreissl et al. (2015) propose a broader variant of the SIA by shifting from social aspects to societal aspects. For him, the term "societal" encompasses the analysis of everything that affects human, natural, or artificial systems. Thus, the *Societal Impact Assessment* considers the potential of a technology to modify society as a whole (for example, the introduction of new energy sources). Another approach is Technology Assessment (TA), which examines the short- and long-term consequences of deploying a new technology (Banta, 2009; Arnstein, 1977; Coates, 1974). TA can be seen as a decision-making tool. The concept is based on the belief that all technological progress has ethical implications. TA is interested in the

dissemination of technologies, the factors leading to their acceptance, and their role in society (Banta, 2009). Estimating impacts is by nature speculative, but TA aims to control it through data, scientific knowledge, and experience (Rip, 2015). Therefore, Technology Assessment evaluates the effects, consequences, and risks of a technology, but also has a predictive function that is useful for strategic planning. Unlike product evaluation, all these methods allow for the identification and consideration of a wide variety of impacts over varying time scales. However, they are most relevant when planned actions are well defined or even already engaged, and when the targeted population is known. These observations lead to the "Collingridge dilemma" (Worthington, 1982) which states that at the beginning of the development of a technology, its nature and how it will be used are still malleable, so its impacts cannot yet be precisely determined. When the consequences become apparent, the technology is well-established and becomes too difficult to change. Two commonly used techniques to limit this problem are technomoral scenarios and sociotechnical experiments. Technomoral scenarios involve imagining and exploring potential future scenarios in which the technology is widely used, whereas sociotechnical experiments involve creating a prototype of the technology and testing it in a real-world setting to observe its social impacts. Sociotechnical experiments have a different setup compared to typical prototype testing. Their focus is on understanding the complex interactions between social and technical elements, such as social structures instead of just one individual. Additionally, sociotechnical experiments have a longer-term perspective. Kudina & Verbeek (2019) use the example of *Google Glass* to illustrate this dilemma and these techniques. However, as with product evaluation methods, in the context of a product that will be deployed in a very long time, these techniques remain limited because they cannot consider an extreme degree of uncertainty.

For exploring long-term timeframes, we come across Futures Studies. As explained in Chapter 1, this research field aims to explore forthcoming developments. Its methodology is systematic, interdisciplinary, and holistic, taking into consideration complex systems. Within a company, the study of the future is used to identify potential opportunities or threats. This is referred to as strategic foresight (Godet & Durance, 2011). Although it has similarities with impact assessment and product evaluation, it is not directly related to either field. This is because the focus is on exploring the future in general, rather than evaluating the impact of a specific product. At best, it can identify trends and issues that could shape the market in which the product could be sold. As explained in Chapter 1, and according to many futures studies experts and researchers, the future must be pluralized into alternative futures. Existing models are based on four classes of futures: possible, plausible, probable, and preferable (Casti, 2013; Figure 40).

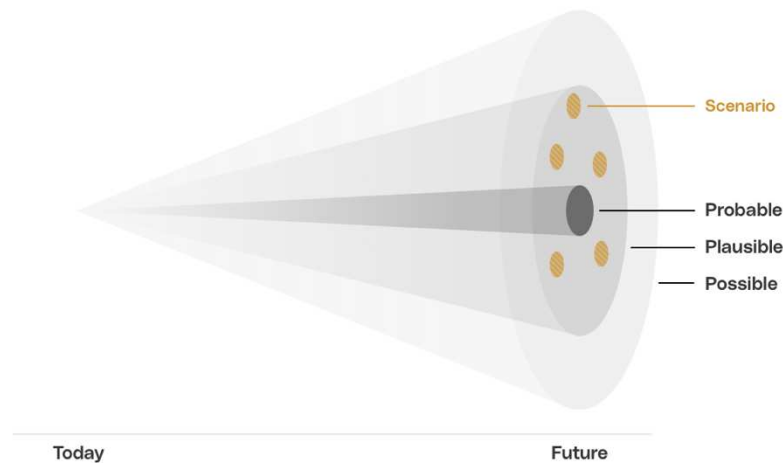


Figure 40. Simplified version of the the Futures Cone adapted from Hancock & Bezold (1994), Henschley, (1978) and Gall et al. (2022).

Futures studies seem to provide excellent techniques for contextualising scenarios of the future. Various methods are used to give substance, realism, and credibility to these scenarios (Spaniol & Rowland, 2019; Urry, 2016; Godet & Durance, 2011; Rhydderch, 2017). For example, ethnographic experiential future immerses participants in imaginary futuristic scenarios and tries to improve them by evaluating the emotions generated in participants. The science-fiction prototyping proposes using science fiction principles to support exploration. We can also mention the causal layered analysis, which adopts a multi-level thinking process to ensure the coherence of imagined futures, or the trend analysis, which exploits trends to generate plausible or probable futures. Many other methods are used to study the future. These include — among many others — morphological analysis (Ritchey, 2013; Johansen, 2018; Lamblin, 2018), Causal Layered Analysis (CLA) (Inayatullah, 1998; Inayatullah, 2013; Inayatullah, 2017; Gall et al., 2022), Backcasting (Robinson, 1990), Cross-impact analysis (Gordon, 1994), Technology roadmapping (Phaal et al., 2004), Technology forecasting (Quinn, 1967), or Aspirational futures (Grandjean, 2017). Ultimately, while futures studies may not be directly suited to studying the probable long-term social impacts of a disruptive product, its methods and principles could be adapted to better contextualize the product and frame its impacts more effectively.

As we have observed, current evaluation techniques are insufficient for predicting the long-term social effects of a product that has not yet been deployed. Product evaluation is used to forecast the performance of a product, particularly its impact on users, and is commonly used for products set to be launched in the near future. On the other hand, impact assessment evaluates the effect of a law, environmental measure, or new technology on society on a larger scale. However, the methods used for impact assessment are often not tailored to individual products and are limited to known populations, which restricts their usefulness to relatively short time frames. Futures studies and strategic foresight provide techniques and methods for exploring possible,

plausible, and probable futures in the long run. While the methods are not specifically designed for analyzing the social impact of a particular product, they can provide ways to address the temporal issues raised by product evaluation and impact assessment. Therefore, in this chapter, we aimed to explore the possibility of anticipating the social impacts of a disruptive product that does not yet exist on the market with a novel approach. We believe that we can use principles of future studies to create credible usage scenarios for the product. These scenarios could then be used as a context for questioning social sciences experts. In other words, our main hypothesis is that sociology experts can anticipate future social impacts by projecting themselves into the future, drawing on their knowledge and expertise.

To anchor our work to a concrete case study, we focus on autonomous vehicles (AV) as defined in Chapter 1. It should be noted that the socio-economic and environmental impacts, assessed in Chapter 3, are more and more studied, notably through numerical modeling. These impacts differ greatly from the social impacts we are interested in exploring in this chapter, because the limitations of current methods highlighted in the previous paragraphs have resulted in a lack of research on the social impacts of AVs (Chapter 2). Additionally, as Townsend (2020) points out in *Ghost Road*, existing quantitative studies may look good on paper, but they may not hold up in the real world. It is this gap that we aim to address with this work. Thus, the specific question:

**Research question No. 2: How to allow designers anticipate the possible long-term social impacts of autonomous vehicles?**

We attempt to provide an innovative impact model called Representation-Usage-Impact (RUI) that compiles and aggregates expert knowledge in sociology to anticipate the social impacts of autonomous vehicles.

In Section 2, we briefly explain the methodology we used to build the RUI impact model. We describe the steps we took to ensure the accuracy and robustness of the model. In Section 3, we present a detailed structure of the model, providing an overview of its components and the relationships between them. We also explain the rationale behind our design choices. Section **Error! Reference source not found.** details the addition of data, including expert input. We cover the specific data sources utilized, the process of validating and refining the data, as well as the significance of expert input in enhancing the accuracy and relevance of the model. In Section 4, we discuss and analyze the results, examining the nature of the data added and the ability of the model to gather various impacts from experts. Finally, in Section 5, we conclude on the potential of the RUI model to anticipate social impacts of autonomous vehicles and other disruptive products that do not yet exist. We summarize the key findings of our study and highlight the practical applications of the RUI model.

## 2. Methodology

We developed the Representation-Usage-Impact model in two main stages. First, we created a preliminary version using our knowledge and some research. Then, we submitted it to experts to receive feedback and further strengthen the model.

We began by conducting extensive research by consulting various scientific literature. Based on our findings, we carefully crafted a structure that would enable us to gather potential usages of autonomous vehicles from a variety of existing representations, such as concept cars or science fiction. By doing so, we were able to identify a range of possible usages, including working, exercising, and sleeping. These usages can be viewed as scenario components, which are an essential part of our model. Our goal was to present these components to experts so that they could project themselves into the future and envision the potential social impacts of autonomous vehicles. To achieve this, we defined and refined the concepts of representation, usage, and impact. Once we had established a clear framework, we began to develop a preliminary version of the model.

As we are not experts in social sciences, it was likely that the preliminary version of our model suffered from numerous methodological biases regarding sociology. Therefore, we have established a protocol to gather feedback from experts. The experts selected to review our model were primarily sociologists. However, we also expanded our search to include professionals in social sciences or individuals working with social mobility issues (specific criteria are shown in Section 3.7.2). To begin identifying these experts, we used multiple methods, including posting on Stellantis social media groups, interviewing researchers from our labs to identify potential experts of their network, searching on social science laboratory websites, and identifying research institutes working on mobility and its impacts, such as the *Forum Vies Mobiles*. After launching the solicitations, we obtained additional contacts through a "snowball effect," where experts recommended other experts who recommended further experts. To gather feedback, we designed an online questionnaire to capture constructive criticism. But to ensure that experts understand the issues, it was important to provide them with a clear explanation of the model. To avoid monopolizing the experts' time, we created a 13-minute video that presents the model concisely (the video is available as supplementary material 7). The questionnaire allowed us to identify the expert and collect their feedback in plain text or via video conference according to their preferences. It is important to note that the experts who responded to the questionnaire could intervene later to add impacts to the model (this part will be further explained in Section **Error! Reference source not found.**). The logical structure of the questionnaire is illustrated in Figure 41.



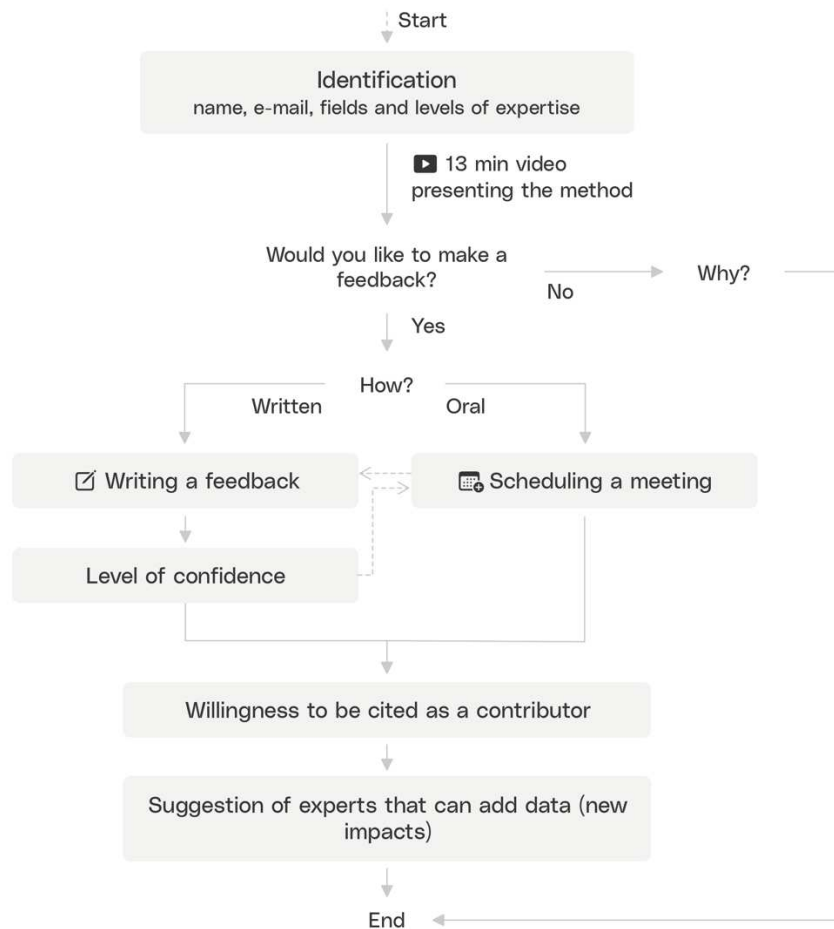


Figure 41. Logical structure of the questionnaire sent to experts.

We received feedback from nine experts, resulting in 17 distinct remarks. 6 of 9 experts provided fundamental/ major changes to the model: the inability to generate impacts without context (3 experts), and the lack of inclusion of experts from fields other than sociology (4 experts) (one expert mentioned both points). To classify the remarks according to their importance, we assigned five different tags to each: *Fundamental* (the validity of the model is being questioned, and a thorough revision is necessary), *Major update* (improvement of the model through a significant addition), *Minor update* (improvement of the model through minimal addition), *Assumed* (based on our choices and assumptions, we have not envisioned any update) and *Advices* (tips given by experts). Out of the 17 remarks, 9 were considered as assumed or advices, leaving us with 8 remarks to help us update the model. You can find the list of experts and all these remarks in the supplementary materials 8 and 9.

This allowed us to identify the strengths and weaknesses of the model. After incorporating experts' feedback, we improved the RUI model and finalized it. At this point, we had a more robust theoretical model. This final model is explained in Section 3.

## 3. The RUI model

### 3.1. Structure

Our main assumption when building the model was that sociologists, who are used to working with past or present phenomena, can use their knowledge to imagine possible long-term social impacts. There is no evidence on this subject (Grossmann et al., 2023). Thus it is a strong assumption. To meet this goal, the model needed to have several key features. First, it had to allow sociology experts to project themselves into future situations. Then, it had to collect, store, organize, and summarize the knowledge of these experts, and finally make it easy to access through specific queries. We used interconnected databases because they are well-structured and easy to update. Each database corresponds to an object for which we defined a specific format. The three main objects of the model are representations, usages and impacts. Representations include all resources that represent an autonomous vehicle (such as a concept car, a functional shuttle, or a science fiction movie). Usages are the basic actions made possible by the autonomous vehicle, such as sleeping or exercising in the vehicle. These usages are all extracted from the representations. Their purpose is to help experts project themselves into future situations. Lastly, Impacts are the likely consequences of usages according to experts, and corresponding to several social impact themes, such as health, well-being, or employment.

The model consists of a set of five interconnected databases (see Figure 42). The first one, *REPRESENTATION*, is used to store and organize various representations of the autonomous vehicle. The *EXTRACTION* database links usages to one to several representations. The *USAGE* database lists and characterizes all usages extracted from representations. The *IMPACT* database contains all information provided by experts for characterizing an impact. It is connected to the *INDICATOR* database, which stores and defines all indicators of social impacts.

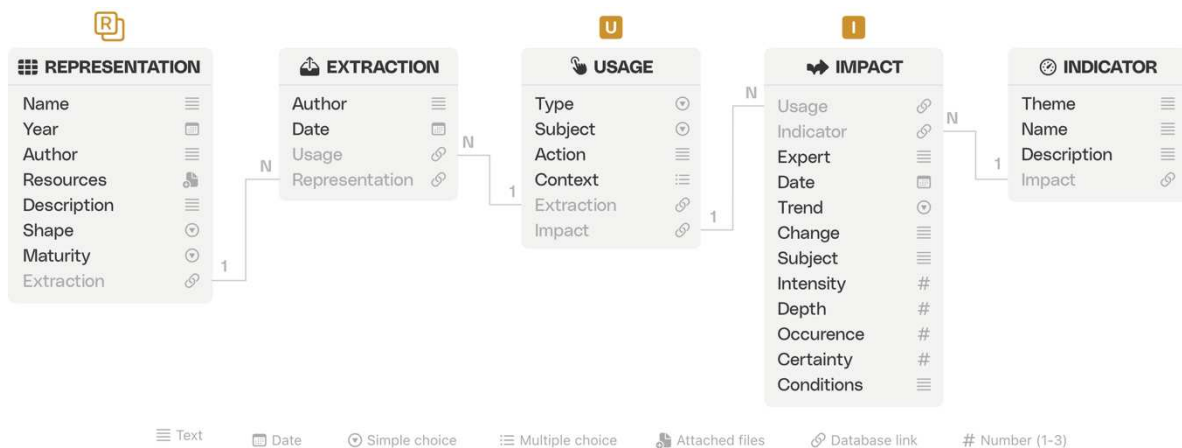


Figure 42. Databases and links of the Representation-Usage-Impact (RUI) model.

The following sections provide details on the databases, including the objects and attributes that make them up. We defined three ontologies for representations, usages, and impacts, and established a protocol for extracting usages from representations. We also created a protocol for adding impacts with the assistance of experts.

### **3.2. REPRESENTATION database**

Here we present a custom format to store, sort, exploit and trace existing representations of AVs that can then be used to extract usages. Exploiting many representations of different natures and origins as input material for our model seemed to be a good way of ensuring a large diversity of usages. This also helped to avoid biases we would have introduced if the usages came from our imagination. Using these representations to extract usages is further justified in Section 3.3.

A representation is a general category encompassing all types of artifacts, physical or virtual. It covers all types of externalization (Boujut & Laureillard, 2002). We have defined a representation by seven attributes: (i) The reference *Name* of the representation. (ii) The *Author* (company or person). (iii) The *Year* of publication. (iv) The *Resources* to illustrate the representation (image, internet link, video). (v) A brief, factual *Description*. (vi) The *Shape* that can be: Design fiction object; Concept ; Non-functional prototype ; Functional prototype ; Functional product ; Film / TV series ; Cartoons ; Book ; Internet article ; Magazine ; Comic book / Graphic novel ; Software / Video game ; Patent ; Imagined usage ; scientific work. (vii) The *Maturity*, inspired by Technology Readiness Levels (Tzini, 2015). The higher the level, the more realistic the representation is: (level 1) Fiction: No willingness to be realistic; (level 2) Project / Vision: Willingness to be realistic but does not exist; (level 3) Real: Exists.

These attributes were determined inductively based on 69 existing representations of autonomous vehicles found by internet searches or discussions with designers, engineers, or futurists. Figure 43 presents three examples classified by *Maturity*. For more examples, an extract of the database is available in the supplementary material 11.

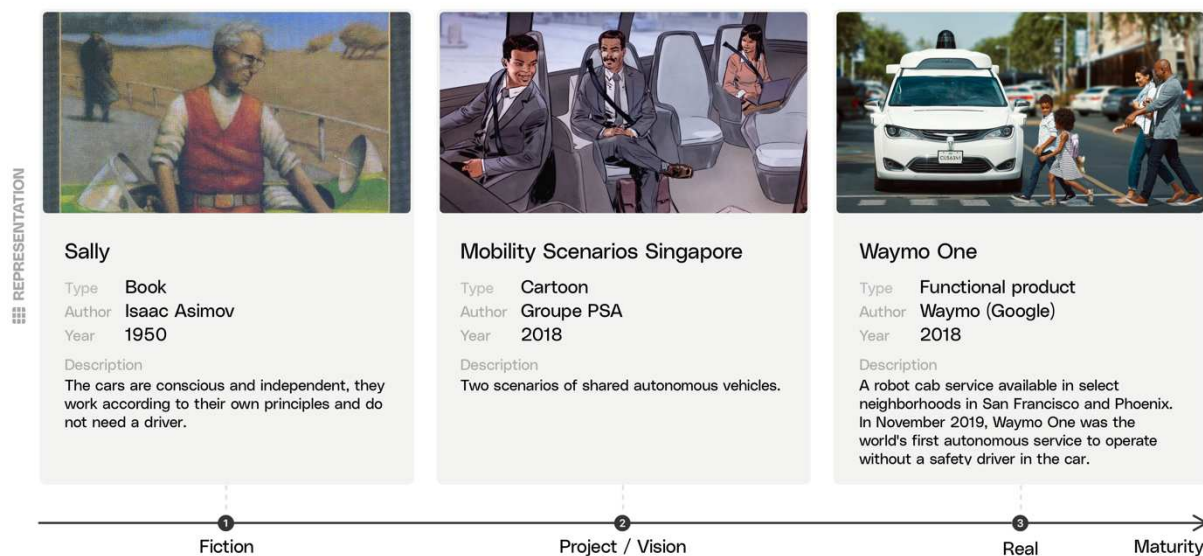


Figure 43. Three examples of representations (more examples in Supplementary material 11).

To list the 74 representations used to build the format, we did not aim for exhaustiveness, but for a good representativeness of the types of representations. Many of these representations are available in supplementary material 11. We did not set any constraint regarding the shape of each representation. Among the knowledge domains we found, we can count: Science fiction (Murphy, 2020; Fischler & Longfellow, 2020; Britt, 2016; Long, 2020), prospective documents, articles on AV history, articles on AV advances, reflections (Cherubini, 2014; Veritasium, 2021), field analysis at Stellantis, patents and legal documents, student productions in design school (*Strate memory*, n.d.) and scientific publications. Several keywords were also used in different search engines such as *Google*, *Google Images*, *DuckDuckGo*, and *Pinterest*. Here are some examples of keywords used: "Self-driving car," "autonomous car," "autonomous vehicle," "science-fiction," "prospective," "design-fiction," "ethics," "patent," "concept," "vision," "imagination," "scenario," and "robo-taxi."

The 74 representations are distributed into the three maturity levels: 18 fictions, 39 projects or visions, and 15 real vehicles (see Section 3.2 for details on the three levels). We audited the 74 representations and classified them qualitatively as utopian, dystopian, or indeterminate. We found that about half of the representations lacked nuance, with 35 being polarized (classified as utopian or dystopian) and 39 being nuanced (classified as intermediate). The lack of nuance is particularly evident in representations from companies promoting their ideas as ideal uses and in science fiction depicting autonomous vehicles as sources of problems. However, there are still numerous nuanced representations in various forms and levels of maturity. We concluded that our 74 representations were nuanced enough to avoid extracting overly polarized usages from them.

The protocol for adding more representation involves two steps: (a) identifying a representation that could present at least one potential usage of the AV, and (b) completing the seven attributes. We did not impose many constraints on adding representations, as our goal was to maximize diversity, much like a divergent phase in conception. As a result, we have not formalized a detailed protocol.

### **3.3. *USAGE* database**

Scenario approaches, which are used in future studies, are known for addressing complex and uncertain issues (Mcgrail & Idil Gaziulusoy, 2014). Many works on scenarios attempt to envision the future of transportation (Gazibara, 2011; Hannon et al., 2016; Kaufmann & Ravalet, 2016; Urry, 2016). Other approaches focus on individuals and their experiences. For example, Trommer et al. (2016) and Rohr et al. (2016) create stories called "a day in the life of [...]" to anticipate human factors and the evolution of social structures. However, due to the uncertainty we face, using detailed mobility scenarios (e.g. Fulton Suri & Marsh, 2000) is not suitable since they are generally adapted to known usages in known contexts. Instead, we chose to use simple steps called "usages," which allowed us to focus exclusively on new specific usage situations (see Bekhradi et al., 2017). According to the Larousse dictionary, a "usage" refers to the destination, function, or use that can be made of something. The weak point of this approach is that it may lose the subtleties associated with a full journey description (see Al Maghraoui et al., 2019a). Nevertheless, we believe that considering a complete scenario with autonomous vehicles would only add an additional degree of complexity without improving the plausibility of the scenarios. This loss of details is a limitation of the model (however necessary).

We created a format to describe how autonomous vehicles (AVs) could be used in a precise and clear way to assist sociological experts in projecting themselves into the future. Instead of using user-centered methods like focus groups, interviews, or user observations (Daae & Boks, 2015; Al Maghraoui et al., 2019b), which could not guarantee that imagined usages from today would be accurate 30 years from now, we used an inductive method. Preferring exhaustiveness over a hypothetically accurate but limited set of usage. We transcribed usages from 74 existing representations (see Section 3.2). The different sources, of various natures, have all allowed to consolidate the usage database. For example, the usage "the passenger works during the transport" was extracted from 10 representations that are concepts, storyboards and science fiction stories. We extracted 26 raw usages and analyzed them to identify a common usage format. This led us to four coding attributes: (i) The *Type* distinguishes new usages introduced by AVs from existing or potential usages that will be significantly impacted by their deployment. These usages are referred to as new and augmented. New usage refers to a usage that does not exist at the time it is being extracted. For instance, if a

vehicle picks up an object without any passenger, it is a new usage. Augmented usage, on the other hand, refers to a usage that already exists but has some new distinct elements. For example, moving from point A to point B with a vehicle while being the only passenger on board is an augmented usage. Although the usage itself is not new (since one can use a taxi service today), the fact that there is no driver is new. Therefore, the usage is considered augmented. The timeframe must be specified to accurately describe the usage. What may be new or uncommon now can quickly become commonplace in the future. The timeframe is established when a person extracts the usage from a representation (see *Date* attribute in the database *EXTRACTION* in Sections 3.1 and 3.4). (ii) The *Subject* attribute answers "Who or what performs the action?". It can be Vehicle, Passenger(s), or External person(s). Any action carried out by a vehicle is still serving a human. (iii) The *Action* attribute describes what the *Subject* does. An action is an infinitive phrase that describes a scene, a step, or an elementary task. It begins with an infinitive verb. For example, "Fetch an object" (for the subject: Vehicle) or "Work" (for the Passengers). When in doubt, we recommend to use the simplest subject-action pair. For example, use "the passenger sleeps" instead of "the autonomous vehicle allows the passenger to sleep". Additionally, it is important not to confuse the means of the action with the action itself. For example, if a science fiction representation shows an AV programmed to kill a person, the corresponding action is "to kill someone" and not "to hack the vehicle". An additional attribute named (iv) *Context* can be added. For example, sleeping inside a vehicle is already possible today, but if the action takes place during transportation, the usage is now augmented. The *Context* can therefore be: "there is only one person inside the vehicle." One or more contexts can be specified (logical AND). At this point, you may have noticed that *Subject*, *Action*, and *Context* follow a logical sequence similar to a sentence: subject, verb, complement. We made this choice to simplify the understanding of usages. Table 9 shows seven examples of usages.

Table 9. Seven examples of coded usages using the *Type*, *Subject*, *Action*, and *Context* attributes.

<b>Usage</b>	<b>Type</b>	<b>Subject</b>	<b>Action</b>	<b>Context</b>
Usage A	New	Vehicle	Go recharge / refuel	Without passenger
Usage B	Augmented	Passenger(s)	Sleep	During transportation
Usage C	Augmented	Passenger(s)	Go somewhere	The passenger can't drive
Usage D	Augmented	Passenger(s)	Go somewhere	The passenger is a minor
Usage E	Augmented	Passenger(s)	Do friendly collective activities	During transportation
Usage F	New	External person(s)	Hack and control the vehicle	
Usage G	Augmented	Passenger(s)	Drink alcohol	During transportation

### 3.4. *EXTRACTION* database

It is important for the model to include a traceability of information. So we have identified three questions to be answered: (1) "Where did this usage data came from?", (2) "Who was responsible for formatting it?", and (3) "When was the usage added?" We have created an intermediate database called *EXTRACTION* between representations and usages. This database allows for one or several representations to be linked to a usage and includes two attributes to help track the data. The first attribute (i) *Author* is for the author of the link, and the second attribute (ii) *Date* is for the date on which the link was entered. A usage can be linked multiple times to the same representation by different people. This new database allows for contextual information to be included in usage data to identify potential errors, such as improper formatting by a specific user. Figure 44 illustrates an example of the role played by the *EXTRACTION* database.



Figure 44. Example of usage extractions compiled into the *EXTRACTION* database.

### 3.5. *IMPACT* database

The impacts format was created to meet four conditions: (1) incorporate the nuances identified by sociologists, (2) align with social sciences, (3) be accessible to non-experts, and (4) allow for the addition of new social impacts on a regular basis. Our study is focused solely on the impacts that occur during the use phase of AVs. Impacts that result from raw material extraction or recycling are not included. Furthermore, impacts that are associated with the way users perceive things directly, such as motion sickness or lack of comfort, were not taken into account. This is because they depend on specific characteristics of the vehicle, which are mostly unknown at present (see Chapter 5).

There are different methods to describe impacts, such as the Logic Model (*Practical Concepts Incorporated*, 1979), the Theory of Change (Weiss, 1997), the Outcome Map (Earl et al., 2001), or the Impact Management Project (*The Impact Management Project*, 2022; Fox & Ruff, 2021). The Impact Management Project (IMP) is a forum that was established in 2016 to develop a global understanding of how to measure, evaluate, and

report impacts on people and the environment. Based on a survey of over 2,000 practitioners, IMP has defined five dimensions of impact: What, Who, How much, Contribution, and Risk (*Five Dimensions of Impact*, 2022). We have decided to adopt all dimensions of the IMP framework to define our impact format. Our approach was to draw inspiration from IMP and add new dimensions specific to the case of a disruptive product that does not yet exist on the market. We divided the four IMP dimensions into seven impact attributes to create the *IMPACT* database.

The first dimension is “What”, which makes statements about what is happening and includes one link to the database *INDICATOR*, (i) the *Trend* and the (ii) *Change*. The indicator is the variable that is likely to change with the arrival of autonomous vehicles, it is further described in Section 3.6. The evolution of the indicator is indicated by the *Trend* attribute, which can take two values:  $\uparrow$  = increase or improvement;  $\downarrow$  = decrease or deterioration. We chose not to add the option:  $\rightarrow$  = constant because it would no longer be an impact according to our definition (Chapter 2). The *change* attribute contains additional and optional information provided by the expert on the indicator and the trend (see Section 3.7.2).

The second dimension is “Who”, and details the individuals impacted. It has one attribute: (iii) the *Subject*, which provides Information about the person affected by the impact. The *Subject* may be different from the person specified in the usage database. For example, a passenger’s usage of AV may impact pedestrians. The question “Who is affected by the impact?” helps fill in this information.

The third dimension is “How much” and includes four quantitative attributes that can take discrete values between 1 and 3: (iv) The *Intensity* captures the evolution of the indicator if autonomous vehicles are deployed in comparison with today. Our approximation is that the contribution of AVs can be assimilated to the total intensity of change. It stems from the condition we imposed in the usage format: usages are either new or increased by the deployment of AVs. The intensity scale we have selected is as follows: “Low” (1/3), “Medium” (2/3) and “High” (3/3). (v) *Depth* captures the approximate share of people matching the subject description and affected by the impact. For example, for the usage “working in the vehicle during transport,” if the indicator and trend are “improvement in physical condition” and the subject of the impact is “regular AV user,” then the *Depth* may be low because not all regular users will necessarily exercise. The *Depth* is highly dependent on the definition of the subject. Its scale is as follows: “Very few people” (1/3), “Several people” (2/3) and “Everyone” (3/3). (vi) *Occurrence* concerns the likely frequency of the impact. It is comparable to the notion of occurrence defined in the failure mode, effects, and criticality analysis (FMEA) or to the notion of “likelihood” defined in the risk dimension of the Impact Management Project (IMP). The scale we have selected is as follows: “Rare” (1/3), “Often” (2/3) and “Systematic” (3/3). The final metric is (vii) *Certainty*. It measures the level of certainty the expert has regarding the causality between usage and impact. This metric



is crucial in calculating the level of uncertainty for each impact and is linked to the Risk dimension of IMP. We have developed a scale as follows "Very uncertain" (1/3), "Not very confident" (2/3) and "Rather confident" (3/3). For all these quantitative attributes, we did not start the scales at 0. Starting at 0 would suggest that there is no impact at all, which does not make sense. However, we added a positive extreme value to *Intensity*, *Depth*, and *Occurrence*: "High," "Everyone," and "Systematic," respectively. We were inspired by De Singly (2012), who stresses the importance of extreme values for questionnaires, even if they are less commonly used than other options. The exception is *Certainty*, because we do not believe it is possible to be completely confident about impacts that will occur in several decades, so the highest value on this scale ("Rather confident") is not considered certain.

The last dimension is "How", which connects the impact to one or more usages. This dimension is characterized by its link with the *USAGE* database.

In addition to IMP dimensions, we have added two attributes to track the data (similarly to the *EXTRACTION* database for representations and usages): (viii) the *Expert* who imagined the impact, and (ix) the *Date* when the impact was added. A last attribute named (x) *Conditions*, allows for contextualizing an impact. This optional attribute is defined by a sentence starting with "If" that describes a condition to be met for the impact to be valid, according to the expert who establishes the link. Experts who define several conditions can also add combinatorial logics (AND/OR logic functions). The purpose of this attribute is to allow experts to specify the context of the impacts they imagine. This is fundamental to properly frame the sociological analysis of a situation and limit the "rigid" aspect of our coding system. The significance of this final attribute is based on the first feedback from experts, as shown in the supplementary material 8. An example of *IMPACT* database data is shown in Figure 45.

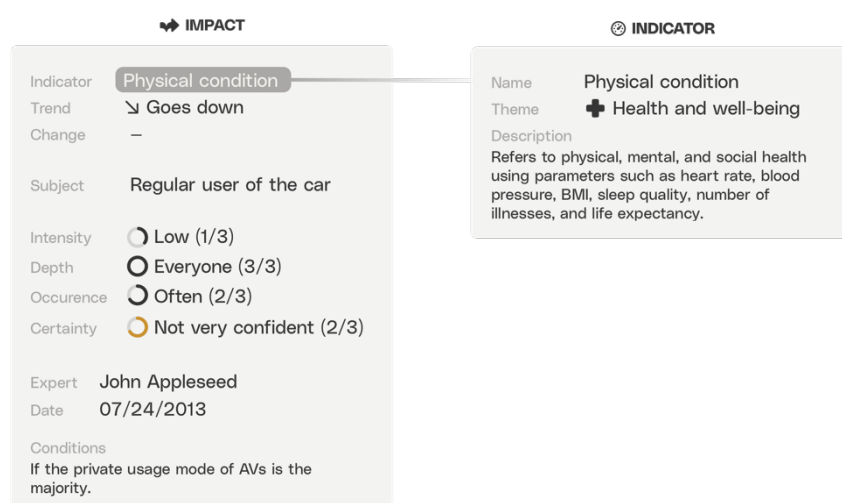


Figure 45. Example of impact linked to an indicator.

### 3.6. *INDICATOR* database

The Cambridge dictionary defines an indicator as follows: "something that shows what a situation is like." We have added to this definition that an indicator can be qualitative or semi-quantitative, must fall under a social impact theme, and must be able to increase or decrease. The following themes come from the work of Rainock et al. (2018) who proposed 11 themes intended to encompass most social impacts.

- **Population Changes.** Immigration and emigration, relocation of families, presence of a seasonal leisure population, arrival of temporary or permanent workers, and changes in the community's age structure.
- **Family.** Roles that families play in society, roles that individuals play within families, and stress factors that lead to tense family relationships.
- **Gender.** Gender norms and expectations.
- **Education.** Access to education, dissemination of information, new knowledge by using a product.
- **Stratification.** Categorization and hierarchization of groups of people (on economic, religious, racial plans).
- **Employment.** Professional opportunities.
- **Health and well-being.** Health, well-being, and safety ("a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" – Grad, 2002).
- **Human Rights.** The protection and promotion of rights that are presumed to apply to everyone. Opportunities or obstacles for disadvantaged groups. For example, improving the accessibility of people with physical disabilities.
- **Networks and communication.** Formation of new relationships or increase or decrease in the strength of relationships
- **Conflicts and crimes.** Activities that go against formal and informal community rules and conflicts between individuals.
- **Cultural Identity and Heritage.** Lifestyles developed by a community and passed down from generation to generation, including customs, practices, places, objects, artistic expressions, and values. For example, loss of language, desecration of sacred cultural sites, or violation of cultural taboos.

These 11 themes could be modified and additional ones could be added in the future, as necessary, based on the impacts anticipated by the experts.

The *INDICATOR* database lists attributes related to an indicator, including (i) the *theme*, (ii) the *Name* of the indicator, and (iii) the *Description*. The *Theme* is inspired by Rainock et al. (2018) and identifies social phenomena influenced by products and technologies. We have chosen 11 broad themes. Themes can give experts ideas (stimulation), as noted by Al Maghraoui et al. (2019b). Additionally, themes can help experts avoid imagining impacts beyond the scope of the study (refocusing). This can also aid experts in distinguishing between impact and usage (usage refers to an action made possible or increased by AVs, while impact refers to the influence of such actions

on people). A more detailed description of the 11 themes can be found in supplementary material 12 (in French).

The *Description* provides written information about the indicator to avoid any misunderstandings. Once these attributes are filled in, they never change because an indicator is permanently defined. In contrast, attributes in the *IMPACTS* database are informed for each data point added by an expert. That is why we have separated the two databases. An example of *INDICATOR* database is shown in Figure 45.

## 3.7. Adding data

### 3.7.1. Usage extraction

The extraction consists of identifying and then codifying a usage from a representation (see Figure 46). This process can be followed by any person trained to use the model and does not require any expertise. To add an impact, we propose some recommendations: The first step is to identify a potential usage in a representation. The second step is to check its correspondence with the four AV conditions presented in the Section 1: (1) The vehicle is primarily designed to transport passengers with the ability to transport objects. (2) The vehicle has a seating capacity of 1 to 9 seats. (3) The vehicle has an automation level of 4 or higher on the SAE scale. (4) The vehicle operates in a country with a high human development index ( $\geq 0.700$ ). It can be difficult to check these conditions because representations are sometimes not complete. In this situation: If one of the conditions has a clear negative answer (e.g. the vehicle has ten seats), then the usage should be rejected. If all four conditions have no clear answer, it is allowed (but not recommended) to add the usage. If at least one condition has a positive categorical response and all the others do not have a clear one, it is recommended to add the usage. Figure 46 shows a flowchart summarizing how to add a usage to the model.

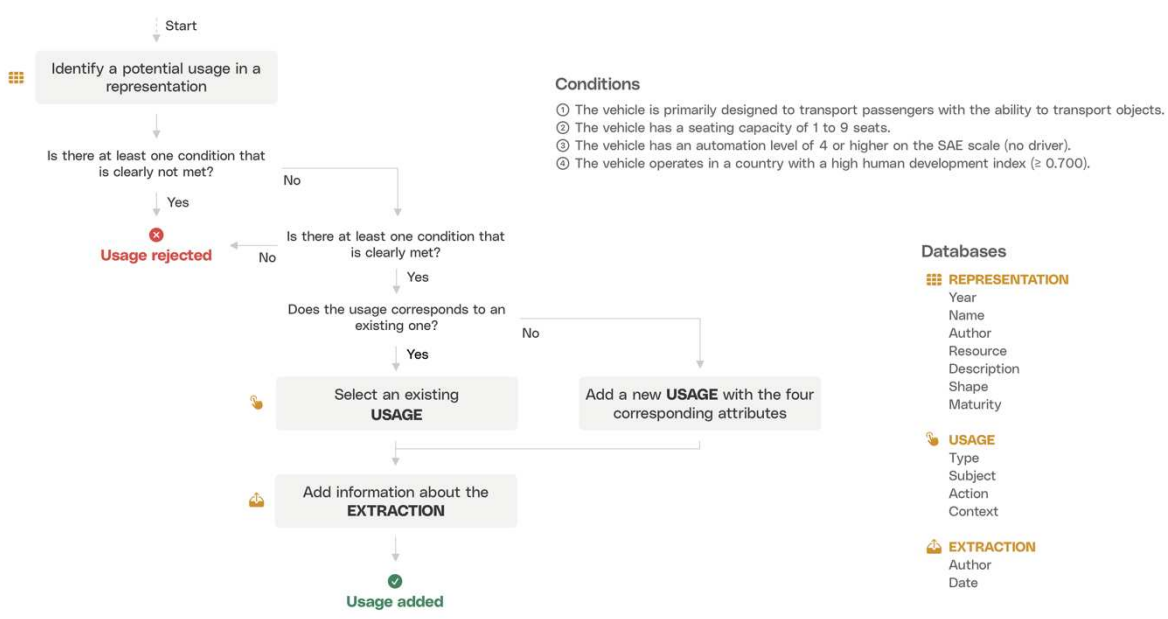


Figure 46. Flowchart to follow to add a usage to the RUI model.

It is important to note that there may be a bias in the extraction of usages. The person conducting the extraction may unintentionally exclude unexpected, diverted, or taboo usages (such as intimate relationships within the AV or illegal exchange of goods). This phenomenon can be worsened by the fact that the name of the person extracting the usage is recorded. Hence, we suggest that individuals extracting usages be aware of this potential bias and take it into consideration during the extraction process. An example of the process for adding a usage is presented in the supplementary material 10.

We then extracted a total of 36 usages from 39 representations following the protocol described in Figure 46.

### 3.7.2. Impact addition

The RUI model focuses on determining social impacts, which is why we give priority to involving social scientists. We believe they are the most competent and concerned in determining this type of impact. We also sought experts in Social Impact Assessment (SIA) or Social Life Cycle Analysis (S-LCA). These experts have experience with a wide range of social impacts, which can complement the specialized views of sociologists. Additionally, we considered researchers who have worked on social impacts in the mobility field. To diversify points of view, we expanded our search to include experts in the 11 selected themes of social impacts. For example, for the theme "health and well-being," we included doctors and psychologists, for "demographic changes," we included geographers and urban planners, and for "human rights," we included lawyers. We did not include designers, futurists, artists, or science fiction authors because we assume that their strength lays in imagining futures rather than establishing rigorous causal links between a situation and its social impacts.

We have defined a list of criteria below. To be selected, each potential expert must satisfy at least one of these criteria.

- **Sociologists.** We think they are the most capable and qualified to evaluate social impacts.
- **Impact assessment or social impact assessment experts.** These experts have knowledge of a wide variety of social impacts, which can complement the specialised visions of sociologists.
- **Researchers on social impacts in mobility.** Some researchers work on social impacts in the field of mobility. They are familiar with this type of impact and with the issues and trends in mobility.
- **Expertise in one of the 11 themes of social impacts.** The social impact themes we have chosen are not solely related to sociology. Other people whose expertise pertains to one of these themes could also provide valuable information.

To consult experts, we initially considered two options: conducting semi-structured interviews or proposing an online questionnaire. We chose the online questionnaire because it is more convenient for busy people and allowed us to interview more experts in less time. This approach also uses a consistent questioning protocol to ensure that all experts have the same information and understand the subject equally. Participants fill out the questionnaire themselves, which saves time and makes the process easier to implement in a company without requiring a trained experimenter. The questionnaire approach has its advantages, but it also has some limitations when compared to interviews. First, experts cannot be guided or corrected in real-time, which may result in off-topic answers. Second, oral communication allows for more subtle nuances to be expressed. During an interview, the experimenter can also assist the expert in explaining and reformulating certain subtleties. Finally, scheduling appointments for interviews allows for a specific time slot during which experts can concentrate on the task at hand. With a questionnaire, people may not take the time to block out time to respond. We took these limitations into consideration when designing the questionnaire but attempted to reduce their impact by testing it with ten non-expert participants before launching the final version.

To build the questionnaires, we used *How to Use Qualitative Methods in Evaluation* by Quinn Patton (1987) and *Le questionnaire* by De Singly (2012). The process of adding usage-impact links to databases is made of two steps: (1) presenting usage scenarios to experts and collecting the impacts they imagine through the questionnaire, and (2) coding the data provided by experts to the databases, after the questionnaires are filled out. Dividing the process into two steps allows for more flexibility in constructing questionnaires with open-ended questions adapted to the nuances that experts may want to express. It enables experts to provide more contextualized impacts and greater depth of insight. Moreover, populating databases can be a tedious and error-prone task, particularly for people with limited understanding of our model.

When creating the questionnaire, we defined three main drivers to ensure good quantity and quality of impacts:

1. Motivate experts to answer the questionnaire.
2. Keep the filling time short to avoid experts losing patience.
3. Have several different experts treat each usage.

We created an easy-to-complete online questionnaire to gather impacts from a set of usages within a specific timeframe (named session and lasting one week). Each session has the following characteristics: A specific number of usages are set. Each participant evaluates five usages. Enough participants are included to ensure that each usage is evaluated by a single group of three experts (See Table 10). Table 10 shows how the usages are randomly distributed among the 6 experts of one session. Here we can deduct from the table that expert 4 handles usages 1, 7, 8, 9, and 10.

Table 10. Example of distribution of usage among experts within a session.

Usage	1	2	3	4	5	6	7	8	9	10
Experts	1, 4, 5	1, 5, 6	1, 2, 5	1, 2, 6	1, 2, 3	2, 3, 6	2, 3, 4	3, 4, 6	3, 4, 5	4, 5, 6

From the perspective of the participant, there were two phases involved. The first phase was registration, which required watching a brief presentation video of the experiment (a video is provided as supplementary material 7). After that, participants could choose to register or not. Registration involved providing personal information such as name, first name, email address, company, and areas of expertise, and consenting to the storage of this data as part of the experience (in compliance with GDPR, see supplementary material 14). Finally, participants had to select one or more sessions.

The second phase was the session in which the impacts were imagined. At the start of each session, every expert was assigned a unique list of 5 usages. To begin filling in an impact, they simply needed to click on the corresponding usage in the e-mail we sent them (Figure 47).

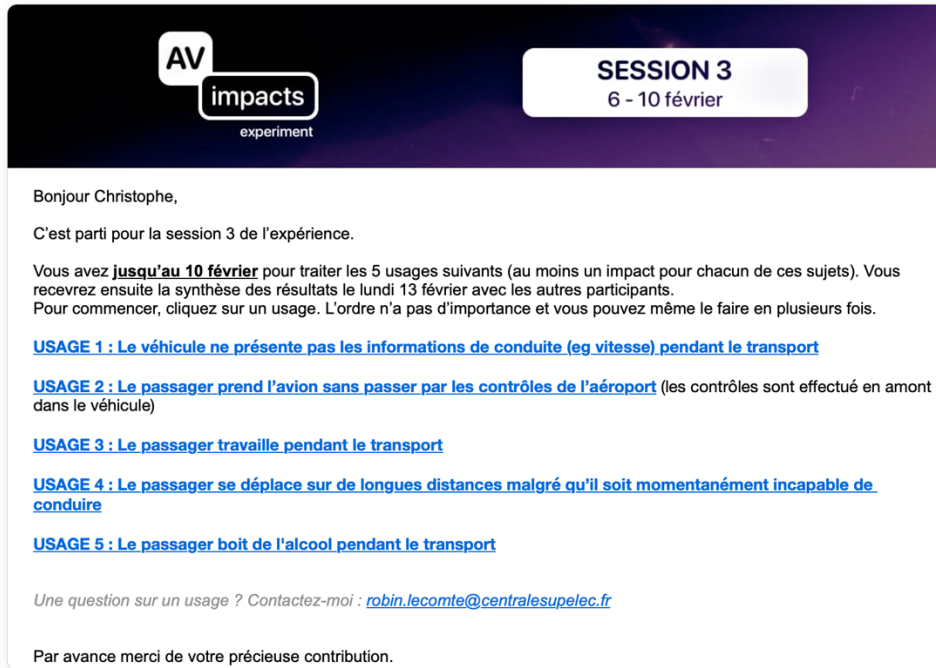


Figure 47. Solicitation email sent to a participant proposing 5 usages to be addressed.

Each hyperlink led to a questionnaire specifically generated for the participant, so he/she did not need to provide its personal information again. The participant could indicate several impacts per usage. The questions are presented in Table 11. Two types of questions were distinguished: closed and open-ended. Closed questions required respondents to choose from pre-formulated answers, while open-ended questions allowed respondents to answer freely (De Singly, 2012). The questions were formulated to be clear, specific, and singular (Quinn Patton, 1987, p124).

Table 11. Set of questions asked in a questionnaire (for each usage clicked by an expert); \* mandatory.

Number	Title	Subtitle	Variable	Question type	Attribute
1	Impact theme*	Which social impact theme does the impact belong to?	Selection from a list of 11 themes	Closed	Theme
2	What will change with this usage?*	In comparison to today	Free text	Open-ended	Change
3	Who is affected by this impact?*	/	Free text	Open-ended	Subject
4	What are the conditions that make this impact possible?	Optional contextual elements (e.g. private vehicle, urban environment, disappearance of parking lots in the city...)	Free text	Open-ended	Conditions
5	Intensity of the impact*	Impact on the people involved	1 = Low 2 = Medium 3 = High	Closed	Intensity

Number	Title	Subtitle	Variable	Question type	Attribute
6	Occurrence of the impact*	Probability of the impact occurring, assuming that the usage has become tangible enough for the people involved	1 = Rare 2 = Often 3 = Systematic	Closed	Occurrence
7	Depth of the impact*	Percentage of people affected by the impact	1 = Very few people 2 = Often 3 = Systematic	Closed	Depth
8	Your level of certainty*	Self-evaluation	1 = Very uncertain 2 = Not very confident 3 = Rather confident	Closed	Certainty

We have chosen a combination of closed and open-ended questions to take advantage of their respective strengths. Closed questions are easier to categorize, while open-ended questions give experts more freedom to respond (Quinn Patton, 1987, pp. 19 and 38). This aligns with the reasoning behind the *Conditions* attribute of the *IMPACT* database, which addresses the importance for experts to contextualize impacts (refer to Section 3.5). The advantage of using the questionnaires is twofold: the expert does not need to learn how to code an impact, and he/she can add whatever level of detail he/she wants. Additionally, we provided theme sheets to experts (inspired by Traverso et al., 2021). These sheets include examples and extra resources. They serve two purposes: to prevent off-topic impacts and to inspire experts. You can find all 11 sheets in the supplementary material 12 (in French).

After the session, each participant who responded to the 5 assigned usages received a summary of the results in a PDF document as a “reward” for their participation. Our goal was to share answers from other participants to fulfill their curiosity and assist them in finding experts to share ideas with. The document showed the impacts generated during the session, classified by usage and impact theme. The final page contained the participants' contact details, but the impacts were not linked to their creators. This approach was chosen to avoid any influence on the interpretation of the impacts due to the author who imagined them. The experts received this document via grouped email, so they could get to know each other and possibly exchange ideas. This summary provided important information and opportunities for experts to gain knowledge and contacts. Three syntheses are available in the supplementary material 15 (in French).

After the session was completed, we coded the information obtained from questionnaires into the appropriate databases. As De Singly (2012) pointed out, the coding process involved translating interviewee free text into digital language. Since the questionnaire included open text fields (*Change*, *Subject*, *Conditions*), coding this data was more complex than closed questions, as it required interpretation to establish connections within the databases. Figure 48 displays the correlations between the retrieved data (*RAW IMPACT*) and the *IMPACT* and *INDICATOR* databases of the RUI model.



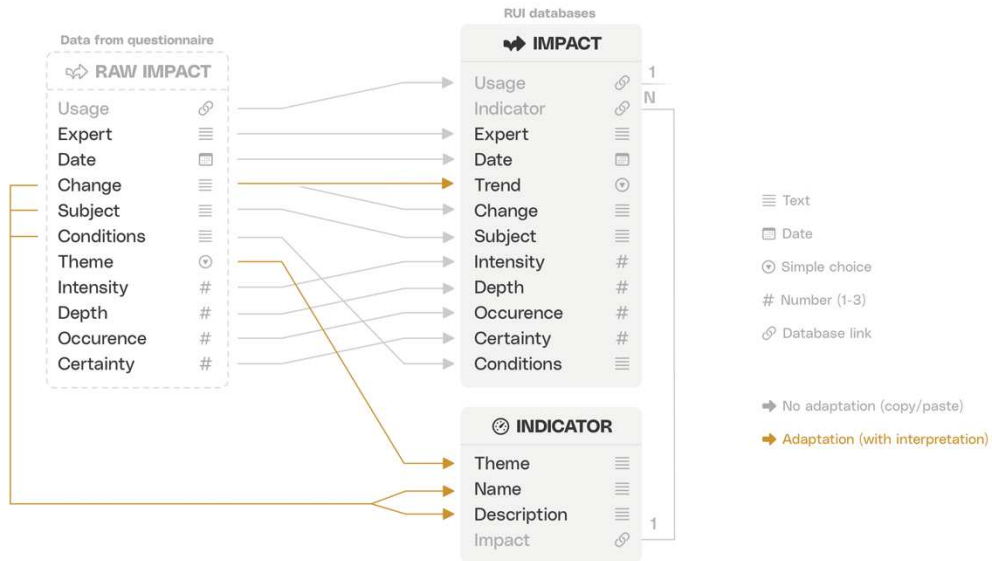


Figure 48. Graphical representation of coding impacts extracted from questionnaires in the *IMPACT* and *INDICATOR* databases.

To summarize the different steps to follow to add new impacts to the RUI model, Figure 49 presents a recapitulative flowchart.

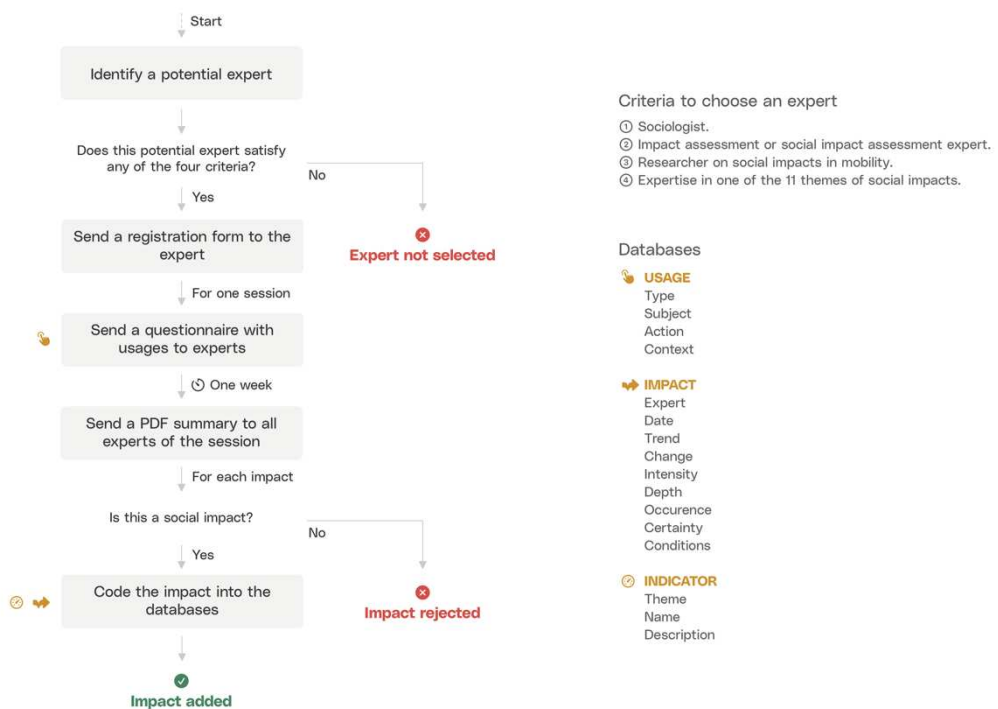


Figure 49. Flowchart to follow to add an impact to the RUI model.

All the sessions we conducted lasted for one week each, covered 10 usages, and involved at least 6 experts. We organized three sessions to complete the databases. Given the difficulty of finding experts willing to give their time, each of them could register for multiple sessions. In total, we contacted 55 experts who met the criteria by email. 16 experts signed up for the different sessions (7 women and 9 men). There were 6

sociologists, 4 experts in ergonomics, 3 experts in law or regulation, 2 experts in psychology, 2 in mobility behaviors, and 2 in urbanism. Some cumulated multiple expertise. Details regarding the confidentiality of personal data are provided in the supplementary material 14.

### Results for each session

The three proposed sessions took place between January 23 and February 10, 2023.

- SESSION 1 — From January 23 to 27
- SESSION 2 — From January 30 to February 3
- SESSION 3 — From February 6 to 10

Out of the 6 experts registered for SESSION 1, we got 49 impacts from the list of 10 usages in session 1. Nine impacts were rejected because they were not social impacts.

Out of the 7 experts registered for SESSION 2, we got a total of 51 impacts from the list of 10 other usages. Three impacts were rejected.

Out of the 9 experts registered for SESSION 3, we got 39 impacts from the list of 10 other usages. Two impacts were rejected.

### Overall results

Of all the sessions, 139 impacts were selected. 14 were rejected. Out of the 30 usages presented to the experts, 24 were treated by at least three different experts (80%). Among the remaining six usages, five were treated by two experts and one by a single expert. Figure 50 shows the number of different experts per usage.

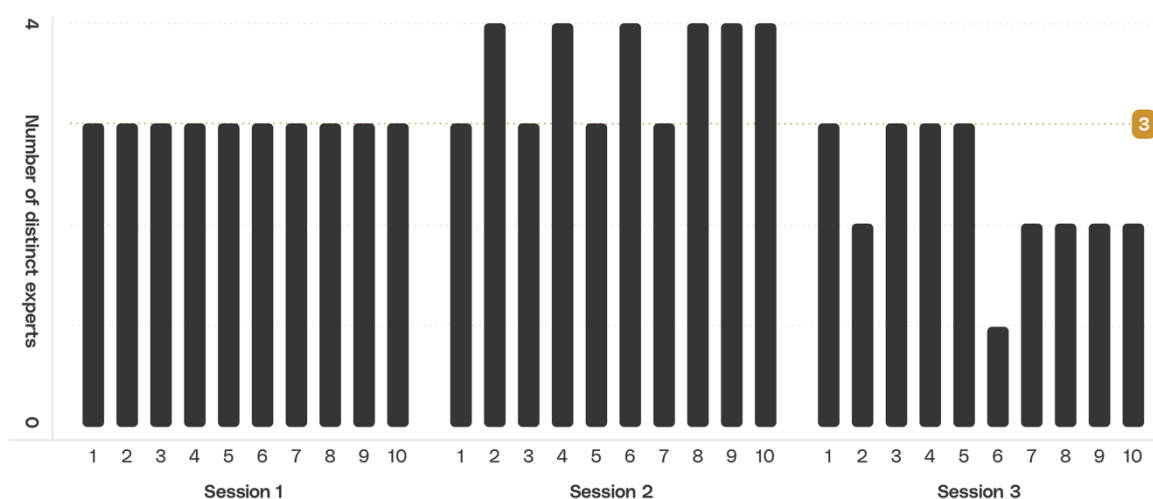


Figure 50. Number of different experts who have dealt with each usage (each usage is identified by a session and a number).

In Figure 51, it can be observed that the themes with the greatest impact are *health and well-being* and *conflicts and crimes*, with 40 and 37 impacts respectively. The theme of *gender* has no impact (although 7 women participated). The significant presence of the theme of *conflicts and crimes* (the category with the most indicators, 23) suggests that

the failure modes and unforeseen uses of autonomous vehicles have been taken into consideration, as concerns raised by sociologists interviewed in Section 2. Participant V, an expert in law who works on topics such as crime and prison, is not responsible for the results of the *conflict and crimes* category, because he provided only 38% of impacts in the theme. We also calculated that on average, each specific indicator was handled by 1.5 experts, meaning that several experts imagined similar impacts without consulting each other.

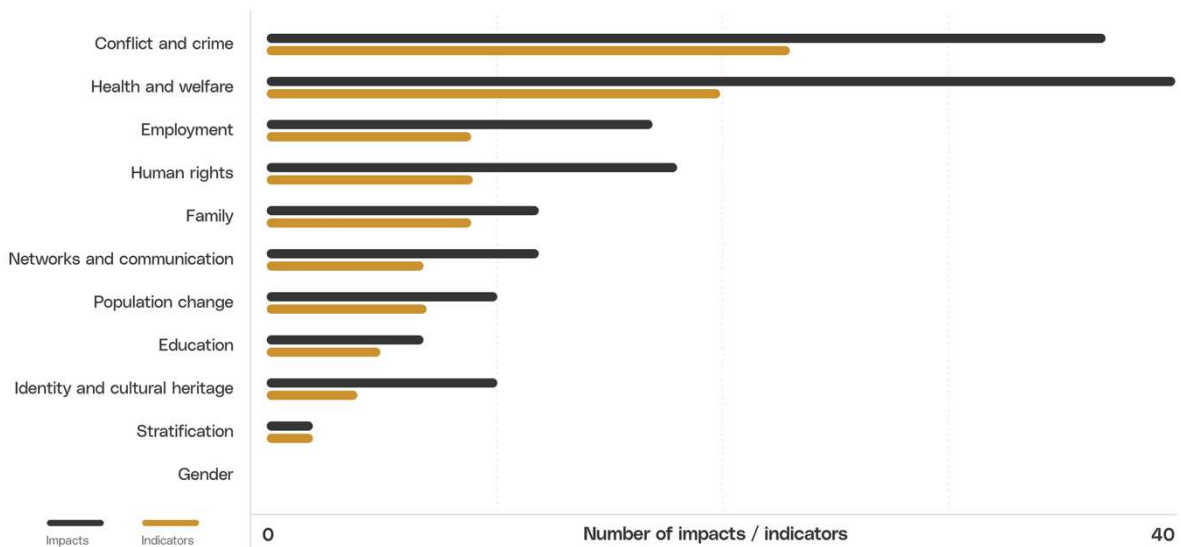


Figure 51. Number of impacts and indicators per theme.

Out of the 17 experts who registered, 16 participated. Some experts registered for multiple sessions. Figure 52 displays the number of contributions of each expert, as well as the number of sessions they participated in. It is evident that participants V and D were the most active participants. As a result, they have the greatest influence on the results (they account for slightly over 50%). They are also the two individuals who provided the most detailed responses.

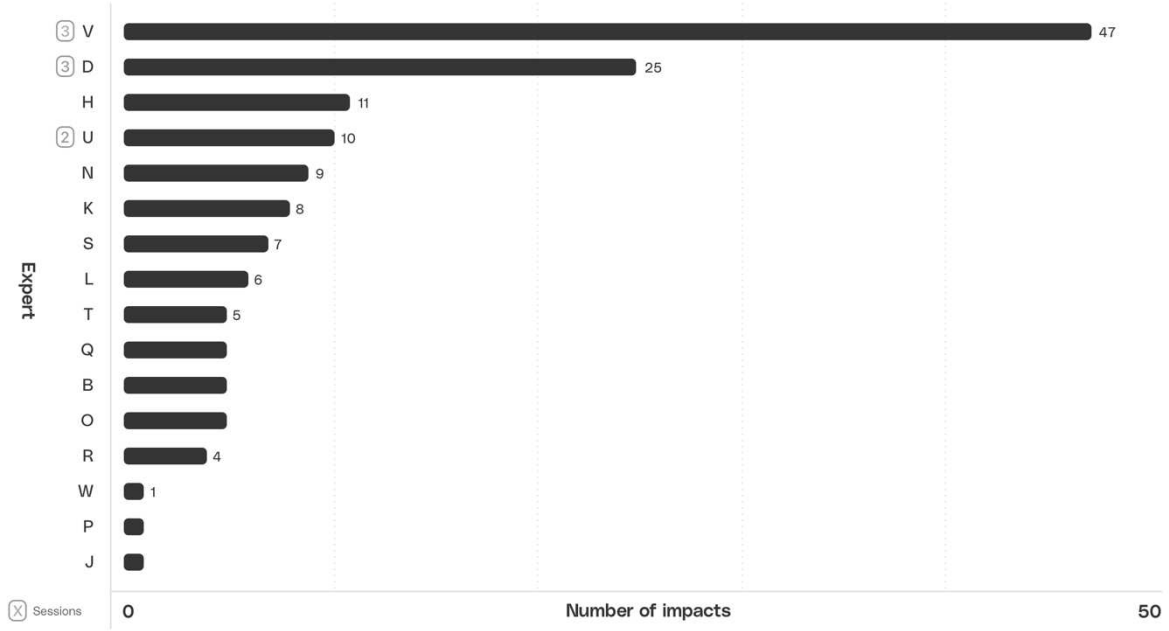


Figure 52. Number of impacts per expert.

Additional details about participants are available in the supplementary material 9. The number of impacts per usage is shown in Figure 53.

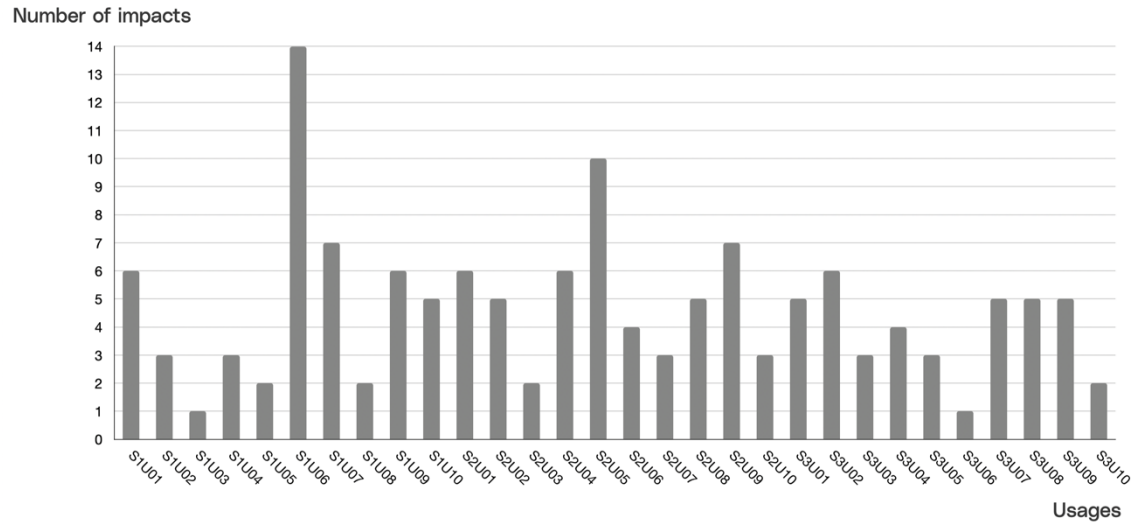


Figure 53. Number of impacts per usage.

### Examples of impacts

With all the accumulated data, it is difficult to conduct a comprehensive analysis of the results. We have chosen to take a few examples here by analyzing three usages. We selected the three usages with the highest impact/indicator ratio (*r*) to show the greatest aggregated results. The three selected usages are presented in Table 12.

Table 12. Selected usages to query the model.

ID	Usage	Impacts	Indicators	r
S2U04	The passenger communicates with the passengers of nearby vehicles during transportation	6	3	2
S2U10	The passenger performs personal tasks during transportation (e.g. a shopping list).	3	2	1.5
S1U09	A person from outside the vehicle kills someone by taking control of the vehicle	6	4	1.5

Below are some examples of statements obtained querying the model. Raw results are available in supplementary material 16.

- If the AV allows the passenger to communicate with passengers in surrounding vehicles during transport, then it could be easier to report a problem (according to one sociologist and urban planner).
- If the AV allows the passenger to communicate with passengers in surrounding vehicles during transport, then it could significantly promote insults and threats among road users (according one expert on ADAS ergonomics innovation).
- If the AV allows the passenger to communicate with passengers in surrounding vehicles during transport, then the number of social interactions could increase moderately (according to two sociologists and one ergonomist). Another sociologist thinks that the number of social interactions will not be impacted.
- If the AV allows the passenger to perform personal tasks during transport (e.g. a grocery list), then this will significantly increase the pressure on the passenger to perform more activities (according to two experts).
- If the AV allows the passenger to perform personal tasks during transport (e.g. a grocery list), then the available free time will be significantly and systematically increased (according to one expert).
- If an outsider can kill someone by taking control of the AV, then there will be a significant increase in the number of accidents (according to one psycho-ergonomist and specialist in mobility innovations).

These statements are given solely based on the attributes *Indicator*, *Trend*, *Intensity*, *Occurrence*, and *Expert*. However, it is possible to go much further by considering, for example, the *Certainty*, the *Depth* or the textual details given by the participants (*Change*, *Subject*, *Conditions*). Supplementary material 16 provides more details.

## 3.8. Using the model

The database structure of RUI allows for the use of queries to extract results. There are two types of queries: (1) Queries to obtain a list of possible impacts resulting from selected usages. (2) Queries to obtain a list of usages likely to generate selected impacts. The first type can provide insight into the potential impacts of a concept. The second type, on the other hand, can help identify usages that are likely to generate undesirable impacts. To visualize how these consultation modes may be used, a graphic interface prototype is presented in a video available in the supplementary material 13.

Different notations have been assigned to the quantitative attributes in the impacts database. The *Trend* is noted  $T$ , *Intensity*  $Q_I$ , *Occurrence*  $Q_F$ , *Depth*  $Q_D$ , and *Certainty*  $q$ . The modalities for the *Trend* are -1 (decreasing) and +1 (increasing). The modalities for the other attributes are 1, 2, or 3 (see Table 11).

### 3.8.1. Type 1: Impacts from usages

The first type of query involves selecting one or multiple usages and obtaining a list of potential impacts. The database may possess several impacts that are related to the same indicator. With a simple query to the databases, this could lead to displaying many impacts, especially when multiple usages are selected. Therefore, we have established aggregation formulas to provide a single aggregated impact by combining data for each indicator. Figure 54 provides an idea of what could be an impact aggregation interface.

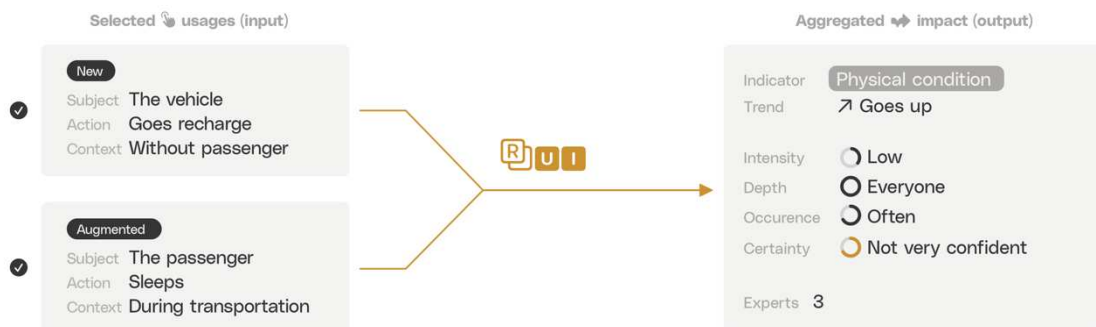


Figure 54. Idea of impact aggregation interface. This idea played a role in the development of the AutoVision tool presented in Chapter 5.

To aggregate the five metrics, we established weighted averages based on the level of certainty. The average trend is weighed by both *Intensity* and *Certainty*. For complete details on the aggregation modes and formulas, please refer to Chapter 5 where we define the AutoVision digital tool.

Moreover, because all usages are linked to existing representations, it is also possible to select one of them as input to obtain the corresponding impacts.

### 3.8.2. Type 2: Usages from impacts

The second type of query involves selecting one or several indicators and assigning a trend (positive or negative) to each. The goal of the model is to calculate the list of usages most likely to generate this selection. To do this, we define the average influence ( $M_u$ ) of a usage on the selected impacts. This metrics is calculated using the average trend weighed by both intensity and certainty. Thus, for a given usage, a positive average influence tends to favor the selected impacts, while a negative influence tends to prevent them. Figure 55 provides an idea of what could be an usage aggregation interface.

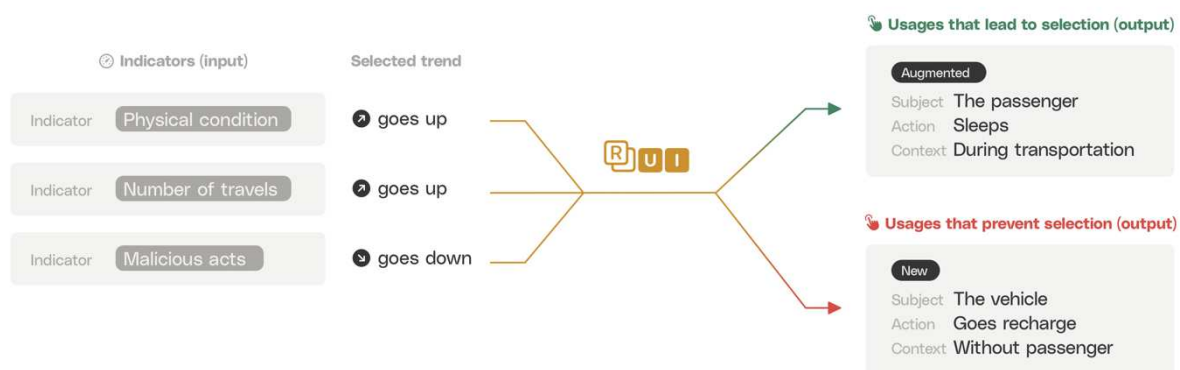


Figure 55. Idea of usage aggregation interface. This idea played a role in the development of the AutoVision tool presented in Chapter 5.

For complete details on the aggregation modes and formulas, please refer to chapter 5 where we define the AutoVision digital tool.

## 4. Discussion

After adding the initial dataset to the RUI model, we put the model into practice and obtained some preliminary results. Our analysis prompted several questions, which we address below.

First, observing the results, we can highlight limitations related to our questionnaire approach. Out of a total of 151 impacts, we obtained 14 off-topic responses. While this value is low, it is significant (9%) and shows that the questionnaire can lead to misunderstandings and off-topic responses, unlike face-to-face interviews. However, we think the questionnaire approach allowed us to establish more valid connections (139) in a shorter time span than we would have through interviews. In addition, we identified five response delays across all three sessions, despite having a clear deadline of one week for each session. The absence of a blocked time slot in participants' schedules, as with an interview, may explain these delays. Although these delays were

predictable, they did not significantly hinder obtaining results. All participants, with few exceptions, responded quickly after the deadline (within a few days).

Second, in a qualitative interview, it is generally advised for the experimenter to adapt the vocabulary of their questions to their interlocutor (Quinn Patton, 1987, p124). Here, we invited experts in sociology, psycho-ergonomics, urban planning, etc. to answer the same questionnaire. As their fields are different, the concepts and terms used could have been understood differently. We observed this limitation through questions that three participants asked by email and by phone (one of whom preferred to withdraw from the experience for this reason). Ideally, we should have adapted the questionnaires to each expertise.

Third, asking open-ended questions in a questionnaire makes the responses highly dependent on the experimenter interpretations during coding (De Singly, 2012). Therefore, it is possible that some indicators do not perfectly match the nuanced responses of the participants. It is important to take this limitation into account.

Fourth, it should be noted that the objective of obtaining responses from at least 3 different experts per usage was not achieved (24 out of 30). This can be explained by an overestimation of the participants' ability to effectively respond to all usages. Session 2 showed that by adding a complementary participant, the chances of meeting (or exceeding) the objective could be maximized. As a recommendation, it would be wise to include more redundancy in the distribution of usages in order to compensate for unforeseen circumstances that prevent some participants from addressing their five usages.

Fifth, the three sessions allowed us to identify 151 impacts (of which 139 were validated). We initially aimed for 30 impacts per session (10 usages  $\times$  3 experts), which makes a total of 90 impacts minimum. The objective was exceeded by 54%, thanks to the participants who did more than what was asked of them. This shows that the participants generally followed the instructions and that some even got into the game by providing additional responses (especially participants V, D and H). This interest indicates that our approach was not too tedious for the experts.

Sixth, among the 11 themes of social impacts, we noticed the prevalence of the themes of *health and well-being* and *conflicts and crimes* both in terms of impacts and indicators. To explain this result, we can consider the following hypotheses: Perhaps these themes are easier to understand than themes like *demographic changes* or *stratification*. Perhaps they are more generic than others, or perhaps they are more related to a usage-based approach. For example, it may be difficult to link an activity performed in a vehicle to population stratification, whereas impacts on health or well-being may be more evident. On the other end of the spectrum, the themes of *gender* and *stratification* did not receive much impact, if any at all. The previous hypotheses also apply to them. The remaining 7 themes are of the same order of magnitude in terms of



impacts and indicators. This shows that despite some extremes, the themes are rather well distributed. However, we think that the number of impacts is still insufficient to decide whether to remove the least treated themes or to justify adding others. However, this could mean that we need to better describe the themes in a future version (like Traverso et al., 2021). For instance, a subdivision of the themes *health and well-being* and *conflicts and crimes* into sub-themes.

Seventh, common trends on indicators given by several experts were identified. For example, for the relationship between the usage "The passenger communicates with passengers of surrounding vehicles during transport" and the indicator "social interactions", three experts believed that the trend would be positive (increase in social interactions), while another expert thought that social interactions would not evolve. Being able to access the nuances mentioned by the experts allowed for a more detailed understanding of the reasoning at work. However, the complexity of the results could make their exploitation tedious and complicated for a novice person. Moreover, some terms may be misunderstood, such as the occurrence or scope of impacts, leading to misunderstandings in the interpretations.

More generally, the RUI model presented here is based on the idea that interviewing sociologists is a good way to gain knowledge about the potential social impacts of a disruptive product that doesn't exist yet on the market. Unfortunately, this hypothesis cannot be validated as is, due to the inability to determine with certainty the long-term social impacts of autonomous vehicles and to compare them with the forecasts of the model. This has forced us to build the model in an open loop. This is why we co-constructed it with 9 experts from the fields of social sciences. By doing so, we made sure to limit as much bias as possible and reinforce the model to the best of our ability. We have noted additional limitations with the help of the nine experts. Some of the issues appear to have been addressed when we analyzed the initial data added to the model. For example, (1) experts said that the representations and usages may lack subtlety and may not accurately reflect current states of mind. To address this, we have increased the number and variety of representations to create a nuanced set of more than 70 various representations (see Section **Error! Reference source not found.**). (2) Experts have warned that taboos and misuses of the product may not be anticipated enough. However, the number of impacts related to the theme *conflicts and crimes* seemed to show that these impacts are well taken into account (Figure 51). (3) It can be difficult for experts to precisely link usages and impacts without context. As the context in which each usage will take place is unknown, this challenges our approach of linking usages to social impacts directly. To address this, we have added a *context* attribute to the *IMPACT* database. Out of the 139 impacts in the model, 122 include a context added by experts, demonstrating its importance. (4) Expert selection bias can be strong. It refers to systematic errors made when selecting experts, leading to a lack of representativeness. To partially address this bias, we have set criteria to ensure that

each usage is reviewed by multiple experts (coverage of usages, see Section 3.7.2). However, we have no way of verifying the complete disappearance of this bias. We believe that this problem should decrease as we consult more experts, as the questionnaire is easy and quick to respond to (eg. an expert can respond to it in 2 minutes on the subway). Additionally, in the future, other problems should be investigated, such as: (5) The evolution of user constraints compared to today's, which usages alone may not be sufficient to anticipate, also acknowledged as a limitation. (6) The use of elementary usages rather than complex mobility scenarios, which deprived us of anticipating the impacts that could arise from a chain of several usages, also acknowledged as a limitation. (7) The model was not developed as a full-fledged design tool adapted to design processes. Therefore, integrating the RUI model into a functional tool would be the next obvious step to test its utility. This tool could add advanced query methods, such as case-based reasoning (Riesbeck & Schank, 1989; Leake, 1996; Kolodner, 2014), and include confidence attributes for experts, usages and impacts (Chapter 5).

## 5. Conclusion and next steps

This chapter introduces an innovative model named Representation-Usage-Impact (RUI) for anticipating social impacts of highly autonomous vehicles. The model was developed with the help of nine social science experts to limit potential biases. Its main idea is to compile a list of autonomous vehicle usages based on various existing representations (such as science fiction and existing prototypes), and then use them to gather opinions from different experts in sociology, psycho-ergonomics, urbanism, and other related fields to obtain social impact about the identified usages. The model consists of five interlinked databases that allow for specific queries to be made. For example, you could ask, "What would be the impact of an autonomous vehicle designed to provide thrilling sensations to passengers?" Lastly, the model is designed to evolve and offers specific protocols for continuously adding new data.

We present in this document the addition of a first set of data. We added 74 representations, extracted 36 usages, and obtained 139 impacts (from 88 indicators) with the help of experts. To do so, we conducted three sessions involving 16 experts. The results obtained so far are very promising and show that social sciences could be relevant for anticipating potential social impacts of autonomous vehicles. To support this statement, we have seen that the 16 experts have envisioned impacts in 11 impact themes, and different experts anticipated similar impacts for given usages. This means the model can favor data consolidation. It is evidenced by the average number of different experts per indicator (1.5). This shows that without consulting each other, several experts envisioned impacts of the same nature. However, the model requires more data in order to reach a convergence and increase the score of 1.5. Furthermore,

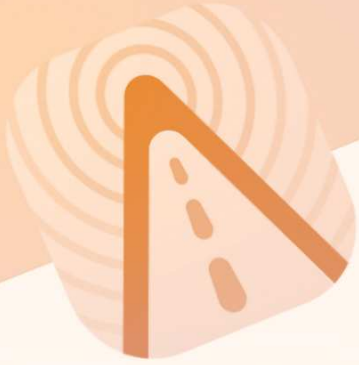
some concerns that experts raised during the construction of the model have been resolved or partially resolved with the analysis of this first set of data. For example, the potential lack of variety in representations, the possible omission of taboo and misuse of autonomous vehicles, the difficulty for experts to generate impacts without context, and the bias in expert selection. Other concerns remain, such as the use of elementary usages instead of complex scenarios, or the failure to consider the causalities that lead to a new usage. Because in reality, multiple usages and impacts are interconnected in different ways, and there can even be feedback loops. For example, working in a vehicle can lead to longer working hours, which can cause burnout and reduce the desire to use autonomous vehicles, which in turn affects AV use. Due to the complexity of assessing each cause and effect over a long period, these factors were not taken into account. Nonetheless, we have not identified any fundamental limitations that could invalidate the model at this point.

Our main hypothesis was: Sociology experts can anticipate future social impacts if they are able to project themselves into the future, drawing on their knowledge and expertise. By making the RUI model, we tried to help experts projecting themselves into future scenarios (materialized by usages), and we successfully obtained 139 impacts from 16 experts. Thus, it would be possible to replicate this using other methods. However, the uniqueness of RUI is its ability to systematize and simplify the solicitation of experts to obtain a large amount of data quickly. Therefore, we can say that our hypothesis is partially validated, as our model has indeed enabled experts accustomed to analyzing present phenomena to imagine impacts in a distant future. It should be stated that the results presented here are not sufficient to prove the accuracy of the impacts. This is because the time scale (30 years) is too long to enable an accurate validation.

Existing impact evaluation methods are limited when it comes to disruptive products that do not yet exist on the market, such as autonomous vehicles. Product evaluation methods typically focus on known products and users, and consider only short-term consequences. In contrast, impact assessment methods focus on well-defined actions that affect a known population. The RUI model draws inspiration from impact assessment methods by considering both broad and long-term social impacts. However, unlike these two families of methods, it does not aim to anticipate impacts precisely, but rather to stimulate reflection by presenting coherent links between possible usages and social impacts. The model has two key features that set it apart from other approaches. First, the approach takes inspiration from scenario methods used in future studies to deal with uncertainty. It explores numerous existing representations to consider a wide range of potential usages. The underlying idea is that, since it is difficult to predict which usages will be predominant, it is best to consider as many usages as possible. Second, the method relies on the expertise of social experts to generate coherent and possible impacts from the usages. The promising results that we have


highlighted in the case study of autonomous vehicles demonstrate the potential of this new approach compared to existing methods of product evaluation and impact assessment. When other methods struggle to anticipate the social consequences of a technology in the face of uncertainty and a high time scale, RUI succeeds in quickly anticipating many impacts. Even though the validity of these impacts remains uncertain, the strength of the model is to position itself as a safeguard intended to guide the reflections of decision-makers, policymakers, or designers on their choices about future technologies. Generalizing the model to other disruptive products would therefore be particularly relevant, for example, to try to anticipate the long-term social impacts of future artificial intelligences.

For this model to be useful, it is important that different actors can take advantage of it. Therefore, we believe that the next step is to build a tool that allows for (1) easy access to the knowledge of the model, (2) proposing different levels of result aggregation, and (3) adapting to the needs of users. The AutoVision tool presented in the next chapter integrates different impact models such as RUI. Through testing various metrics related to this tool within an automotive company, we aim to validate the effectiveness of the RUI model in decision-making processes that consider the social impacts of autonomous vehicles. By assessing the knowledge gained by users, examining the influence of the tool on their decision-making, and evaluating the potential impact of their proposals, we hope to demonstrate that the RUI model is an effective model that can truly influence the industry. To go further, this type of model could also be useful for helping communities, urban planners, legislative bodies, or governments to broaden their knowledge about the long-term impacts of potentially disruptive products.



# AutoVision





What are the potential impacts of your concept?

[➔ Impact Guesser](#)

 What are the potential impacts of your concept?



## CHAPTER 5

# **AutoVision** **industrial tool**

AutoVision is a tool for evaluating the social, socio-economic, and environmental impacts of autonomous vehicles. It is built upon the two impact models introduced in previous chapters and offers a stimulation and a simulation mode. The tool is designed for strategic decision makers and car manufacturers' designers.

# 1. Introduction

As already stated in Chapter 1, as well as in the introductions of Chapters 3 and 4, when a company develops a brand-new technology, such as AVs, and wishes to deploy it in new products, it faces a great responsibility (Jonas, 1985). Indeed, it is likely that in the hands of the public, this new technology will escape the control of its designers and have undesirable, even catastrophic, consequences in the long run. This conducts to the "Collingridge dilemma" (Worthington, 1982). This phenomenon often leads designers to adopt techno-driven strategies (Jaruzelski et al., 2014): the means are mostly allocated to the development of the technology, deemed promising, with the hope that it will lead to an economic opportunity. We are convinced that it is the responsibility of companies to imagine and design products that are likely to lead us towards desirable futures (see the concept taken from the *Institut des Futurs souhaitables*, 2023).

Today, companies use various tools to position their products in the market and in a societal context. However, most of these tools focus on the company's interests, such as threats to the product, rather than its impact on society. For example, SWOT analysis studies a business's market position (Ifediora et al., 2014). The Five Forces Model defends a market position (Porter, 2008), and PEST analysis examines political, economic, social, and technological factors (Johnson et al., 2009) but does not provide any comprehensive view of a product's impact on society. They have a role to play from a societal point of view but can also find economic advantages. For example, automotive manufacturers anticipating ecological regulations in advance is essential to avoid government sanctions and improve their image, which can lead to the conversion of new customers. Regarding the current situation (Chapter 1, Section 2). We have put forward two hypotheses: either companies do not have sufficient interest in anticipating the long-term impacts of a disruptive future product, or they do not have sufficient means to do so.

However, there are methods for anticipating the impacts of new technologies, often referred to as "technology assessment" (Banta, 2009; Arnstein, 1977; Coates, 1974; Ported, 1995), which are derived from more general "impact assessment" methods (Becker, 2001; Morgan, 2020; De Jesus, 2009). These methods concern the evaluation of companies' or parts of companies' impacts, not products'. In an industrial context, companies can rely on external providers - such as consulting firms - to carry out impact analyses. They may also consult internal experts. We can also cite strategic foresight: a process used in companies to identify potential opportunities or threats in the future (Godet & Durance, 2011). Strategic foresight can identify trends and issues that may shape the market in which a product will be sold and anticipate potential societal consequences. For our case study, these approaches remain quite cumbersome to implement. In addition, depending on the expertise domains of the providers or experts, they are often oriented towards a particular subject (i.e. carbon footprint or

health consequences) and do not always allow for a comprehensive view of the possible impacts of a product (in the sense of Henchey, 1978). Also, the studies carried out are restricted either to a general technology or to isolated product concepts. This means that companies must conduct a new study for each new concept. This problem is less of an issue when the company consults an internal expert, but it brings another constraint: when the expert leaves the company, their knowledge is also lost. These observations lead us to lean towards the hypothesis that companies do not have sufficient means to anticipate impacts. In this chapter, we therefore wish to address the question:

**Research question No. 3:** How to leverage knowledge on the impacts of autonomous vehicles within a corporate design process framework, so automotive companies can make informed choices and prevent negative outcomes?

Technology assessment uses several recognized approaches: Scenario planning (Amer et al., 2013) consists of creating several hypothetical scenarios to describe how a technology or product could be used in the future and then analyzing the potential impacts of each scenario. The technology acceptance model studies how a new technology would be received by users and society (Davis, 1989; Venkatesh & Davis, 2000). Expert panels involve gathering experts to provide information, advice, or recommendations on a subject. An expert panel can be formed to assess the potential impacts of a new technology or product and provide guidance on how to minimize risks or maximize benefits. Technology forecasting aims to anticipate and understand future technological changes and their potential impacts, adding a philosophical and ethical perspective to the introduction of a technology (Firat et al., 2008). The latter mostly uses economic or statistical approaches. Models and simulations are also widely used in technology assessment, particularly for certain impacts that are easy to simulate with specific computer models (such as distances traveled) (see Fagnant & Kockelman, 2018; Greenblatt & Saxena, 2015). A last widely used approach is literature review (see Othman, 2022). This allows summoning and confronting the results of diverse studies to draw trends or probable impacts. Other specific initiatives like the ethical method proposal from Lecomte & Jean (2022) or the *Ethical OS* (2018) toolkit, jointly developed by the Institute for the Future (IFTF) and the Omidyar Network, help companies anticipate certain social impacts and prevent the harmful use of technology by malicious actors. These two methods have been used to inspire ethical innovation in companies. However, neither of them was updated (*Ethical OS* was no longer available online when this thesis was published). This made us realize that the biggest challenge in the models and platform was updating the data. Until a fast and reliable solution for updating is found, this kind of tool will not become the standard. Over long-time scales (+30 years), none of these approaches can accurately predict the impacts of a new product. Indeed, it seems irrelevant to establish fine probabilities of such impact, as the



future context will inevitably change. We consider completely different users, with usages and living conditions also very different from today. Nevertheless, we believe that the strength of these approaches lies in their ability to provide new knowledge about potential impacts. We believe that a designer or decision-maker does not need to be certain that an impact will occur to take it into account; they must first know that it could exist. In other words, the goal is not to avoid uncertainty, but to be aware of it.

The downside of technology assessment methods is that they are often difficult to implement and are not well-suited to an innovation context. However, they remain effective in anticipating possible impacts. In the context of typical product development, "agile" methods (such as Design Thinking) prioritize flexibility and frequent iteration over rigid planning and documentation. They help to quickly and efficiently develop products that meet customer needs and adapt to changing market conditions. However, if these methods integrate product evaluation to systematically verify that concepts correspond to short-term future users, they may not be suitable for longer time scales (as discussed in Chapter 4). That is why, in this chapter, we propose an industrial tool that combines principles of technology assessment and agile methodology. The main goal is to enable designers or decision-makers to quickly assess the possible impacts of a new concept, to improve it through successive iterative phases.

The autonomous vehicle (AV) is a good example of a product that integrates a brand-new technology, and whose consequences are still difficult to discern. We have developed a tool called AutoVision that is designed for both designers and decision-makers. The tool's aim is to prevent the development of autonomous vehicles that could lead to social, environmental, or socio-economic catastrophes. Therefore, it is not suited to predict the future with precision. It is better to see it as a "safeguard" that helps users anticipate or alert certain consequences as early as possible. We have positioned it to be able to respond to two questions: (1) Which AV ideas should be selected to avoid/favor certain impacts? and (2) What impacts is an AV idea likely to generate? Thus, the tool proposes two distinct modes of use: the Advisor mode, which helps build an autonomous vehicle concept (or scenario) based on the impacts that one wants to avoid or favor, and the Impact Guesser mode, which, conversely, provides a list of possible impacts from an autonomous vehicle scenario. A scenario consists of different elements such as a list of usages, modes of use (private, shared), or a geographical deployment area. This tool is based on the two models developed in Chapters 3 and 4: the Study-Method-Impact (SMI) model, which aggregates scientific literature to anticipate quantitative long-term socio-economic and environmental impacts of AVs, and the Representation-Usage-Impact (RUI) model, which combines expert knowledge from sociology and other fields to anticipate the social impacts of AVs.

In this chapter, we provide a detailed presentation of the tool and its structure.

## 2. The AutoVision tool

The main feature of the AutoVision tool is to link concepts of AVs with one or more long-term impacts they could have. Each concept can be defined by a set of characteristics, such as the number of passengers it can carry, the activities it allows, its suitability for urban or rural areas, the countries where it will be used, the type of energy it uses, and so on. Therefore, we decided to link characteristics directly to possible impacts. During our research, we identified two types of impacts: (1) socio-economic and environmental impacts, which are well studied in scientific literature, and (2) social impacts, which focus on individuals and groups of individuals, for which existing impact assessment methods are very limited. For each type of impact, we developed an original model that links characteristics to impacts. A comparative summary of the models is presented in Table 13.

Table 13. Summary table of the two models developed (more info in Chapters 3 and 4 respectively).

Model	Impact type	Knowledge source	Input characteristics	Example of impact	Themes
SMI (Study-Method-Impact)	Socio-economic and environmental (quantitative)	Scientific studies	Domain of validity (e.g. mode of use, type of infrastructure, geographical area of deployment)	- Average increase in the number of kilometers traveled by 20% - Average decrease in CO2 emissions by 5%	8
RUI (Representation-Usage-Impact)	Social (qualitative)	Experts interrogation	Usage made possible by the AV (e.g. sleeping in the vehicle during the journey)	- Increased dependence on smartphones - Decreased health status of users	11

We constructed the models using various objects, such as representations, usages, social impacts, socio-economic and environmental impacts, and areas of validity. Each of these objects was defined using specific ontologies, which are fully described in Chapters 3 and 4. To create a cohesive set linking autonomous vehicle characteristics with their potential impacts, we combined these different objects to build the AutoVision tool.

## 3. Objects

This section introduces the objects that are crucial to the functioning of AutoVision. Each object possesses specific characteristics that are detailed, justified, and exemplified in Chapters 3 and 4. The tool employs a network of 14 databases, with each one named after the corresponding object. Databases are identified by names in capital letters, while the objects they contain are in lowercase letters. To understand their roles, we have classified them into two categories. Main objects serve as inputs and/or outputs for the tool, while secondary objects function as intermediaries that either connect

main objects to each other (e.g. *EXTRACTION*) or provide additional information (e.g. *STUDY*). In other words, the secondary objects can be seen as the back-office objects of the tool. These objects form a network of databases, as shown in Figure 56.

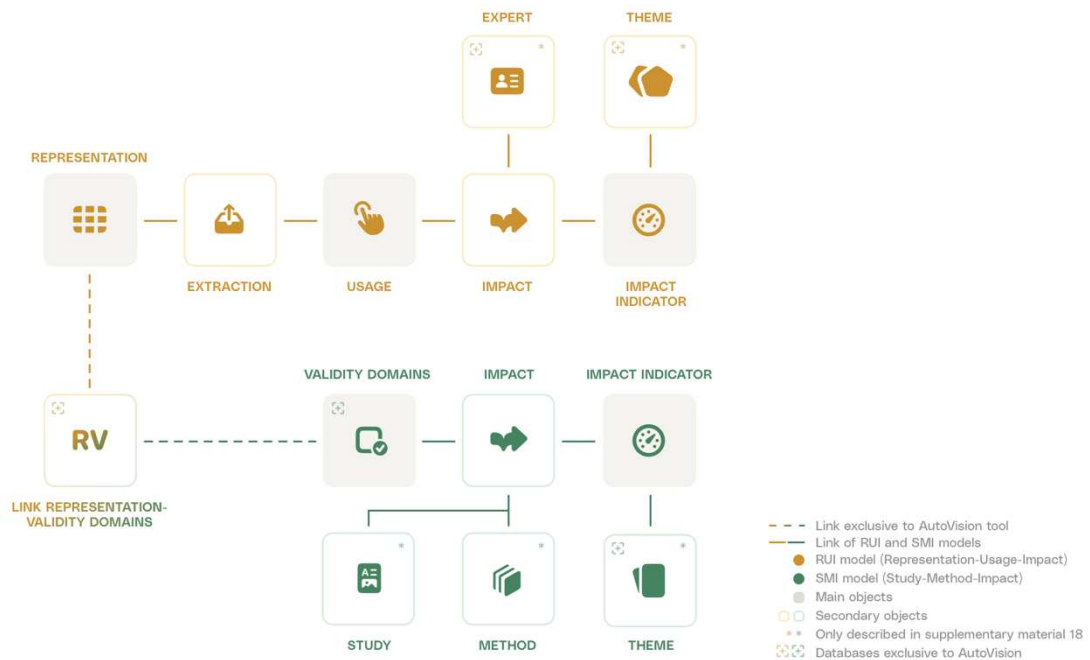


Figure 56. Objects used in the tool are spread across 14 linked databases (derived from Figure 34 and Figure 42).

In this chapter, we mainly use a simplified version of the database network. The following subsections introduce the main objects and important secondary objects. Some secondary objects are only described in the supplementary material 17, to keep this chapter brief. With regards to the respective databases of the SMI and RUI models, the ones presented here have undergone some variations. Therefore, we provide details in the following sections.

### 3.1. REPRESENTATION

A representation encompasses all types of physical or virtual artifacts of an autonomous vehicle (Boujut & Laureillard, 2002). We have defined a representation using height attributes (refer to Table 14). To see examples of representations, you can refer to the supplementary material 11 associated with the RUI model (Chapter 4).

Table 14. Attributes of a representation.

Name	Description	Modalities
<i>Name</i>	Reference name of the representation.	Free text (example: Waymo one)
<i>Author</i>	Name of the person or company considered as the author of the representation.	Free text (example: Google)
<i>Year</i>	Year of publication of this representation.	Year

Name	Description	Modalities
<i>Resources</i>	Resources related to this representation (image, internet link, video).	Any type of document (example: photo of the Waymo one car)
<i>Description</i>	Brief and factual description of the representation allowing easy identification (focused on AV and not on other non-relevant elements of the representation).	Free text (example: A robot cab service available in select neighborhoods in San Francisco and Phoenix. In November 2019, Waymo One was the world's first autonomous service to operate without a safety driver in the car)
<i>Shape</i>	Shape of the representation.	Design-fiction object; Vehicle concept; Non-functional prototype; Functional prototype; Functional product; Film/TV series; Cartoon; Book; Web article/website; Magazine; Comic book/graphic novel; Program/video game; Patent; Scientific work; Model
<i>Maturity</i>	Characterization of the maturity of a representation (inspired by Tzinis, 2015). The higher the level, the more realistic the representation is. The lower it is, the more fictional the representation is.	(1) Fiction: No intention of realism; (2) Project/Vision: Intention of realism but does not exist (yet); (3) Real: Exists
<i>Aim</i>	Author's bias.	Utopia: The representation presents only intended uses; Unclear/Informative: The representation does not openly favor intended or unintended uses; Dystopia: The representation mostly presents unintended usages and consequences

### 3.2. USAGE

A usage corresponds to the "destination, function of something, and the use that can be made of it" (Larousse dictionary, sense 3). A usage is defined by six attributes (Table 15).

Table 15. Attributes of a usage.

Name	Description	Modalities
<i>Type</i>	The usage type distinguishes new usages brought by the AV and existing or possible usages without AV but which are likely to be significantly modified by its deployment.	New; Augmented
<i>Subject</i>	The subject is an attribute that contextualizes the usage. The question it answers is: "What/who performs the action?"	Vehicle: The AV itself; Passenger: The passenger(s) of the AV; External person: Person(s) who are not passengers of the AV.
<i>Action</i>	The action attribute describes what is done by the subject.	An infinitive phrase describing a scene, a step, or an elementary task. It starts with an infinitive verb (example: Go get someone)
<i>Context</i>	This attribute provides information about the context that guarantees that the usage is new or augmented.	Free text (example: Nobody is inside)
<i>Usage phrase</i>	Simplified sentence that summarizes the Subject, Action, and Context attributes.	Free text (example: The vehicle is picking someone up and there is nobody inside).
<i>Description</i>	A short description of the usage to try to clarify any ambiguities in understanding.	Free text (example: The vehicle can come to meet the passenger(s) by itself. If the vehicle is private, it can

Name	Description	Modalities
		leave the garage and come to pick up the owner at his front door. If it is shared, the passenger can order the vehicle on his phone in the same way as a VTC but without a driver).

### 3.3. Social *IMPACT INDICATOR*

A social impact indicator is a qualitative or semi-quantitative measure that can increase or decrease over time. Social impact refers to the effect a product has on the quality of people's daily lives (Burdge, 2015). It is defined by two attributes (Table 16).

Table 16. Attributes of a social impact indicator.

Name	Description	Modalities
<i>Name</i>	The name of the indicator.	Free text (example: Health status)
<i>Description</i>	Description of the indicator.	Free text (example: This indicator shows the general health status of people. An increase in this indicator means that the average health status of people is getting better)

### 3.4. *VALIDITY DOMAINS*

A validity domain refers to the assumptions and factors that affect socio-economic or environmental impact. The term originally referred to the areas of scientific studies that were used in the SMI (Study-Method-Impact) model presented in Chapter 3. For this version of the tool, there are two types of areas to consider: (1) Mode of use - how the AV is used, such as shared or private; and (2) Continent - where the AV is deployed, such as North America or Europe. Each area is covered by a specific database. Thus, there are two validity domains databases, with two attributes each (Table 17). To keep it general, we did not separate them in the schemas. Additionally, as this tool is meant to evolve, other domains could be added in the future (such as penetration rate of AVs, presented in Chapter 3).

Table 17. Attributes of a validity domain.

Name	Description	Modalities
<i>Name</i>	The name of the validity domain.	Selection from a list (example: Car-sharing)
<i>Description</i>	A description of the validity domain.	Free text (example: The vehicle does not belong to the user, but they do not share the ride with other people (operating similarly to a taxi))

### 3.5. Socio-economic and environmental *IMPACT INDICATOR*

A socio-economic and environmental impact is a quantified change in a parameter (called an indicator) caused by the introduction of autonomous vehicles into a given system (Table 18).

Table 18. Attributes of a socio-economic and environmental impact indicator.

Name	Description	Modalities
<i>Name</i>	The name of the indicator.	Free text (example: Parking spaces required)
<i>Description</i>	Description of the indicator.	Free text (example: The evolution of the required number of parking spaces in a specific area)

### 3.6. *EXTRACTION*

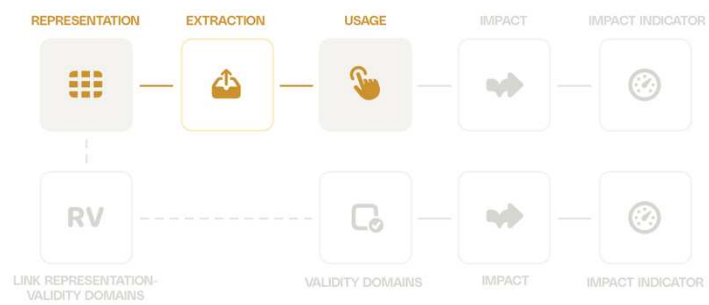


Figure 57. Positioning of an extraction in the database network of the tool.

Each usage is linked to one or several representations, and each representation can be linked to one or several usages (Figure 57). A link between a representation and a usage has two attributes shown in Table 19. The corresponding database is called *EXTRACTION*.

Table 19. Attributes of an extraction.

Name	Description	Modalities
<i>Author</i>	The person who established the impact	Free text (example: Didier O.)
<i>Date</i>	The date on which the impact was established	Date

### 3.7. Social *IMPACT*



Figure 58. Positioning of a social impact in the database network of the tool.

Usages are linked to social impact indicators through the *IMPACT* database (Figure 58). An indicator can be linked to one or several usages. Each entry in the database is also linked to an expert (see supplementary material 17). Attributes are described in Table 20 and Table 21.

Table 20. Qualitative attributes of a social impact.

Name	Description	Modalities
<i>Date</i>	The date on which the impact was established.	MM/DD/AAAA
<i>Change</i>	What will change according to the expert.	Free text (example: Social interactions between people will increase)
<i>Subject</i>	The person or group of people affected by this impact according to the expert.	Free text (example: Car-pooling users)
<i>Conditions</i>	Conditions and contextual elements proposed by the expert.	Free text (example: When all vehicles are shared)

Table 21. Quantitative attributes of a social impact.

Name	Description	Notation	Modalities
<i>Trend</i>	Describes the evolution of the linked indicator.	$T$	Decrease: -1; Increase: +1
<i>Intensity</i>	Expresses the strength of the impact, as perceived by the expert.	$Q_I$	Low: 1; Medium: 2; High: 3
<i>Occurrence</i>	The frequency at which this impact is likely to occur.	$Q_F$	Rare: 1; Regular: 2; Systematic: 3
<i>Depth</i>	The approximate proportion of people (corresponding to the subject description) affected by the impact.	$Q_D$	Very few people: 1; Several people: 2; Everyone: 3
<i>Certainty (Expert)</i>	Quantitative self-evaluation of the expert's confidence in their statement.	$q$	Very uncertain: 11; Not very confident: 22; Rather confident: 33

### 3.8. Socio-economic and environmental *IMPACT*

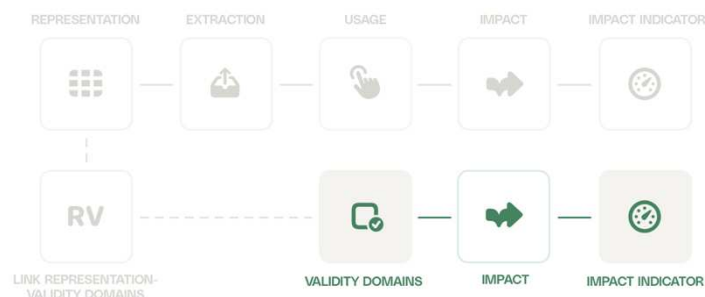


Figure 59. Positioning of socio-economic and environmental *IMPACT* in the database network of the tool.

Each socio-economic or environmental impact is linked to one or several validity domains through the *IMPACT* database (Figure 59). A validity domain can be linked to several impacts. The link has three attributes, as shown in Table 22. Two other databases are also linked: *STUDY* and *METHOD* (see supplementary material 17).

Table 22. Attributes of a socio-economic and environmental impact.

Name	Description	Notation	Modalities
<i>Trend</i>	The tendency of evolution of the linked indicator.	<i>T</i>	Decrease: -1; Increase: +1
<i>Value</i>	The value of evolution of the indicator.	<i>V</i>	] - ∞; +∞[
<i>Certainty (study)</i>	Level of approximate confidence given to the impact (calculated through the quality coefficient of the SMI model, see below).	<i>q</i>	[0,1]

We defined the coefficient of quality (*q*) as relative so that the study with the most citations (on average per year), which is peer-reviewed and comes from the journal with the highest impact factor, would receive a quality score of 1, while the worst would receive a score of 0. For more details, see Chapter 3, Equation (1) on the SMI model.

### 3.9. LINK REPRESENTATION-VALIDITY DOMAINS

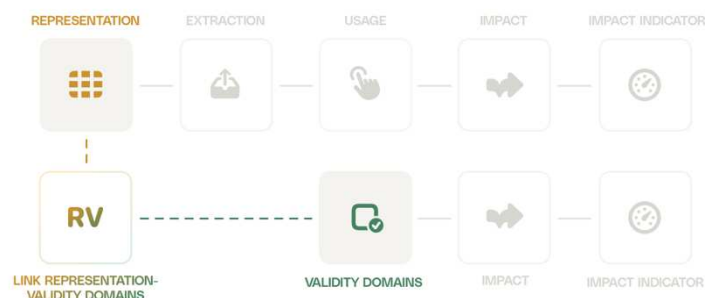


Figure 60. Positioning of a link between a representation and validity domains in the database network of the tool.



Each representation can be linked to a validity domain (Figure 60). This link is unique to the tool because it is made between two objects from two different models: SMI and RUI. The corresponding database includes contextual information about the link; attributes are presented in Table 23.

Table 23. Attributes of a link representation-validity domains.

<b>Name</b>	<b>Description</b>	<b>Modalities</b>
Author	The person who established the impact.	Free text (example: Didier O.)
Date	The date when the impact was made.	MM/DD/AAA

## 4. Users

The tool is intended to be used by two different types of people. The first type is called the *User*, who has access to the tool's usage modes (Section 5), and the second type is the *Administrator*, who can update or modify the tool's data (Section 6).

### 4.1. *User*

The user can access all usage modes of the tool but is not authorized to update the databases. Therefore, they cannot alter anything. No specific knowledge is required to use the tool, but it is recommended to read the user guide to avoid any misinterpretation of results or inappropriate use of the tool. The user guide is an instruction manual designed to help users. It simply describes the different objects and explains how to use the different user modes. It also clarifies some ambiguities in understanding or interpretation. The user guide is available as supplementary material 18.

A typical AutoVision user can be a strategic decision-maker for a company seeking to work on autonomous vehicles. The user can also be a designer who uses the tool to generate new ideas or refine existing autonomous vehicle concepts.

### 4.2. *Administrator*

In addition to accessing all user modes, the administrator can add or modify data (admin modes). They can add usages, links between representations and validity domains, socio-economic and environmental impacts, and even add social impacts by consulting experts. Users can become administrators after completing specific training. To automate knowledge acquisition, explanatory videos followed by a skills evaluation quiz are being considered. After this training, an administrator's guide could be added to the user guide to provide details on admin modes. This guide could also serve as a reminder by recalling important elements to know, and links to explanatory videos would be made available. While this online training and augmented guide have

not yet been developed, they could be included in an updated version of the AutoVision tool if deployed within a company.

## 5. User modes

User modes are intended for use by designers or decision-makers in a business setting. There are two primary modes: the *Advisor*, which provides guidance for ideating an autonomous vehicle concept by suggesting what characteristics to avoid or promote, and the *Impact Guesser*, which anticipates the possible impacts of an existing representation, a new concept, or a scenario imagined by the user.

### 5.1. Advisor mode

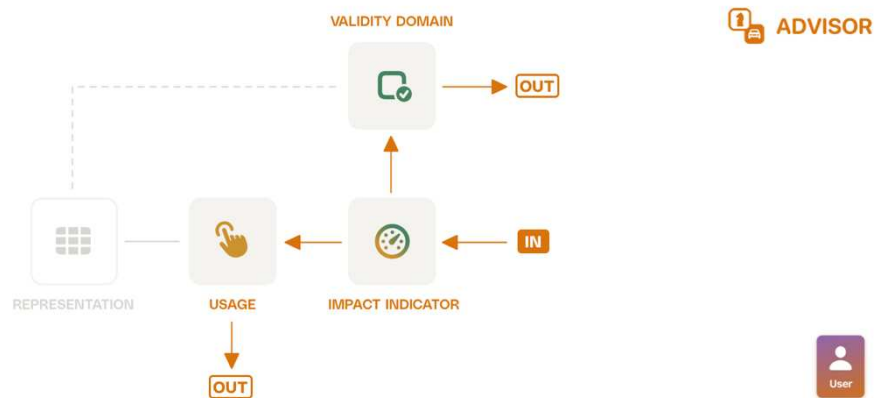


Figure 61. Advisor mode logic diagram.

The Advisor positions itself in the ideation phase of new concepts by providing responsible creative stimuli (Howard et al., 2011). It allows users to select desired trends for various indicators. Then, the tool provides corresponding lists of usages and validity domains to promote or avoid (see Figure 61 and Table 24). The purpose of this mode is to advise users on the choices to make regarding a new concept. It acts as a compass for designers or decision-makers who do not know where to start when designing an autonomous vehicle, even if they work in an automotive company. That is why ideation methods exist and are used, especially at Stellantis (workshops, user journey maps, UX routine, etc).

Table 24. Input and output of the Advisor mode.

	Input	Output
Description	Select one or more impact indicators from a list and specify the trends to avoid or prioritize for each of them ( $\uparrow$ , $\downarrow$ ). This set of impacts (social, socio-economic, and environmental) that the user wants or not is called a strategy.	List of usages to promote; list of usages to avoid; list of continent to promote; list of continents to avoid; list of modes of use to promote; list of modes of use to promote.
Example	Stress: $\downarrow$ ; CO2 emissions: $\downarrow$ ; Health condition: $\uparrow$	To promote : The passenger exercises during the transport, Shared mode of use

### 5.1.1. Calculating corresponding usages (RUI model)

The user can browse a list of social impact indicators and indicate whether they want an increase or decrease in each one. From there, it is first necessary to identify all the usages that favor or disfavor the selected impacts.

Before delving into the calculations, we need to define the indicators, impacts, and usages using mathematical sets. Let  $L$  represent the set of all social impacts in the database *IMPACT*.  $L_i$  denotes the subset of impacts within  $L$  that correspond to the indicator  $i$  (which can be selected by the user as input). Similarly,  $L_u$  represents the subset of impacts within  $L$  that correspond to the usage  $u$  (which can be displayed as output).

Furthermore, let  $T'_i$  denote the trend chosen by the user for indicator  $i$ . If the user indicates a positive trend, then  $T'_i = 1$ ; if the user indicates a negative trend, then  $T'_i = -1$ ; and if the user does not indicate a trend, then  $T'_i = 0$ .

We define  $L_s$  as the set of indicators selected by the user, which corresponds to the union of the sets  $L_i$  where  $T'_i \neq 0$ . Additionally, we assign the selected trend for indicator  $i$  to all impacts linked to this indicator ( $\forall j \in L_i, T'_j = T'_i$ ). Figure 62 provides a graphical representation of these sets.

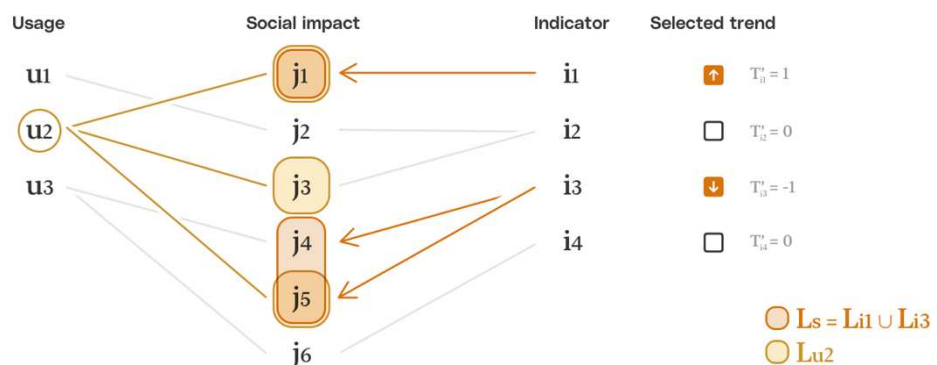


Figure 62. Graphical representation of the sets  $L_i$ ,  $L_u$  and  $L_s$  with an example. The considered usage is  $u_2$ .

To identify usages that favor or disfavor the scenario defined by the user, we have considered two metrics related to each impact: The intensity of the impact (ranging

from 1 to 3) and the certainty of the experts (also ranging from 1 to 3). Let  $Q_{I_j}^* \in [-1,1]$  be the normalized intensity calculated from the intensity  $Q_{I_j}$  and the trend  $T_j$  of the impact  $j \in L$ . We multiply by the trend to differentiate positive and negative intensities. We also define  $q_j^* \in [0,1]$  as the normalized certainty of the impact  $j \in L$  (Equation (2)).

$$Q_{I_j}^* = \frac{T_j Q_{I_j}}{3} \quad q_j^* = \frac{q_j}{3} \quad (2)$$

Then we calculate the average intensity ( $\overline{Q_{I_u}^*} \in [-1,1]$ , Equation (3)) of usage  $u$  for all selected indicators and weighted by certainty ( $q_j^*$ ). This average is calculated with respect to the direction of trends selected by the user ( $T'_j$ ). In other words, for each impact  $j \in L_u \cap L_s$ , if trend  $T_j$  is the same as the trend selected by the user  $T'_j$ , then the average intensity is positively influenced.

$$\overline{Q_{I_u}^*} = \frac{\sum_{j \in L_u \cap L_s} Q_{I_j}^* T'_j q_j^*}{\sum_{j \in L_u \cap L_s} q_j^*} \quad (3)$$

From this, we calculated the majority influence  $M_u \in \{-1,1\}$  of usage  $u$  on the selected indicators (Equation (4)).

$$M_u = \text{sgn}(\overline{Q_{I_u}^*}) \quad (4)$$

- If  $M_u = 1$ , the usage  $u$  on average favors the trends chosen by the user.
- If  $M_u = -1$ , the usage  $u$  on average disfavors the trends chosen by the user.

The total number of impacts for the usage  $u$  on the set of selected indicators is represented by  $n_u$  (Equation (5)). This metric is important for evaluating the amount of data from which the previous calculations were performed.

$$n_u = |L_u \cap L_s| \quad (5)$$

To consider the dispersion of the data, we introduce the conflict coefficient  $k_u$  (Equation (6)). It is defined as the root mean square of the deviations from the weighted mean  $\overline{Q_{I_u}^*}$ . It is equivalent to a weighted standard deviation.

$$k_u = \sqrt{\frac{\sum_{j \in L_u \cap L_s} q_j^* (Q_{I_j}^* T'_j - \overline{Q_{I_u}^*})^2}{2 \frac{n_u - 1}{n_u} \sum_{j \in L_u \cap L_s} q_j^*}} \quad (6)$$

A high coefficient ( $k_u \approx 1$ ) indicates a large dispersion of the data, meaning that trends and intensities are not in agreement. On the contrary, a low coefficient ( $k_u \approx 0$ ) indicates

homogeneity in the data. This means that the calculated majority influence is more widely accepted.

Figure 63 graphically represents the average intensity ( $\overline{Q_{I_u}^*}$ ), the conflict ( $k_u$ ) and the number of impacts ( $n_u$ ).

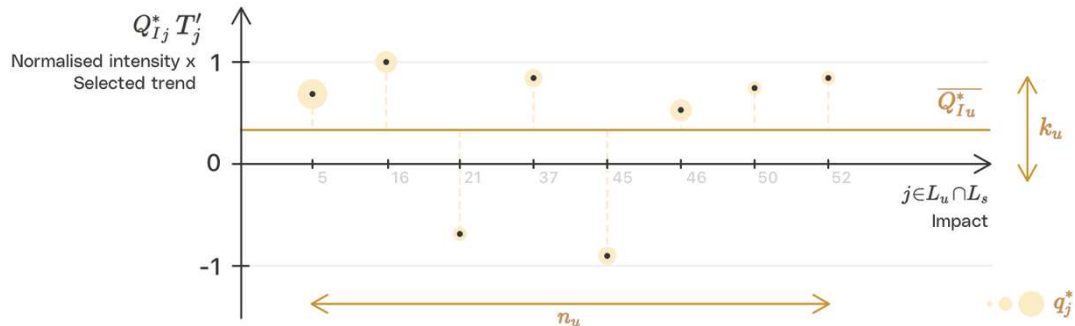


Figure 63. Graphical representation of the average intensity ( $\overline{Q_{I_u}^*}$ ), conflict ( $k_u$ ) and total number of impacts ( $n_u$ ), weighted by certainty ( $q_j^*$ ), for a given usage  $u$ . The size of the circles represents the level of certainty  $q_j^* \in [0,1]$ .

The combination of  $M_u$ ,  $n_u$ , and  $k_u$  allows characterizing the influence of a usage on the selected indicators. Some examples of interpretation are given in the Table 25.

Table 25. Example of calculating and interpreting  $M_u$ ,  $n_u$ , and  $k_u$  metrics based on five usages, following the selection of one or more social impact trends by a user.

Usage ( $u_x$ )	Majority influence ( $M_{u_x}$ )	Total number of impacts ( $n_{u_x}$ )	Conflict coefficient ( $k_{u_x}$ )	Interpretation
$u_1$	1	2	82%	There is little data on usage 1, and the impacts contradict each other (high conflict). We cannot give importance to the majority influence.
$u_2$	1	31	18%	Usage 2 clearly favors the selected trends.
$u_3$	-1	3	0%	There is little data on usage 3, but all three impacts indicate the same trend (no conflict). We can say that usage 3 could unfavorably impact the selected trends.
$u_4$	-1	28	94%	There is a lot of data on usage 4, but the impacts contradict each other (high conflict). We cannot conclude on the majority influence.

To sort the various results generated by the Advisor mode, we have developed a sorting function that considers the number of impacts and the conflict coefficient (Equation (7)). The function is designed in a way that assigns a lower ranking to usages with high conflict, regardless of the number of impacts (hence the polynomial form).

$$s_u = n_u(k_u^2 - 2k_u + 1) \quad (7)$$

### 5.1.2. Calculating corresponding validity domains (SMI model)

The user can view a list of indicators related to socio-economic or environmental impact and choose whether they want each one to increase or decrease. The calculations for the validity domains are like those for usages, but this time we use quantitative data (*Value*).

First, we define the indicators, impacts, and validity domains using mathematical sets. Let  $L$  represent the set of all impacts in the database *IMPACT*.  $L_i$  denotes the subset of impacts within  $L$  that correspond to the indicator  $i$  (which can be selected by the user as input). Similarly,  $L_v$  represents the subset of impacts within  $L$  that correspond to the validity domain  $v$  (which can be displayed as output).

Furthermore, let  $T'_i$  denote the trend chosen by the user for indicator  $i$ . If the user indicates a positive trend, then  $T'_i = 1$ ; if the user indicates a negative trend, then  $T'_i = -1$ ; and if the user does not indicate a trend, then  $T'_i = 0$ .

We define  $L_s$  as the set of indicators selected by the user, which corresponds to the union of the sets  $L_i$  where  $T'_i \neq 0$ . Additionally, we assign the selected trend for indicator  $i$  to all corresponding impacts  $j$  corresponding to this indicator ( $\forall j \in L_i, T'_j = T'_i$ ).

Note that at this stage, the only major difference from social impacts is the consideration of validity domains ( $L_v$ ) instead of usages ( $L_u$ ). Figure 64 provides a graphical representation of these sets.

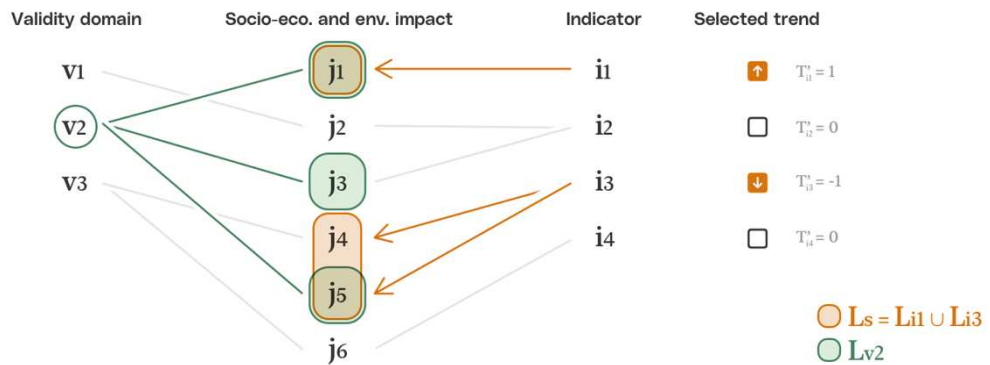


Figure 64. Graphical representation of the sets  $L_i$ ,  $L_v$ , and  $L_s$ . The considered validity domain is  $v_2$ .

To identify validity domains that favor or disfavor the scenario defined by the user, we have considered two metrics related to each impact: the *Value* ( $V$ ) and the *Certainty* ( $q$ ). Let  $V^* \in [-1,1]$  be the normalized value calculated from the value  $V_j \in ]-\infty, +\infty[$  (Equation (8)). It is important to normalize the values because they are then aggregated between all the selected indicators, which may have different reference scales.

$$\forall j \in L_i \quad V_j^* = \frac{V_j}{|\max_{j \in L_i} V_j|} \quad (8)$$

For the validity domain  $v$ , we calculate the weighted average of the normalized values  $\overline{V}_v^*$  selected, by the trends ( $T_j'$ ) and the certainty ( $q_j$ )(Equation (9)).

$$\overline{V}_v^* = \frac{\sum_{j \in L_v \cap L_s} V_j^* T_j' q_j}{\sum_{j \in L_v \cap L_s} q_j} \quad (9)$$

We calculated the majority influence  $M_v \in \{-1,1\}$  of the validity domain ( $v$ ) for all selected indicators (Equation (10)).

$$M_v = \text{sgn}(\overline{V}_v^*) \quad (10)$$

- If  $M_v = 1$ , the validity domain  $v$  generally favors the trends chosen by the user.
- If  $M_v = -1$ , the validity domain  $v$  generally disfavors the trends chosen by the user.

The total number of impacts corresponding to the validity domain  $v$  on the set of selected indicators is denoted by  $n_v$  (Equation (11)).

$$n_v = |L_v \cap L_s| \quad (11)$$

The conflict coefficient ( $k_v$ ) is defined as the root mean square of the deviations from the weighted mean  $\overline{V}_v^*$  (Equation (12)). It is equivalent to a weighted standard deviation.

$$k_v = \sqrt{\frac{\sum_{j \in L_v \cap L_s} q_j (V_j^* T_j' - \overline{V}_v^*)^2}{2 \frac{n_v - 1}{n_v} \sum_{j \in L_v \cap L_s} q_j}} \quad (12)$$

Figure 65 graphically represents the average of normalized values ( $\overline{V}_v^*$ ), conflict ( $k_v$ ) and the number of impacts ( $n_v$ ).

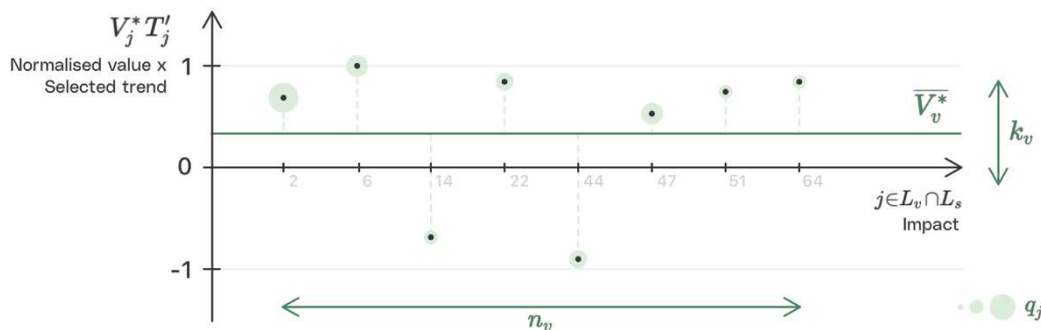


Figure 65. Graphical representation of the average of normalized values ( $\overline{V}_v^*$ ), conflict ( $k_v$ ) and total number of impacts ( $n_v$ ) by certainty ( $q_j$ ), for a given validity domain ( $v$ ). The size of the disks represents the level of certainty  $q_j \in [0,1]$ .

The combination of  $M_v$ ,  $n_v$ , and  $k_v$  allows for characterizing the influence of a validity domain on selected impacts.

We defined a sorting function that considers the number of impacts and the conflict coefficient (Equation (13)). The function is designed to give lower rankings to validity domains that have high conflict, regardless of the number of impacts.

$$s_v = n_v(k_v^2 - 2k_v + 1) \tag{13}$$

### 5.1.3. Going into more detail

In addition to the lists of usages and validity domains, users can also access the links between a usage/validity domain and an impact. For example, users can select a usage from the output of the Advisor mode and then view the justifications provided by experts for the causal link with each selected input social impact. Similarly, users can access the scientific studies that have established the causality between a validity domain and a socio-economic or environmental impact (*STUDY* database visible in supplementary material 17).

## 5.2. Advisor alternative use

We have also defined another way to use the advisor mode, which enables the display of the most similar representations to a strategy.

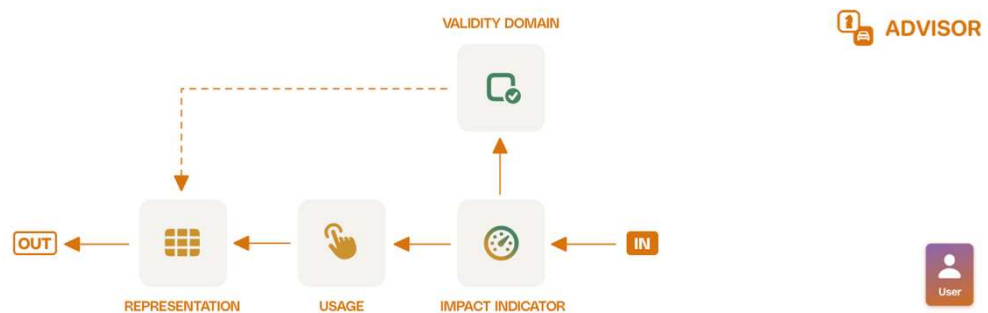


Figure 66. Alternative use of the advisor mode to display the closest representations to a strategy.

The principle of this mode is to calculate an average matching score for each representation using the aggregation formulas from the Impact Guesser (Section 5.3; Equations (21) and (27)). These formulas allow calculating a score for each impact theme, linked to an arbitrary grid (see supplementary material 19). This arbitrary grid corresponds to a strategy. Thus, it is possible to use these formulas to assign a score to each of the 19 impact themes for a given representation, according to a given strategy. By calculating the average of these 19 themes, it is then possible to assign a global score to each representation. This allows providing the user with a list of representations ranked by their matching score with their strategy (Figure 66 and Table 26). It is then possible to access the score of each theme, and then the score of each impact, to see



how a representation with a good score could be further improved to better match the strategy. The Advisor is a stimulation tool, so it can help designers to consider other possibilities than their preconceived ideas (showing representations). Thus, it could be useful for addressing fixation biases among designers (Linsey et al., 2010; Moreno et al., 2016).

Table 26. Input and output of the alternative use of the Advisor mode.

	Input	Output
Description	Select one or more impact indicators from a list and specify the trends to avoid or prioritize for each of them (↑, ↓). This set of impacts (social, socio-economic, and environmental) that the user wants or not is called a strategy.	List of the closest representations to the strategy (with a correspondence score).
Example	Stress: ↓ ; CO2 emissions: ↓ ; Health condition: ↑	Citroën Skate Concept (score: 65%); Toyota E-palette concept (score: 43%)

### 5.3. Impact Guesser mode

The principle of the *Impact Guesser* mode is to propose a list of possible impacts based on a list of usages and validity domains. It could serve as a safeguard, allowing the evaluation and prioritization of the most responsible ideas in a design process (Ferioli et al., 2010).

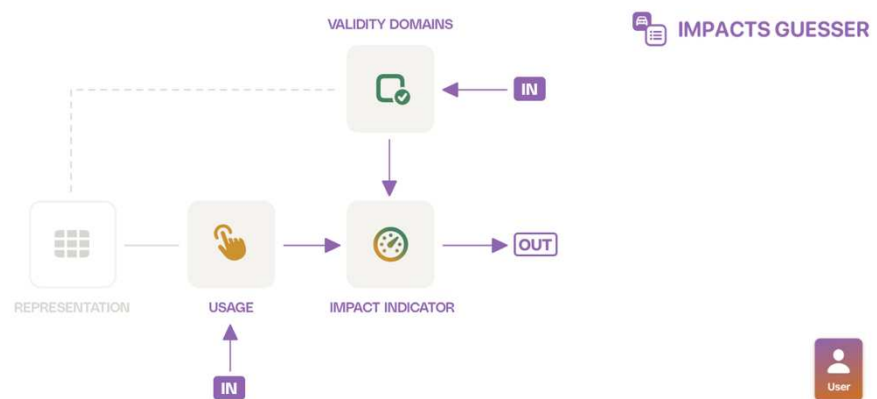


Figure 67. Impact Guesser mode logic diagram.

The set of selected usages and domains of validity is called a *scenario* (Figure 67 and Table 27).

Table 27. Input and output of the Impact Guesser mode.

	Input	Output
Description	Selecting usages and validity domains from lists (scenario).	List of potential social impacts; List of potential socio-economic and environmental impacts.
Example	The passenger exercises during the transport, Shared mode of use	Stress: ↓ ; CO2 emissions: ↓ ; Health condition: ↑

### 5.3.1. Calculating corresponding social impacts (RUI model)

For the social impacts part, the objective is to provide a list of impacts corresponding to the usages selected by the user. Like the *Advisor* mode, when several usages are selected as input, it is possible to end up with many impacts. This is why we propose a way to aggregate multiple impacts considering the level of certainty of experts ( $q$ ).

First, we define the indicators, impacts, and usages using mathematical sets. Let  $L$  represent the set of all impacts in the database IMPACT.  $L_u$  represents the subset of impacts within  $L$  that correspond to the usage  $u$  (which can be selected by the user as input). Similarly,  $L_i$  denotes the subset of impacts within  $L$  that correspond to the indicator  $i$  (which can be displayed as output). Figure 68 provides a graphical example of these sets.

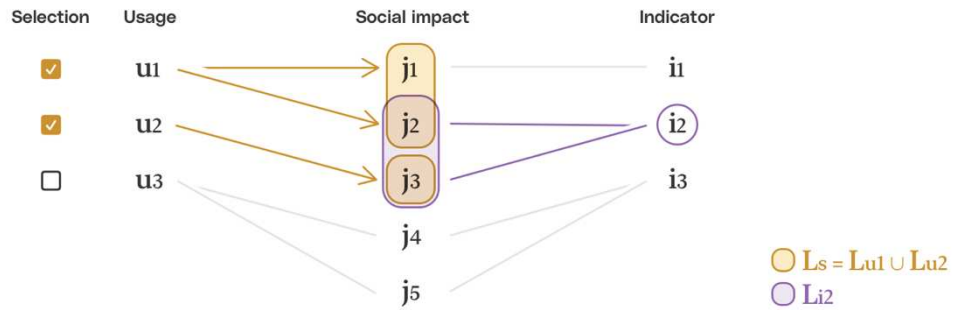


Figure 68. Graphical representation of sets  $L_i$ ,  $L_u$ , and  $L_s$  with a fictional example. The indicator considered is  $i_2$ .

$Q_{I_j}^* \in [-1,1]$  corresponds to the normalized intensity calculated from the *Intensity*  $Q_{I_j}$  and the trend  $T_j$  of the impact  $j$ . The trend  $T_j$  is the trend provided by an expert for the impact  $j$ . We also denote the normalized *Occurrence* ( $Q_{F_j}^*$ ), *Depth* ( $Q_{D_j}^*$ ), and *Certainty* ( $q_j^*$ ) (Equations (14)).

$$Q_{I_j}^* = \frac{T_j Q_{I_j}}{3} \quad Q_{F_j}^* = \frac{Q_{F_j}}{3} \quad Q_{D_j}^* = \frac{Q_{D_j}}{3} \quad q_j^* = \frac{q_j}{3} \quad (14)$$

The weighted average intensity ( $\overline{Q_{I_i}^*}$ ) is calculated for each indicator related to the selected usages by the user. Weighted averages of occurrence ( $\overline{Q_{F_i}^*}$ ) and depth ( $\overline{Q_{D_i}^*}$ ) are also calculated (Equations (15)).

$$\overline{Q_{I_i}^*} = \frac{\sum_{j \in L_i \cap L_s} Q_{I_j}^* q_j^*}{\sum_{j \in L_i \cap L_s} q_j^*} \quad \overline{Q_{F_i}^*} = \frac{\sum_{j \in L_i \cap L_s} Q_{F_j}^* q_j^*}{\sum_{j \in L_i \cap L_s} q_j^*} \quad \overline{Q_{D_i}^*} = \frac{\sum_{j \in L_i \cap L_s} Q_{D_j}^* q_j^*}{\sum_{j \in L_i \cap L_s} q_j^*} \quad (15)$$

From the average intensity ( $\overline{Q_{I_i}^*}$ ), we calculate the majority trend  $M_{I_i}$  of indicator  $i$  (Equation (16)). This value determines whether indicator  $i$  is likely to increase on average ( $M_{I_i} = 1$ ) or decrease ( $M_{I_i} = -1$ ).

$$M_{I_i} = \text{sgn}(\overline{Q_{I_i}^*}) \quad (16)$$

The total number of impacts for the indicator  $i$  on the selected usages is denoted by  $n_i$  (Equation (17)).

$$n_i = |L_i \cap L_s| \quad (17)$$

The conflict coefficient of intensity ( $k_{I_i}$ ) is calculated using a standard deviation weighted by the certainty  $q_j^*$  (Equation (18)). A high value of this coefficient indicates a large dispersion of the intensity values  $Q_{I_j}^*$ .

$$k_{I_i} = \sqrt{\frac{\sum_{j \in L_i \cap L_s} q_j^* (Q_{I_j}^* - \overline{Q_{I_i}^*})^2}{2 \frac{n_i - 1}{n_i} \sum_{j \in L_i \cap L_s} q_j^*}} \quad (18)$$

The conflict coefficients for occurrence and depth are calculated in the same way (Equation (19)).

$$k_{F_i} = \sqrt{\frac{\sum_{j \in L_i \cap L_s} q_j^* (Q_{F_j}^* - \overline{Q_{F_i}^*})^2}{\frac{n_i - 1}{n_i} \sum_{j \in L_i \cap L_s} q_j^*}} \quad k_{D_i} = \sqrt{\frac{\sum_{j \in L_i \cap L_s} q_j^* (Q_{D_j}^* - \overline{Q_{D_i}^*})^2}{\frac{n_i - 1}{n_i} \sum_{j \in L_i \cap L_s} q_j^*}} \quad (19)$$

The Figure 69 graphically represents the weighted average intensity ( $\overline{Q_{I_i}^*}$ ), the conflict ( $k_{I_i}$ ), and the number of impacts ( $n_i$ ).

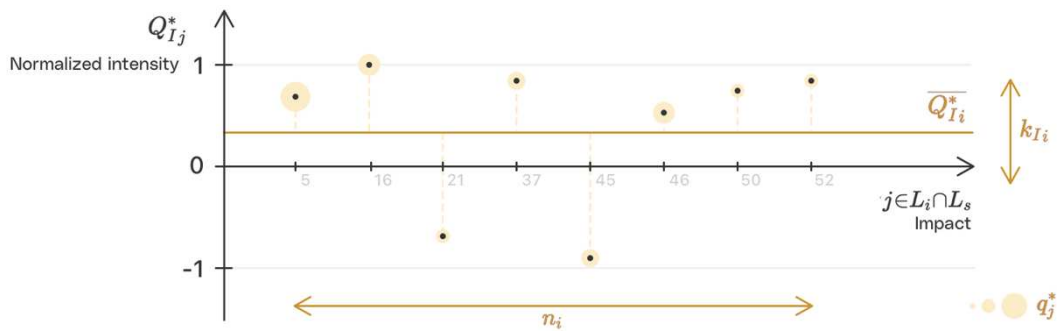


Figure 69. Graphical representation of the weighted average intensity ( $\overline{Q_{I_i}^*}$ ) and conflict ( $k_{I_i}$ ) for indicator  $i$ . The size of the circles represents the level of certainty  $q_j^* \in [0,1]$ .

The combination of  $M_{I_i}$ ,  $n_i$ , and  $k_{I_i}$  serves to characterize the influence of a series of usages on a given indicator ( $i$ ). The values  $\overline{Q_{I_i}^*}$ ,  $\overline{Q_{F_i}^*}$ , and  $\overline{Q_{D_i}^*}$  provide an approximate value of the intensity, occurrence, and depth of the aggregated impact.

We have added a second level of aggregation to the impact list to make it easier to understand within the tool. This level breaks down the eleven themes of social impacts into individual scores. These scores help users better understand the overall impact of their selection without having to review a long list of impacts. Before calculating a theme's score, we must first calculate the score of each impact. Specifically, for each impact indicator belonging to a theme, we define in advance whether an increase in this indicator positively or negatively influences the score of the theme. A positive score means that the chosen usages improve this theme. All trends can be found in a specific grid called the arbitrary grid (an example is provided in supplementary material 19; an arbitrary grid is equivalent to a strategy as described in the Advisor section). However, certain trends are difficult to categorize as positive or negative and can be excluded from the calculation. The trend of the indicator  $i$  favoring the score of the theme  $t$  is represented by  $T''_{it}$ .

Let  $q_i^*$  be the sum of the certainties for the impact indicator (Equation (20)).

$$q_i^* = \sum_{j \in L_i \cap L_s} q_j^* \tag{20}$$

We then calculate the average score of each theme ( $S_t$ ) by taking a weighted average (Equation 21).  $I_t$  is the set of indicators belonging to theme  $t$ . This score is weighted by the sum of certainties ( $q_i^*$ ) and the conflict coefficient of intensity ( $k_{I_i}$ ). This gives more importance to indicators with the most impacts, with the highest certainties, and with the least conflict.

$$S_t = \frac{\sum_{i \in I_t} q_i^* (1 - k_{I_i}) T''_{it} \overline{Q}_{I_i}^*}{\sum_{i \in I_t} q_i^* (1 - k_{I_i}) |T''_{it}|} \tag{21}$$

- A positive score indicates that on average, for theme  $t$ , the selected usages have a desirable influence on the theme.
- A negative score indicates that on average, for theme  $t$ , the selected usages have an undesirable influence on the theme.

This aggregated value implies a significant loss of information. This is why we consider this score as a simple aid for interpretation. It is not recommended to use it to justify a design choice.

### 5.3.2. Calculating corresponding socio-economic and environmental impacts (SMI model)

The calculation of socio-economic and environmental impacts is essentially the same as for social impacts. The only difference is in the *Value* attribute, which replaces the

*Intensity, Occurrence, and Depth* attributes. The level of *Certainty* is also denoted by  $q$ , but this time it comes from studies from which the values are extracted.

First, we define the indicators, impacts, and validity domains using mathematical sets. Let  $L$  represent the set of all impacts in the database IMPACT.  $L_v$  represents the subset of impacts within  $L$  that correspond to the validity domain  $v$  (which can be selected by the user as input). Similarly,  $L_i$  denotes the subset of impacts within  $L$  that correspond to the indicator  $i$  (which can be displayed as output).

Note that at this stage, the only major difference from social impacts is the consideration of validity domains ( $L_v$ ) instead of usages ( $L_u$ ). Figure 70 provides a graphical representation of these sets.

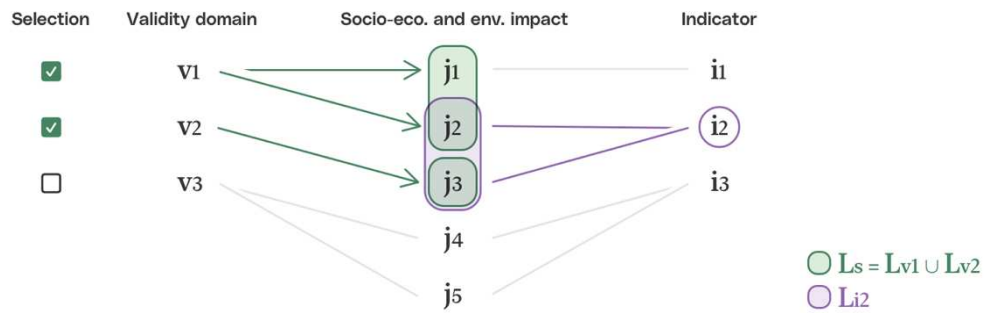


Figure 70. Graphical representation of the sets  $L_i$ ,  $L_v$ , and  $L_s$ . The considered indicator is  $i_2$ .

The weighted average value ( $\bar{V}_i$ ) is calculated for each indicator  $i$  related to the validity domains selected by the user (Equation (22)).

$$\bar{V}_i = \frac{\sum_{j \in L_i \cap L_s} V_j q_j}{\sum_{j \in L_i \cap L_s} q_j} \quad (22)$$

The total number of impacts corresponding to the indicator  $i$  on the selected domains set is denoted by  $n_i$  (Equation (23)).

$$n_i = |L_i \cap L_s| \quad (23)$$

The conflict coefficient of intensity ( $k_i$ ) is calculated using a standard deviation weighted by the certainty  $q_j$  (Equation (24)). A high value of this coefficient indicates a large dispersion of the values  $V_j^*$ .

$$k_i = \sqrt{\frac{\sum_{j \in L_i \cap L_s} q_j (V_j - \bar{V}_i)^2}{2 \frac{n_i - 1}{n_i} \sum_{j \in L_i \cap L_s} q_j}} \quad (24)$$

The Figure 71 graphically represents the weighted average value ( $\bar{V}_i$ ) and the conflict ( $k_i$ ).

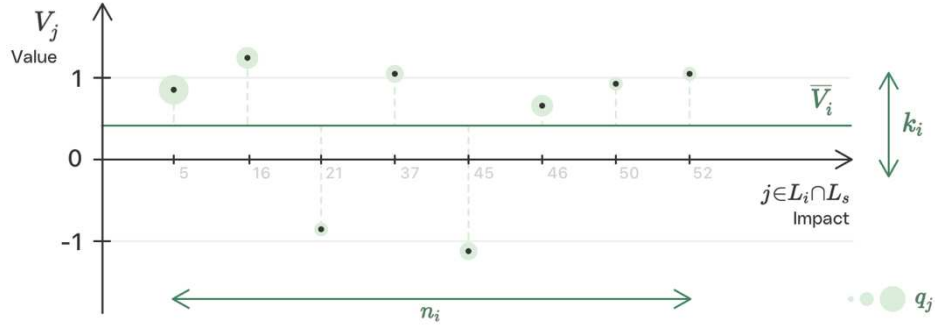


Figure 71. Graphical representation of the weighted average value ( $\bar{V}_i$ ) and conflict ( $k_i$ ) for indicator  $i$ . The size of the circles represents the level of certainty  $q_j \in [0,1]$ .

Just like with social impacts, we calculate an indicative score for each socio-economic and environmental impact theme. We denote  $T''_{it}$  as the trend of indicator  $i$  favoring the score of the theme  $t$  (chosen arbitrarily). All these trends are recorded in the arbitrary grid (see an example on supplementary material 19).

The sum of certainties for indicator  $i$  is noted as  $q_i$  (Equation (25)).

$$q_i = \sum_{j \in L_i \cap L_s} q_j \quad (25)$$

To aggregate different indicators, we normalize the value  $V_j$  so that  $V_j^* \in [-1,1]$ . We then calculate the weighted average  $\bar{V}_i^*$  of the normalized value for the indicator  $i$  (Equations (26)).

$$\forall j \in L_i \quad V_j^* = \frac{V_j}{\max_{j \in L_i} |V_j|} \quad \bar{V}_i^* = \frac{\sum_{j \in L_i \cap L_s} V_j^* q_j}{\sum_{j \in L_i \cap L_s} q_j} \quad (26)$$

We then calculate the average score of a theme ( $S_t$ ) (Equation (27)).  $I_t$  is the set of indicators belonging to theme  $t$ . This score is weighted by the sum of certainties ( $q_i$ ) and the conflict coefficient of intensity ( $k_i$ ). This gives more importance to indicators with the most impacts, with the highest certainties, and with the least conflict.

$$S_t = \frac{\sum_{i \in I_t} q_i (1 - k_i) T''_{it} \bar{V}_i^*}{\sum_{i \in I_t} q_i (1 - k_i) |T''_{it}|} \quad (27)$$

- A positive score shows that on average, for the theme  $t$ , the selected validity domains have a desirable influence on the theme.
- A negative score shows that on average, for the theme  $t$ , the selected validity domains have an undesirable influence on the theme.

### 5.3.3. Going into more detail

In addition to the different metrics related to each impact, the user can also have access to each link between a usage/validity domain and an impact. For example, the user can select a social impact from the output of the Impact Guesser mode, and then access the justifications provided by experts to justify the causal link with each selected input usage (attributes in Table 20). An example is presented in Figure 72 for a social impact. Similarly, the user can access the scientific studies that have established the causality between a validity domain and a socio-economic or environmental impact (*STUDY* database visible in supplementary material 17).

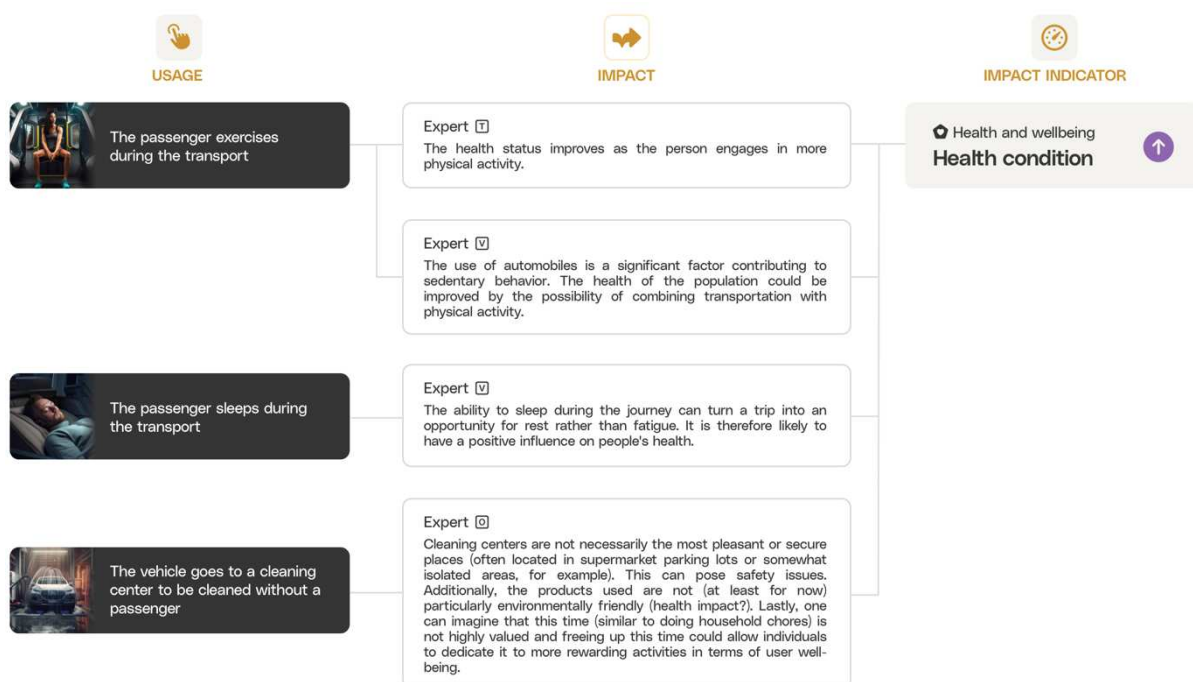


Figure 72. Example of detail elements that the user can obtain by selecting the "Health condition" indicator from the output of the Impact Guesser mode. The text written by the experts corresponds to the "Change" attribute defined in Table 20.

### 5.4. Impact Guesser alternative uses

There are two alternative ways to use the Impact Guesser. Representation selection and representation addition.

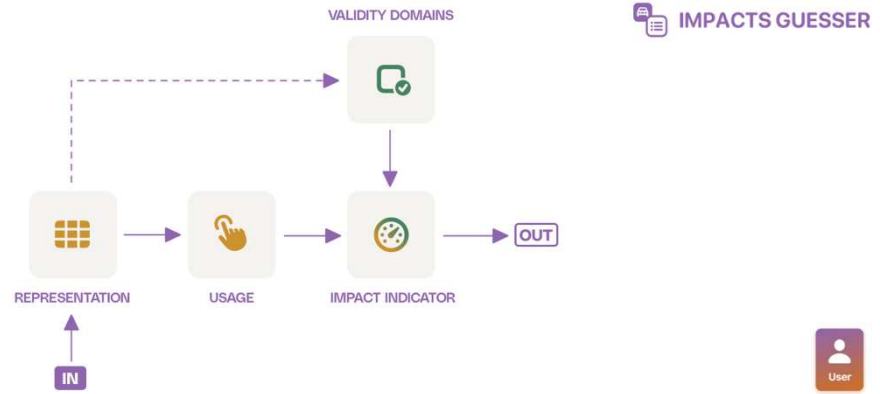


Figure 73. Logic behind the representation selection mode for Impact Guesser.

The representation selection allows the user to browse existing representations, choose one, and see its potential impacts. The user can select a representation from a list (Figure 73 and Table 28). Each of these representations is linked to usages and validity domains. Once the representation is selected, the tool calculates impacts the same way as described in Section 5.3.

Table 28. Input and output of the Impact Guesser’s representation selection mode.

	Input	Output
Description	Select a representation.	List of potential social impacts; List of potential socio-economic and environmental impacts
Example	Citroën Skate Concept	Stress: ↓ ; CO2 emissions: ↓ ; Health condition: ↑

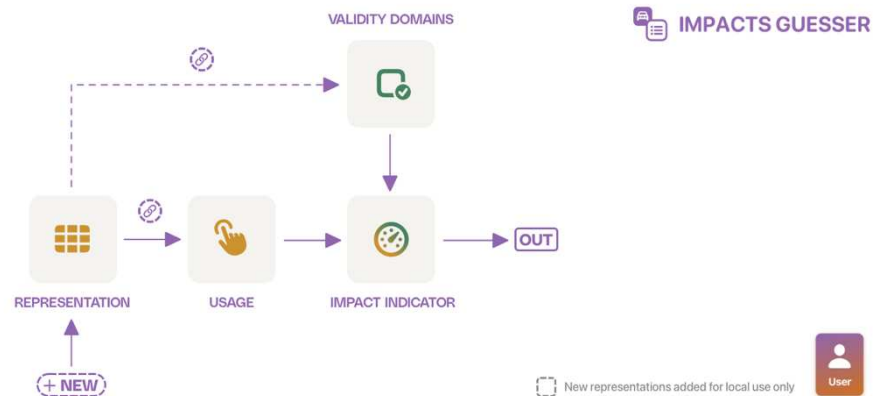


Figure 74. Logic behind representation addition of Impact Guesser mode.

The representation addition allows querying the tool with a new representation (for example, testing a new concept or adding a science fiction book about AVs) so that the tool anticipates its impacts (Figure 74 and Table 29). The typical case is that of a designer who wants to test a concept or an idea of AV and wants to save it into the tool. As the new representation is not referenced in the database, it is the responsibility of the user to add links to the usages and validity domains. The process involves creating



a new representation and then linking it to existing usages and validity domains. This addition is only for local use and is not shared with other users. As we saw in Section 4, users are not authorized to modify databases. Therefore, users can only choose from existing usages and validity domains. However, in a later version of the tool, an administrator could manually validate, adapt, or reject a proposal from a user to upgrade the shared version of the database.

Table 29. Input and output of the Impact Guesser’s representation addition mode.

	Input	Output
Description	Add a new representation (concept, designer sketch, other...) and link it to usages and validity domains.	List of potential social impacts; List of potential socio-economic and environmental impacts
Example	“The new Apple Car”	Stress: ↓ ; CO2 emissions: ↓ ; Health condition: ↑

## 5.5. Walkthrough: Example of tool use

In this section, we present a hypothetical use case of the tool in an innovation configuration within a company. This example is intended to be representative, but it should not be considered as the only way to use the tool. Figure 75 illustrates the various phases involved. For more information, refer to the supplementary material 20, which provides a comprehensive walkthrough with screenshots of a prototype of the tool throughout the different phases.

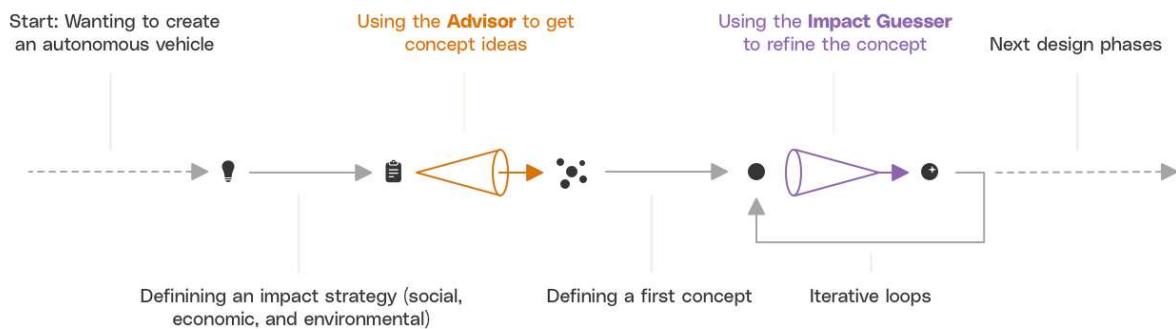


Figure 75. Example of using the tool within an early design phase (details in the supplementary material 20).

## 6. Admin modes

Admin modes aim to enrich or consolidate the knowledge already present in the databases. There are six modes: (1) Adding new representations, (2) Adding usages, (3) Adding links between representations and validity domains, (4) Validating a representation proposed by a user, (5) Adding social impacts with the help of experts,

and (6) Adding socio-economic and environmental impacts with the help of scientific studies.

## 6.1. Adding representations

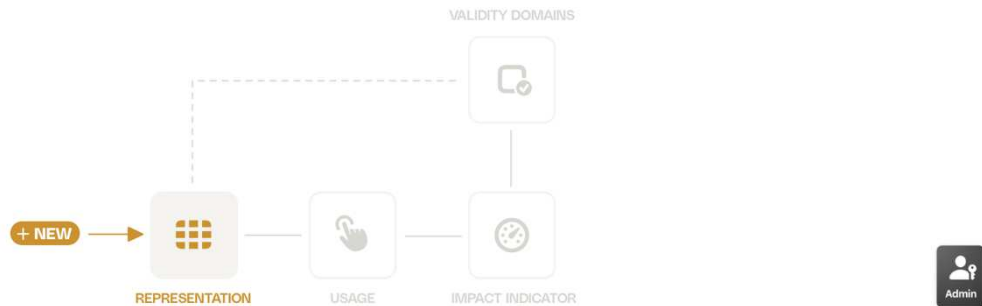


Figure 76. Logic of adding representations.

Adding a new representation is quite simple and concerns exclusively the RUI model (Figure 76): It consists of (1) identifying an existing representation that seems to have at least one potential usage for the AV, and then (2) filling in the 8 attributes as precisely as possible. To determine if a representation is relevant for the RUI model, it is recommended to adhere to the four initial conditions (see Chapter 4):

1. The vehicle is primarily designed for passenger transport.
2. The number of seats ranges from 1 to 9 (category M1 of the United Nations Economic Commission for Europe, 2017).
3. The vehicle has an automation level of 4 or higher on the SAE scale (SAE International, 2021).
4. The vehicle operates in a country with a high human development index ( $\geq 0.700$ ) (Gibbs, 2022; UNDP, 2020).

## 6.2. Adding usages

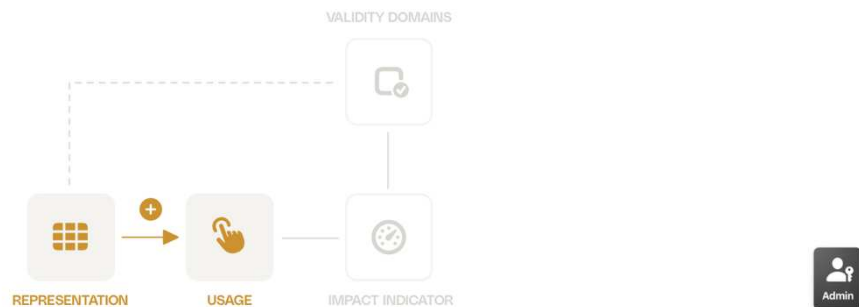


Figure 77. Logic of adding usages.

Adding a usage is also known as extraction and concerns exclusively the RUI model. This involves identifying a usage in an existing representation (Figure 77). To add a usage, it must include a vehicle that meets the four initial conditions presented in the previous section (Section **Error! Reference source not found.**). The process of adding a usage is described in detail in Chapter 4, Section 3.7.1.

### 6.3. Adding Representation-Validity Domain links

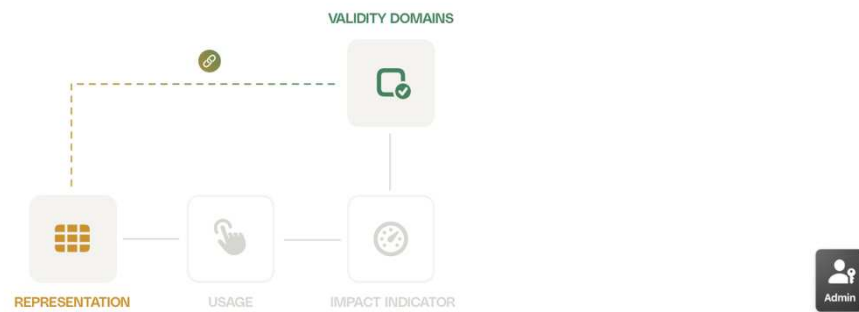


Figure 78. Logic of adding links between representations and validity domains.

Representations and domains of validity belong respectively to the RUI (*Representation-Usage-Impact*) and SMI (*Study-Method-Impact*) models. This step aims to assign validity domains to each representation (Figure 78). To do this, it is sufficient to provide, for each representation, one or more mode of use as well as one or more continent of deployment.

### 6.4. Adding social impacts (experts)

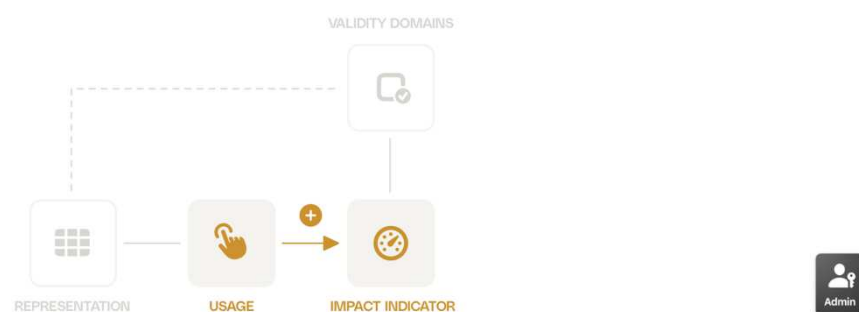


Figure 79. Logic of adding social impacts.

Adding social impacts (Figure 79) is the most important part of the RUI model. It is separated into two successive steps:

1. **Questionnaire.** A questionnaire is sent to experts to collect impacts from a list of usages.

2. **Coding.** An administrator integrates the information collected from experts into databases.

All of this is explained in detail in the Chapter 4, Section 3.7. Specifically: the criteria for selecting experts, the structure of the questionnaires, the organization of sessions, the synthesis of results, and the coding of impacts.

It is important to clarify that when adding "free text" type attributes during the coding phase, such as the *Name* of an indicator (Table 5), it is the responsibility of the administrator to be vigilant and not define two indicators that are formulated differently but mean the same thing. For example, "More room to park needed" and "Parking spaces required" should be listed under a single name.

## 6.5. Adding socio-economic et environmental impacts (scientific studies)

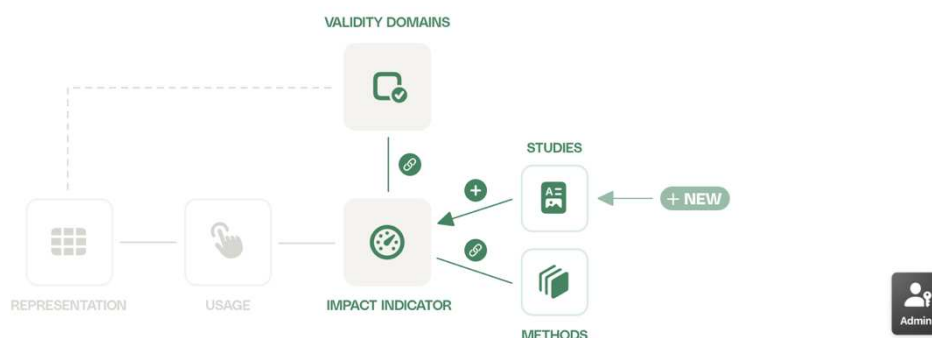


Figure 80. Logic of adding socio-economic and environmental impacts.

The addition of socio-economic and environmental impacts concerns exclusively the SMI model. It consists of identifying a scientific study and extracting quantitative impacts while respecting several criteria (see Figure 36 and Chapter 3). To ensure traceability of information, the *STUDIES* and *METHODS* databases must also be completed. The impact addition protocol is presented in Chapter 3, Section 2.3.

## 7. Limitations and perspective of the tool

It is important to note the numerous limitations of the AutoVision tool and its two modes. We use averages and other metrics to aggregate results from the databases. However, these metrics may not always reflect reality, as biases related to expert interrogation (RUI model) or interpretation of studies (SMI model) can impact quality of results. For example, if 16 experts claim that "exercising in a vehicle" improves health, while only 2 disagree, those 2 experts may be more knowledgeable about sports. What if exercising in a vehicle could be harmful for health because sessions are less regular

or of unequal duration? Unfortunately, these nuances cannot be captured in our calculated metrics. To limit this problem, we provided a feature named “Going into more details” for users to access the elements mentioned by experts by clicking on the impacts’ links. In perspective, the tool could be improved by complementing the quality coefficient ( $q$ ) with a "consolidation" coefficient. This coefficient could give credit to specific studies or experts, following a review process carried out by other experts. For example, a healthcare specialist could evaluate the quality of experts' statements on "health and well-being" issues.

Aggregation has two disadvantages. Firstly, it can obscure important phenomena caused by compensatory effects. This means that when two opposing trends are strong enough, they can cancel each other out, making them difficult to detect (hence the conflict coefficient). Secondly, when many usages or validity domains are selected as input, some of them may have more weight in the calculation of an impact, simply because more experts or scientific studies have focused on the subject. This is a choice because we think it helps prioritize the impacts that were most documented. However, it is crucial to note this aspect when interpreting the results.

The tool has another limitation: the two SMI and RUI models do not interact with each other. This means that the choice of usage has no influence on the socio-economic and environmental impacts at the output. Similarly, the choice of a validity domain has no influence on the social impacts at the output. We have specified some of these limitations in the user guide to avoid users from misinterpreting the results (see supplementary material 18). In perspective, both models could be interconnected. For example, by linking each usage from the RUI model to its compatible mode of uses from the SMI mode (e.g. “The passenger gets discounts by using certain vehicles” would be only possible in shared mode of use).

## 8. Conclusion

The AutoVision tool that we have developed offers two modes of use. These modes allow users to link autonomous vehicle characteristics, referred to as usages and validity domains, to potential long-term impacts. These impacts can be qualitative social impacts or quantitative socio-economic and environmental impacts. Our main objective for developing this tool was to expand the knowledge of its users regarding the potential impacts of autonomous vehicles and to assist decision-makers in making more responsible choices.

The AutoVision tool has been developed to provide designers with prompt and valuable feedback on their ideas and choices during the early design phase of autonomous vehicles (AVs). However, unlike more comprehensive impact analysis methods such as prospective structural analysis or social life cycle analysis, AutoVision cannot conduct

a detailed analysis of causal relationships. This means that it is unable to evaluate the probability of one impact compared to another. At the early design stage, the product is still undefined, making it impossible to provide a robust probabilization of the impacts and causal chains involved, which is known as the "Collingridge dilemma". As stated in the introduction, the goal of AutoVision is not to eliminate uncertainty but rather to acknowledge it. To achieve this, the tool has been designed to be more efficient than complex impact assessment methods by quickly providing information on the possible impacts of a concept. It can be likened to agile methods or product evaluation methods, but with a long-term focus. The tool is user-friendly, even for individuals who are not experts in impact analysis. Additionally, it is designed to be easily updated with new studies data, knowledge, projects, and representations, either manually or automatically.

With this in mind, we developed AutoVision under the assumption that companies would only consider impacts if the effort required to anticipate them was not too significant. This is why the tool has been built with ease of use in mind. In our opinion, the main obstacle to its adoption is the resistance encountered when implementing it. This refers to the difficulty of consistently integrating it within the company over an extended period.

The initial statement was: companies either lack sufficient interest in anticipating the long-term impacts of a disruptive future product, or they lack the means to do so. If companies lack the means to anticipate impacts, the AutoVision tool is good news because it demonstrates that it is possible. However, we cannot dismiss the first assumption, as it is also likely that companies are not interested in considering the long-term impacts of their products. Financial reasons can be a contributing factor here, as avoiding certain impacts can sometimes conflict with business opportunities. We believe that the truth lies somewhere between these two hypotheses, as companies may also have an interest in anticipating the consequences of their products, particularly to comply with legislation.

In the following two chapters, we perform experiments using the Impact Guesser and Advisor modes of the tool. These experiments involve 27 and 8 participants respectively. The objective of these experiments is to assess the effectiveness of the Impact Guesser in providing users with new knowledge and fostering critical thinking about their proposed concepts. Additionally, we aim to evaluate the Advisor's effectiveness in generating concepts that align with a car manufacturer's strategy.



Citroën Skate Concept used as a case study during the experiment



CHAPTER 6

# Impact Guesser evaluation

This chapter evaluates the Impact Guesser mode of the AutoVision tool with 28 participants and tests its effectiveness in helping users acquire new knowledge, propose responsible concepts of autonomous vehicles, justify choices, and warn of impacts. The results suggest the tool's relevance in promoting responsible innovation for future disruptive products.



# 1. Introduction

In Chapter 5, we discussed the AutoVision tool, which was created to help decision-makers and designers involved in autonomous vehicle development. This tool has two modes: the Impact Guesser mode and the Advisor mode. The Impact Guesser mode generates a list of potential impacts based on a given autonomous vehicle concept (or scenario). The Advisor mode provides guidance for defining a concept that aligns with a preferred or non-preferred impact strategy.

In this chapter, our focus is on the Impact Guesser mode. We aim to test its effectiveness in providing knowledge about impacts to users and helping them become more critical of the concepts they propose for autonomous vehicles.

We start this chapter by describing the experimental protocol used to test our four hypotheses (Section 2). We then present the results (Section 3) and analyze them in a discussion section (Section 4). We conclude on the Impact Guesser mode's potential to help a company anticipate the long-term impacts of a future disruptive product.

## 2. Experiment design

In this section, we describe a controlled experiment to test the four hypotheses presented in the introduction, using the Impact Guesser mode.

We have created an experiment where each participant acts as a strategic decision-maker in an automotive company. The experiment is positioned before the design of a new product, when it is essential to define strategic directions. The task of each participant is to define a design brief for future designers of the autonomous vehicle. A design brief is a document that describes the objectives and requirements of a design project. It usually includes information about the target audience, intended usages, constraints to follow, and risks. Designers use it as a guide to ensure that the final product meets the company's instructions. In the experiment, participants must create a design brief based on a fictional user profile and a specific mode of use (private or shared). The design brief includes a "Usages" section where the participant must imagine usages (like those in the tool). It also includes a warning section where the participant can add all the information, he/she deems important to communicate to the designers to avoid potential undesirable impacts. This way, the designers would pay particular attention to certain aspects. An example is shown in Figure 81.

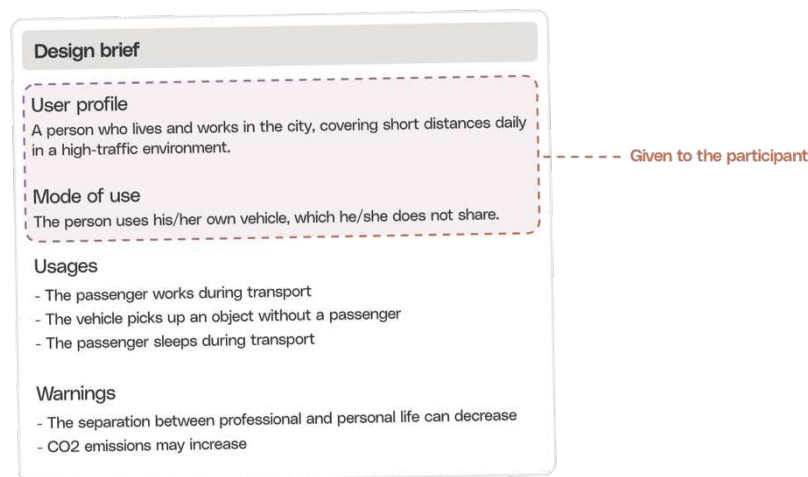


Figure 81. Example of a design brief adapted to the experiment.

Regarding the desired effects of the mode, we have formulated four hypotheses. (h1) The use of the tool allows users to acquire knowledge about the likely impacts of autonomous vehicles, which could lead to more informed decision-making. (h2) The use of the tool allows for more usages (as defined by Yannou & Cluzel, 2015) to be rejected, especially those likely to generate undesirable impacts. (h3) The use of the tool has a positive influence on the number of justifications for rejections related to the risk of causing undesirable impacts. (h4) The use of the tool has a positive influence on the number of warnings, to prevent undesirable consequences during product design. The four hypothesis are summarized below:

- h1.** The use of the tool allows users to acquire knowledge about the likely impacts of autonomous vehicles.
- h2.** The use of the tool allows for more usages to be rejected, especially those likely to generate undesirable impacts.
- h3.** The use of the tool has a positive influence on the number of justifications for rejections related to the risk of causing undesirable impacts.
- h4.** The use of the tool has a positive influence on the number of warnings.

The following sections detail the experimental protocol, the evaluation criteria used for each of these hypotheses, as well as the calculation of results.

## 2.1. Protocol

To evaluate the four hypotheses, we conducted an experiment in two consecutive parts. The first part was conducted without the AutoVision tool, and the second part was conducted with it. We designed this experiment for participants with varying levels and fields of expertise. Each participant carried out the experiment individually. It involved evaluating the same group of participants twice, once without the tool and once with

the tool, in what is called a within-subjects design. We compared the results from both parts to determine the tool's influence on multiple metrics. This approach differs from a between-subjects experiment, which separates two groups - a control group without the tool and a test group with the tool. Despite the potential for bias, we chose this approach for two reasons: (1) We can achieve high statistical power with fewer participants, which is convenient as it is difficult to monopolize half a day of experimentation for teams in an automotive group. (2) A between-subjects experiment would mean that half of the participants would not use the tool. We preferred to make the experiment attractive to all participants by giving them the opportunity to use the tool, especially since the experiment lasts for three hours.

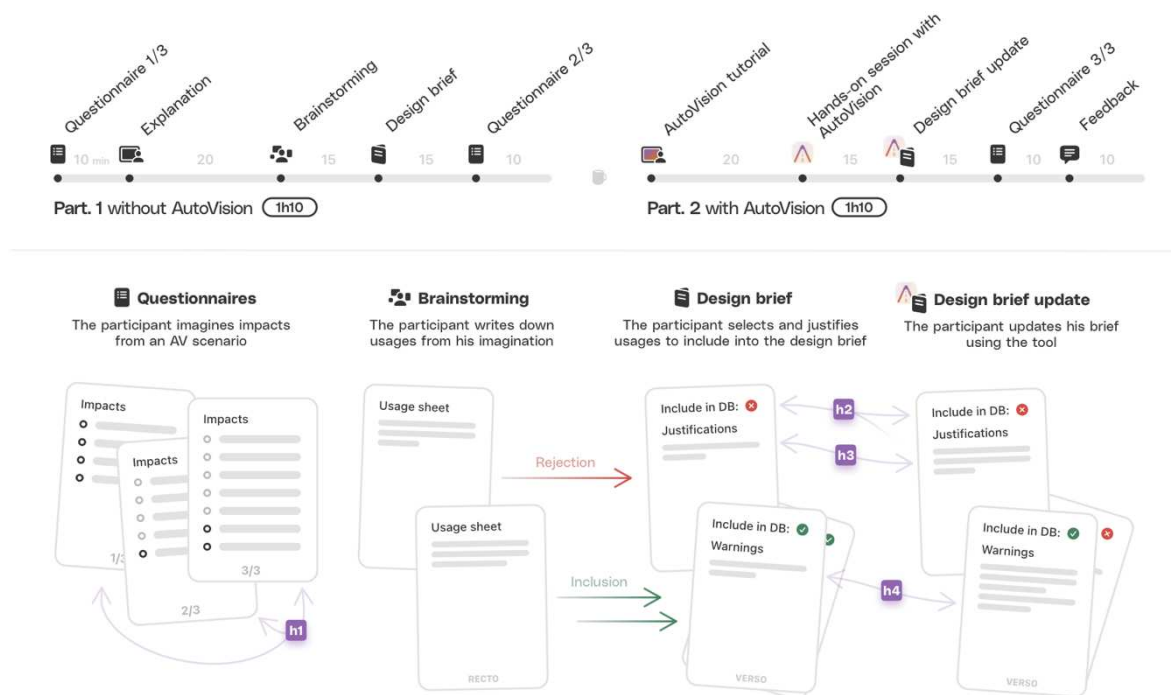


Figure 82. The experiment procedure.

The experiment is divided into two parts, each lasting 1 hour and 10 minutes, with a break in between (Figure 82). In the first part, participants (detailed in Section 3.1) begin by completing a questionnaire where they must anticipate the impacts of an autonomous vehicle concept (shown as a video available in Section 2.1.1). One domain of validity, the continent, was removed, and only 30 usages were available in the prototype. Following this, they receive an explanation of the experiment and are asked to imagine a design brief that corresponds to a specific user profile and mode of use. They have a total of 30 minutes, with the first 15 minutes dedicated to brainstorming various usage ideas (with no constraints), and the last 15 minutes spent formulating a brief by assigning usages (deciding whether to keep them in their design brief or not) and adding warnings. The user profile and mode of use are only given in the second 15-minute slot. Participants are instructed to propose a responsible design brief that

considers the needs of society, individuals, and the environment. In addition, they are asked to consider the responsibility and image of the car manufacturer. to exhaust the participants' ideas. After this, they complete the same questionnaire as the first one before taking a break. In the second part, participants spend 35 minutes learning how to use the AutoVision tool through a tutorial and initial discovery (just hands-on). They then have an additional 15 minutes to adapt their design brief using the tool. Once their design brief is completed, they answer the first questionnaire once more. Finally, they participate in a feedback phase where they can give their opinion on the tool.

A session takes place in a large meeting room and lasts for three hours. The session is led by one experimenter (here it was the author of this thesis, as a PhD student) using digital and paper materials (see supplementary material 21). Each participant is given pens of various colors and must have access to a computer to use AutoVision. To achieve significant results, we had planned to call on a minimum of 27 participants, eventually in multiple sessions (see Section 3.1 for details). We have designed the experiment to be open to participants of all levels and areas of expertise. In the experiment we conducted, we prioritized individuals focusing on mobility innovation within an automotive group. Additionally, we have contacted other participants, including researchers. For more details about these participants, please refer to the results section (Section 3). The following subsections provide further details on the various materials used for the experiment.

### 2.1.1. Questionnaire

The goal of the questionnaire is to capture the impacts that participants can forecast from their viewpoint related to a specific autonomous vehicle concept. Each participant is invited to answer the same questionnaire three times. This way, it is possible to calculate the participant's progression on the number of impacts generated at the end of the two parts (with and without AutoVision). For our experiment, we have chosen a video about the autonomous vehicle concept "Skate" presented in 2021 by Citroën (Citroën France, 2021). The video is short, showcasing various usages of autonomous vehicles, and is from the Stellantis group. We chose a concept with triivial usages, such as working or sleeping in an AV, so that participants are not too influenced when they come up with ideas during the brainstorming phase (they would have had these ideas whether or not they had seen the concept before). The questionnaire is divided into three parts. The first one is a reminder of the concept studied (shown in the video). The second part consists of indicating 19 impact themes – corresponding to the AutoVision's themes - to ensure that participants imagine impacts within the scope of the experiment. Finally, the last part is dedicated to participants' answers. It is a free text field in which each participant is invited to list all the impacts they imagine. Figure 83 shows the layout of these three parts.

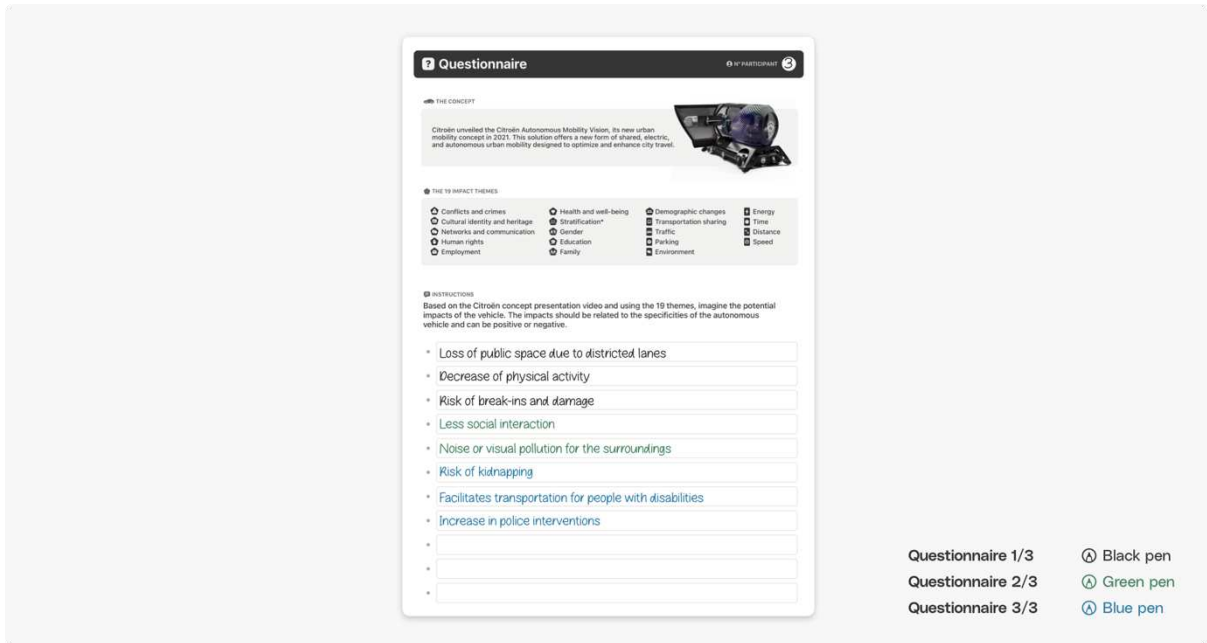


Figure 83. The questionnaire distributed three times to the participants (examples are from participant responses).

The questionnaire is distributed to participants three times. Participants are asked to add new impacts in three different colors: black for impacts imagined before the experience, green for impacts imagined after working on the design brief, and blue for impacts imagined after using AutoVision to update the design brief. The resource is available in supplementary material 21.

### 2.1.2. Brainstorming

During the brainstorming phase (15 minutes), participants are provided with several identical usage sheets (Figure 84). Each participant is then asked to describe the usages of the autonomous vehicle they have envisioned, with one usage per sheet. Participants are free to provide a detailed or brief description of the usage in the free field provided on each sheet. The instruction given is that the usage must consist of a basic action performed by the passenger, the vehicle, or an external person. We ask each participant to provide about ten usages during the brainstorming session. It is important to note that at this stage, no constraints are given, such as a user profile or usage mode, so participants are free to propose whatever they want. The resource is available in supplementary material 21.

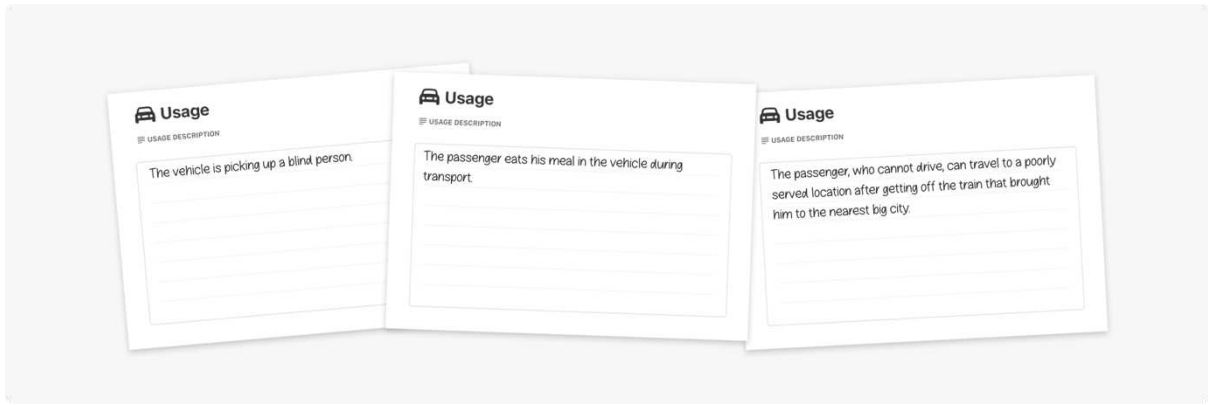


Figure 84. Usage sheets used during the brainstorming phase (examples are from participant responses).

### 2.1.3. Design brief

After the brainstorming phase, design brief materials are distributed to participants (Figure 85). Each receives a design brief, which includes an imposed user profile, an imposed mode of use, and a free text field for adding warnings. Before the experiment, we defined three different design briefs. The first (design brief A) is about a city dweller who uses a shared autonomous vehicle. The second (design brief B) is about a person living in the countryside who uses his/her own AV. The third (design brief C) is about a traveler who uses a shared AV. For more details, the design brief materials, as well as all other experiment materials, are provided in supplementary material 21. We imposed the user profile and mode of use to avoid giving participants a too heavy workload and to avoid creative blockages by adding a minimum set of constraints that can foster creativity (Rosso, 2014). We also proposed three different briefs to ensure that the experiment results are not different whatever the user profile and mode of use.

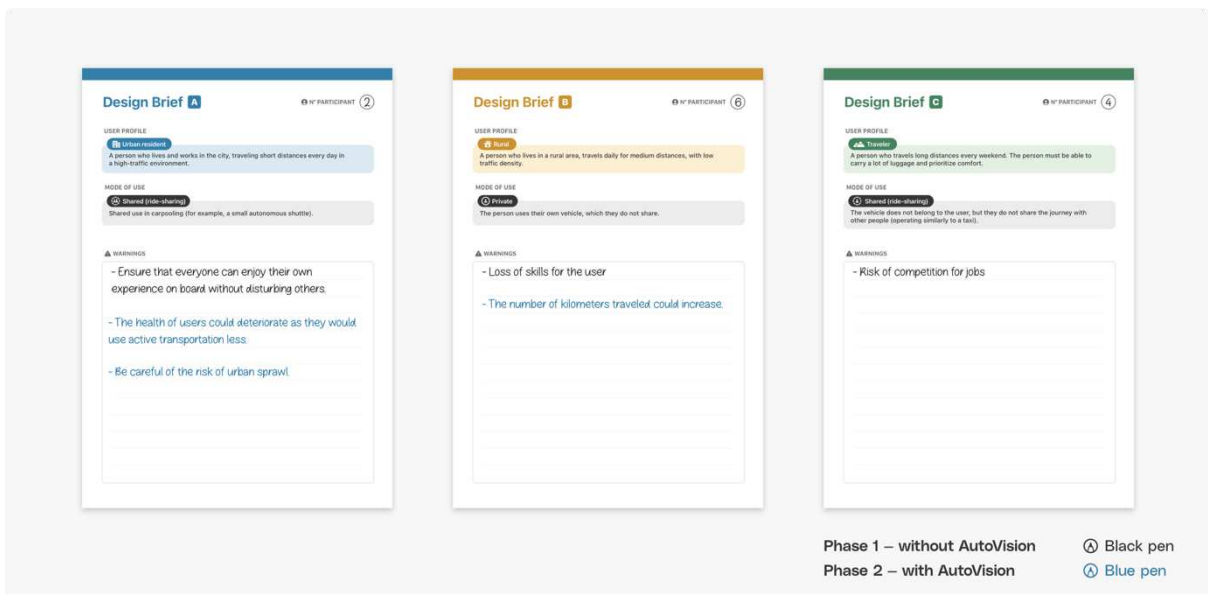


Figure 85. The three types of design briefs randomly assigned to users (one per person, examples are from participant responses).

During this 15-minute phase, each participant reviews the usage sheets he/she filled out in the brainstorming phase. On the back of each usage sheet, there are two parts (Figure 86). The first part requires the participant to indicate whether the proposed usage is included in the design brief or rejected. If he/she chooses to reject it, the participant must explain why in the field below. A participant might reject a usage if it does not fit the user profile, the mode of use or if the usage is likely to have significant long-term impacts. We also explained to the participants that their choices involved the responsibility of the company (as defined by the European Commission, 2011). Additionally, if the participant chooses to include the usage in the design brief, he/she can provide warnings. For instance, if the usage is "A child traveling alone in the vehicle," a warning such as "The child may be unsupervised" can be added. Participants are told that the purpose of these warnings is to draw the attention of designers who will receive the design brief to potential impacts that must be considered as early as possible. Participants fill out these sheets twice: first without the tool (using a black pen) and then with it (using a blue pen, corresponding to the design brief update phase). The same goes for design brief support, for which additional warnings can be added (Figure 85). It should be noted that a participant may change his mind about whether to include a usage in their design brief. For example, the middle sheet in Figure 86 shows that the participant initially chose to include the usage in its design brief, but ultimately rejected it during the phase with the tool (part surrounded in blue).

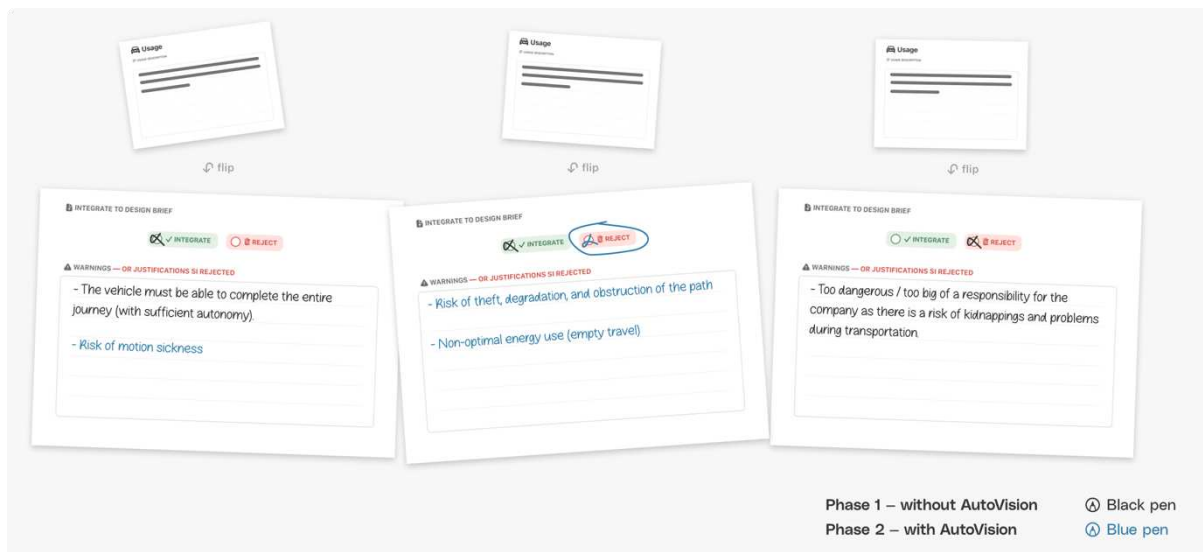


Figure 86. When participants flip the usage sheets, they can indicate whether they want to integrate the usage into their design brief or not (examples are from participant responses).

At the end, the participant slides all the cards into their design brief support, which folds in on itself.

## 2.1.4. Feedback

At the end of the experimentation, we distribute a feedback questionnaire to all participants. The questionnaire has nine questions that complement the quantitative results with participants' subjective opinions. You can find detailed information about the questions in the criteria section (3.2). The resource is available in supplementary material 21.

## 2.1.5. AutoVision prototype

During the second part of the experiment, participants use a simplified version of the AutoVision tool. They have access only to the Impact Guesser mode. On the scenario page (on the left, Figure 87), they are able to select a list of usages and validity domains, and then obtain a list of impacts with different metrics such as trend, intensity, number of experts or scientific studies used to calculate the results, and level of conflict (on the right, Figure 87). If they wish, they can also display the occurrence, depth, and selected usages related to each impact. Additionally, the interpretation help, which calculates a score for each impact theme, is available to assist with interpreting the results.

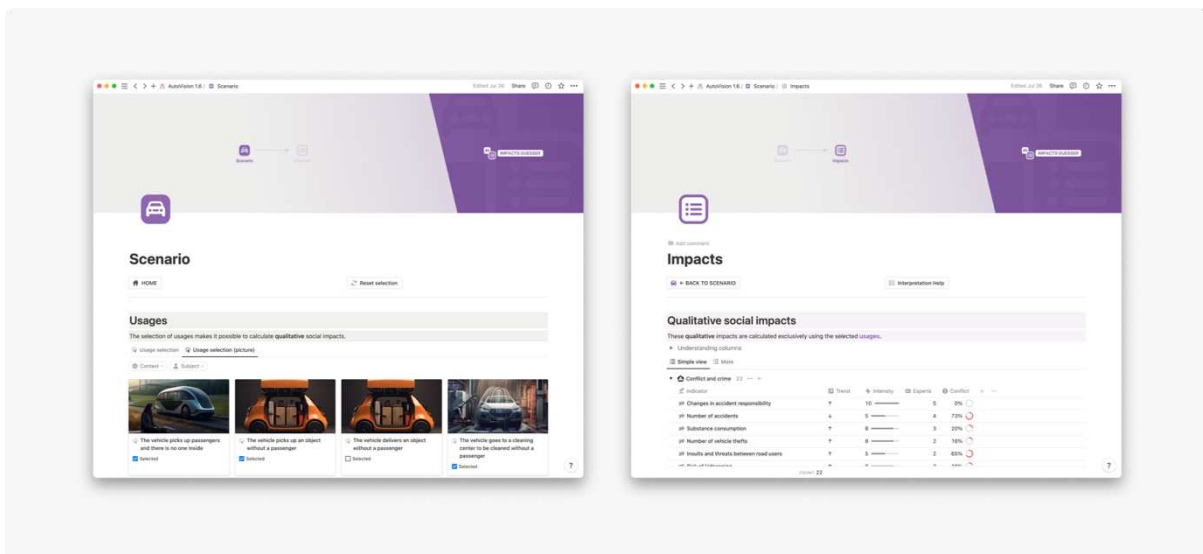


Figure 87. The two main pages of the AutoVision tool used by participants (Impact Guesser mode only).

## 2.2. Criteria

This section provides a detailed explanation of the criteria used to test the four hypotheses. The first part is about how the tool affects the participants' knowledge (hypothesis 1). The second part is about how it affects the rejection of usages (hypothesis 2). The third part is about how it affects the justifications given for rejecting those usages (hypothesis 3). The fourth part examines how it affects the warnings for



the design brief (hypothesis 4). There is also a non-quantitative section that discusses how the tool impacts the responsibility of design briefs.

### 2.2.1. Knowledge acquisition (KNOWLEDGE)

We use the questionnaires that participants answer before, during, and after the experience to compare how their knowledge of the possible impacts of autonomous vehicles changes. You can find more details on the questionnaire structure in Section 3.1.1.

Let  $I_0$  be the set of impacts reported in the questionnaire before the experiment. Let  $I_1$  be the set of additional impacts reported after phase 1 (without the tool). Let  $I_2$  be the set of additional impacts reported after phase 2 (with the tool). To calculate the progression rate after each phase in terms of the number of impacts, we include all impacts reported by the participant. At this point, it is important to exhaust their ideas, even if it means slightly exceeding the allotted time. The progression rate  $k_1$  includes impacts reported without the tool, while the progression rate  $k_2$  combines impacts reported both with and without the tool (Equations (28)).

$$k_1 = \frac{|I_1|}{|I_0|} \quad k_2 = \frac{|I_1| + |I_2|}{|I_0|} \quad (28)$$

We use a one-sample unilateral T-test (Ross, 2019) to compare the average progress of participants. We chose this test because we are comparing two values (before and after using the tool) from the same population, and we are only interested in cases where the tool's rate is higher. Our evaluation criterion is called KNOWLEDGE and corresponds to the hypothesis: The use of the tool enables users to gain knowledge about the likely impacts of autonomous vehicles. If the results were significant, it would mean that the acquired knowledge is greater than what the participants would have found on their own without using the tool.

During the feedback phase of the experiment, participants are asked to answer two questions about the knowledge they gained. The first question asks them to rate the statement "The use of the industrial tool allowed you to acquire new knowledge on the impacts of autonomous vehicles" using a 5-point Likert scale that ranges from "Strongly disagree" to "Strongly agree" (Likert, 1932). The second question is open-ended and asks participants to list any knowledge they acquired while using the tool. These personal responses aim is to assist in interpreting the results of the questionnaires.

### 2.2.2. Rejection of usages (REJECTION)

In this part, we want to check whether the tool helps participants to select the best usages for their design briefs. It is important to note that any usages that were rejected

due to not being compatible with the design brief are not factored into any calculations. Participants added "does not match the usage mode" or "does not match the user profile" for the non-compatible usages, and were trusted in this assessment. So the rejections are specifically attributed to the risks of negative impacts.

Let  $U$  be the set of usages that a participant has imagined.  $U_r$  is a subset of  $U$  that consists of all rejected usages. The index  $r$  is the rate of rejected usages divided by the total number of usages (Equation (29)).

$$r = \frac{|U_r|}{|U|} \tag{29}$$

The scale of this rate ranges from 0 to 1. A value of 1 indicates that all generated usages are rejected, while a value of 0 means that no usage is rejected. To compare the average of this rate, we use a one-sample unilateral T-test. The associated criterion is called REJECTION and the hypothesis being tested is: The use of the tool allows for more usages to be rejected, especially those likely to generate undesirable impacts. If the results were significant, it would suggest that, on average, the tool could help reject more usages and, therefore, help users be more critical of their proposals.

In the feedback section, participants are asked to rate the statement "The use of the tool has helped you reject usages that could have negative consequences" using a 5-point Likert scale. This subjective feedback is worth comparing with the results on the rejection rate.

### 2.2.3. Justifications for rejections (JUSTIFICATION)

To further investigate rejected usages, we can also assess the impact of the tool on the justifications given for each rejection.

Let  $J$  denote the set of justifications provided for the set of rejected usages  $U_r$ . We define index  $j$  as the average number of justifications per rejected usage (Equation (30)).

$$j = \frac{|J|}{|U_r|} \tag{30}$$

To compare the average of this index with and without the tool, we use another one-sample unilateral T-test. The criterion associated with it is called JUSTIFICATION. The hypothesis being tested is: The use of the tool positively impacts the number of justifications for rejections related to the risk of causing undesirable impacts. A significant result would indicate that the tool enables additional justifications for rejecting usages related to potential impacts.

In the feedback section, participants are asked to evaluate the influence of the tool on their justifications using a scale. The question is: "What percentage of your

justifications do you attribute to the use of the tool?" Participants can choose from 11 options between 0% to 100%. If the tool was not used at all for justification, the appropriate answer would be 0%. Conversely, if all justifications came from the tool, the answer would be 100%. These subjective responses should help put the obtained quantitative results into perspective.

We did not find a satisfying way to also measure the quality of a justification because it is very subjective.

#### **2.2.4. Warnings about integrated usages (WARNING)**

When creating the design brief, participants have the option to fill in a warning field for each usage, as well as for the brief. This field is intended to inform designers of potential risks so that they can be addressed during the design process. Here, we want to measure the influence of the tool on these warnings.

Let  $W$  be the set of warnings added to the design brief (there may be several per usage). Let  $U_a$  be a subset of  $U$  corresponding to the set of usages added to the design brief. We define the index  $w$  as the ratio of the number of warnings to the number of accepted usages (plus the design brief itself, for which warnings can be given) (Equation (31)).

$$w = \frac{|W|}{|U_a| + 1} \quad (31)$$

We can compare the average of this index with and without the tool using a one-sample unilateral T-test (warnings of part 1 vs warnings of part 1 and 2). The criterion associated with this test is called WARNING and corresponds to the hypothesis that: The use of the tool has a positive influence on the number of warnings. If the results are significant, it would indicate that the tool helps participants to warn more about the risks of the proposed usages and validity domains. The duplicate warnings between the design brief and the usages are removed.

In the feedback section, participants are asked to rate the following statement on a 5-point Likert scale: "The use of the industrial tool helped you better warn of the risks of your proposals." These personal opinions should help provide context for the WARNING criterion results.

#### **2.2.5. Responsibility of the design briefs**

To determine if participants believed that the tool affected the responsibility of the design briefs they created (i.e. less likely to generate negative impacts), we ask participants to evaluate the statement "Using the tool allowed you to build a design brief that is likely to generate fewer undesirable impacts" on a 5-point Likert scale in the feedback questionnaire. Finally, we ask an open-ended question: "What benefits did the

tool bring you in creating the design brief?" Participants can freely answer using a text field.

These two questions work together to provide a qualitative assessment. They are designed to gather the participants' overall opinion on the usefulness of the tool. By interpreting the responses to these questions, we could gain perspective on all the results, as well as their relevance in a real industrial setting.

## 2.3. Minimum number of participants

To size the number of participants in the experiment, we rely on one-sample unilateral T-tests conducted on the RESPONSIBILITY, REJECTION, JUSTIFICATION, and WARNING criteria. We aim to detect a medium to high effect of the tool on these four criteria, which is why we choose an average effect size of 0.5. We set the error risk at  $\alpha = 5\%$  and the statistical power at 0.8. Using statistical software, we calculated a minimum number of participants of 27.

# 3. Results

## 3.1. Participants and sessions

We conducted five sessions involving a total of 28 people. Two of these sessions took place within the Stellantis automotive group in France, with 13 participants in total. Among them were six designers, four engineers, three ergonomists (all ergonomists were also designers), and three PhD students. The remaining three sessions were held at the LGI industrial engineering laboratory of CentraleSupélec in France, with a total of 15 participants. Among them were 12 PhD students and three researchers/professors. See Figure 88 for examples in the field.



Figure 88. On the left: Session at the laboratory. On the right: Session at Stellantis. photos by Zhenguo Cui and Guillaume Thibaud, respectively.

In the following sections, we systematically calculated the differences between the two groups (company and laboratory).

## **3.2. Differences between the three design briefs**

As stated in Section 2.1.3, we started with three design briefs. The first brief (design brief A) pertains to a city dweller using a shared AV. The second brief (design brief B) pertains to an individual living in the countryside who uses their own autonomous vehicle. The third brief (design brief C) pertains to a traveler using a shared autonomous vehicle. Each participant was randomly assigned one of the three design briefs.

Before presenting the different results, we had to make sure that the results remained consistent among the participants regardless of the design brief received. This condition is essential to be able to calculate the results of the four indicators for all participants. We conducted a one-way ANOVA statistical test on the three design briefs. In total, we conducted eight tests, two for each indicator (results without tool and with tool). With a significance level of 0.05, we found p-values all greater than 0.10, which shows that the briefs do not have a significant influence on the results (all results are available in the supplementary material 22). Therefore, the contributions of AutoVision remained consistent regardless of the characteristics of the design briefs. This result enabled us to calculate the outcomes for all participants, irrespective of the design brief used.

## **3.3. Data**

### **3.3.1. Knowledge acquisition (KNOWLEDGE)**

Figure 89 illustrates the progression of participants' knowledge. Each participant was instructed to identify the potential impacts of Citroën's autonomous vehicle concept three times: Before the experiment; after working on a design brief without the tool; after working on a design brief with the tool. We then calculated the progress without tool and with tool, relative to the initial number of impacts. Without the tool, participants envisioned approximately 38% more impacts after completing the design brief (left bar). When using the tool, the number of impacts increased to approximately 75% (right bar), nearly doubling the progression.

**KNOWLEDGE**

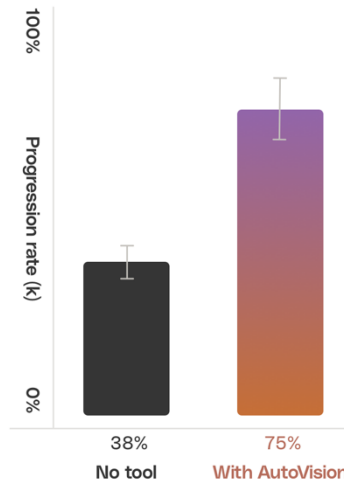


Figure 89. Mean and standard error for the variable KNOWLEDGE without tool and with tool.

We conducted a one-sided Student's T-test on the variable KNOWLEDGE ( $k$ ) among the 28 participants. We obtained  $t(27) = 7.6$  and a corresponding p-value  $p < 0.01$ . Since this p-value is less than our significance level  $\alpha = 0.05$ , we rejected the null hypothesis. In other words, the tool had a significant influence on increasing the number of impacts imagined by the participants.

To verify that there was no difference between the two groups (laboratory and company), we performed a two-tailed between-subjects T-test. For each phase (without and with tool), we calculated that the differences between the two groups were not significant ( $p = 0.24 > 0.05$  and  $p = 0.43 > 0.05$  respectively). Figure 90 shows the means and standard errors for each group.

**KNOWLEDGE**

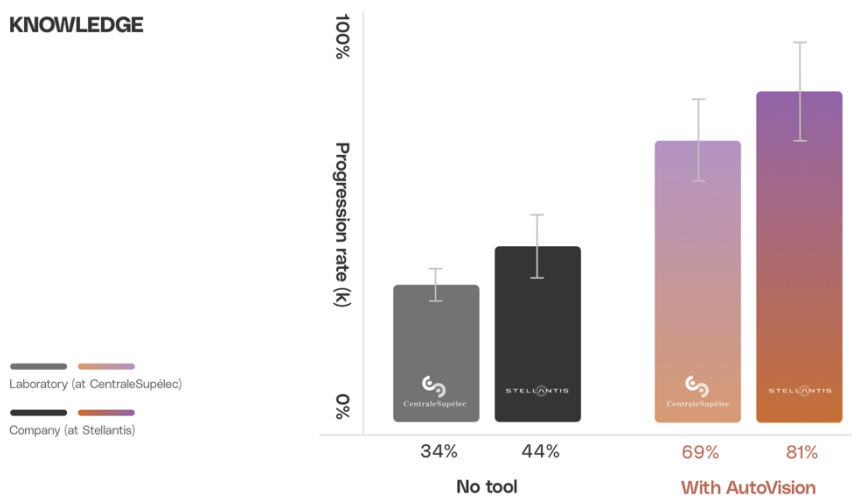


Figure 90. Mean and standard error for the variable KNOWLEDGE without tool and with tool, separating laboratory and company participants.

Most participants agreed or strongly agreed with the statement: "Using the industrial tool helped you learn about the impacts of autonomous vehicles" (see Figure 91). The only participant who chose "Strongly disagree" believed that he had gained "skills"

instead of “knowledge”. The participant who chose “Disagree” explained that he already had a solid understanding of the subject and thus felt that the tool did not offer significant additional value (he has a PhD in a similar domain).

**KNOWLEDGE**

Participants’ opinion about: “Using the industrial tool helped you learn about the impacts of autonomous vehicles”

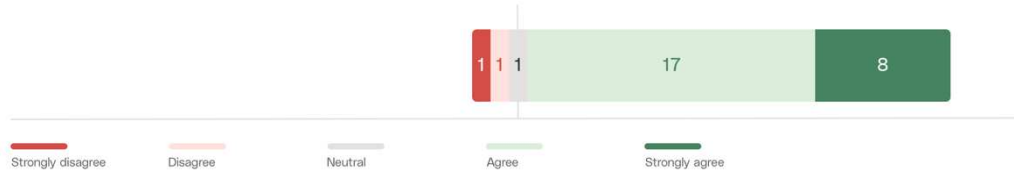


Figure 91. Values reported on a 5-point Likert scale regarding the knowledge acquired by participants on the impacts of autonomous vehicles.

**3.3.2. Rejection of usages (REJECTION)**

Figure 92 shows the average rejection rate of usages by participants before and after using the tool. We have recorded all the rejected usages manually, and then we included the rejected usages using the tool. We can see that around 8% of the usages were rejected in the first phase without the tool, and 15% were rejected in the second phase with the tool.

**REJECTION**

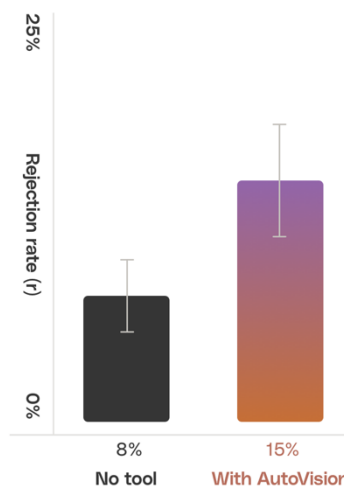


Figure 92. Mean and standard error for variable REJECTION without tool and with tool.

We conducted a one-tailed T-test on the REJECTION (r) variable among the 28 participants. The result obtained is  $t(27) = 2.3$  and  $p < 0.02$ , with a p-value below our significance level  $\alpha = 0.05$ . What allows us to reject the null hypothesis. There were 26 rejections without the tool, and 44 with.

Please note that out of the 28 participants, 12 of them (43%) did not reject any usages, regardless of whether they used the tool or not. Additionally, 21 of the participants (75%) rejected the same number of usages with and without the tool. In other words, only 7 out of 28 participants were influenced by the tool. To better interpret these results, we

have singled out the opinions of these 7 participants from the rest in the Figure 95. Among these seven participants, three were from the laboratory, and four were from the company. This group of seven also consisted of three PhD students, three designers, and one full professor.

To verify that there was no difference between the two groups (laboratory and company), we conducted a two-tailed between-subjects T-test. For the phase without tool, the participants from the laboratory had an average rejection rate of 12%, while the participants from the company had an average of 3%. Since this difference is significant ( $p < 0.03 < \alpha = 0.05$ ), it means that there is a real difference between the two groups. However, for the phase with tool, the averages are closer (18% and 11% respectively), and we have not seen a significant difference between the two groups ( $p > 0.30 > \alpha = 0.05$ ). Please refer to Figure 93 for the means and standard errors of each group.

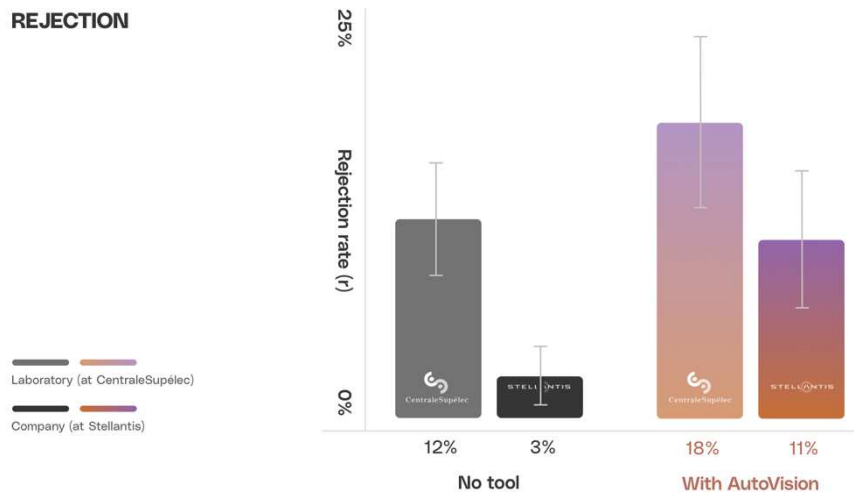


Figure 93. Average and standard error for the variable REJECTION without tool and with tool, separating participants from the laboratory and the company.

The participants estimated an average influence of the tool of about 26% regarding the usage rejection (Figure 94). While we have calculated an increase of 47% with the REJECTION indicator.



## REJECTION

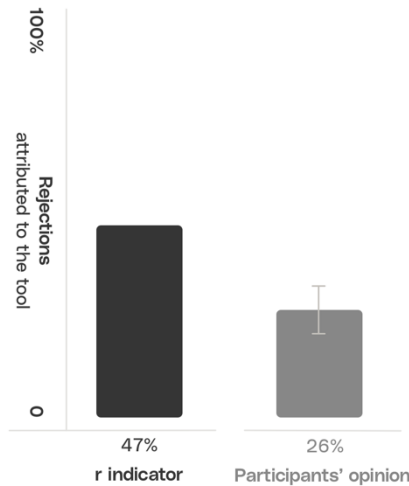


Figure 94. Mean and standard error for the percentage of rejections attributed to the tool (according to the REJECTION indicator evolution and participants' opinions respectively).

Participants had varying opinions on the statement: "The use of the tool helped you reject usages that could have negative consequences." Roughly one-third believed that the tool did not or hardly helped reject usages, another third believed that the tool helped them reject usages, and the remaining third did not express an opinion (Figure 95, top). One participant who did not agree explained that the need to reject usages had not been well explained during the experiment, resulting in few rejects. Another participant in disagreement explained that he did not understand the indicators well enough to use them for an informed choice. Finally, one of the participants who selected "Strongly disagree" simply explained that his usages were not suitable for rejection. The other participants did not justify their disagreement.

To delve deeper, we compared the opinions of participants from two different populations: the laboratory and the company. On average, we have not observed any major differences in opinion (Figure 95, middle).

In addition, we also compared the opinions of the 21 participants for whom the number of rejections did not change with the 7 other participants for whom this number changed. As expected, most of the participants for whom the number of rejections changed found that the tool had influenced them (the participant who responded "disagree" provided the justification that the indicators were not clear enough without access to the explanations of the experts; the participant who responded "neutral" did not provide any justification). For the participants who did not change the number of rejections, most of them are neutral (10 people) or believe that the tool did not help them (7 people). It is more surprising that 4 participants think that the tool helped them. However, these participants did not provide any justification (Figure 95, bottom).

### REJECTION

Participants' opinion about: "The use of the tool helped you reject practices that could have negative consequences."

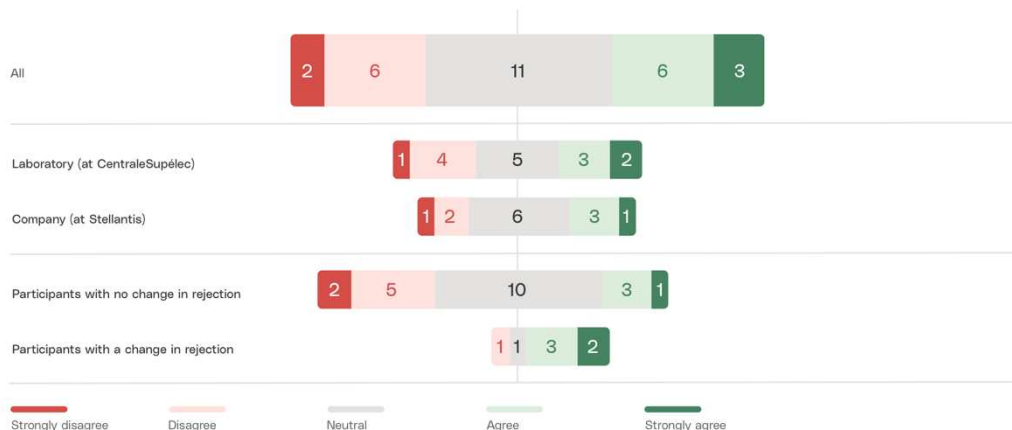


Figure 95. Values reported on a 5-point Likert scale concerning usage rejections attributed to the tool by participants.

### 3.3.3. Justifications for rejections (JUSTIFICATION)

We analyzed whether the tool affected the number of justifications given for rejected usages by the participants. We conducted a one-sided Student's test on the variable JUSTIFICATION ( $j$ ) for the 28 participants (Figure 96). We obtained a significant result with  $t(27) = 2.6$  and  $p < 0.01$ . However, it should be noted that the standard errors overlap. Although this does not affect the significance of the result (Lanzante, 2005), caution is advised.

#### JUSTIFICATION

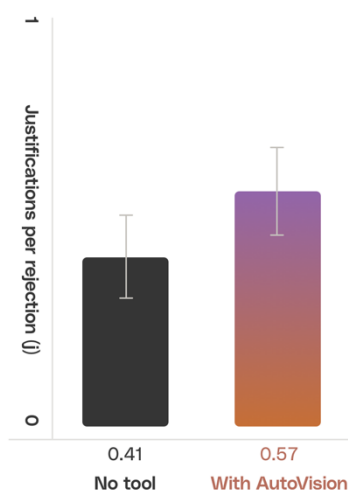


Figure 96. Mean and standard error for the variable JUSTIFICATION without tool and with tool.

We used a between-subjects T-test (two-tailed) to compare the two groups (laboratory and company). We found a significant difference ( $p < 0.05$ ) for the REJECTION variable in the phase without tool, but we did not find a significant difference ( $p =$

0.34 > 0.05) in the phase with tool. Please refer to Figure 97 for the means and standard errors of each group.

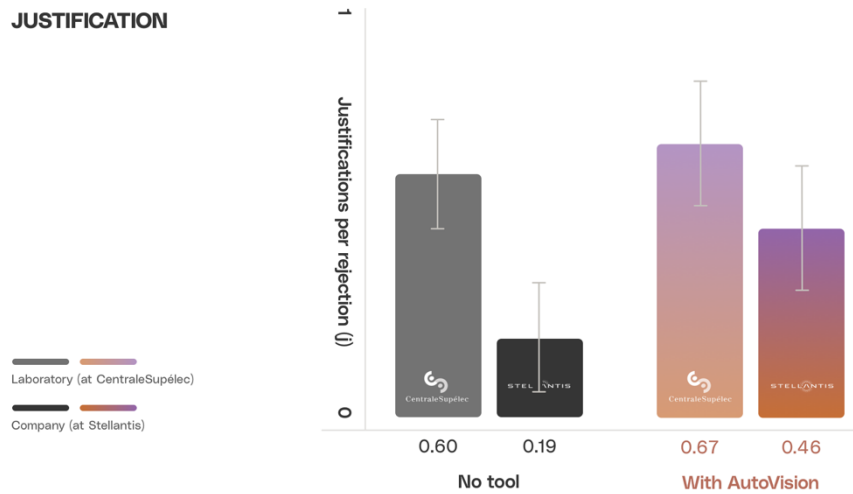


Figure 97. Mean and standard error for the variable JUSTIFICATION without tool and with tool, separating laboratory and company participants.

### 3.3.4. Warnings about integrated usages (WARNING)

Figure 98 shows the average warning rate per usage before and after using the tool. We can see that without the tool, each participant added an average of 1.29 warnings per usage. With the tool, this average increases to 1.92. Thus the number of warnings has a growth rate of 33% ( $= \frac{1.92-1.29}{1.29}$ ) when the tool is added (refer to Figure 98 and Figure 100).

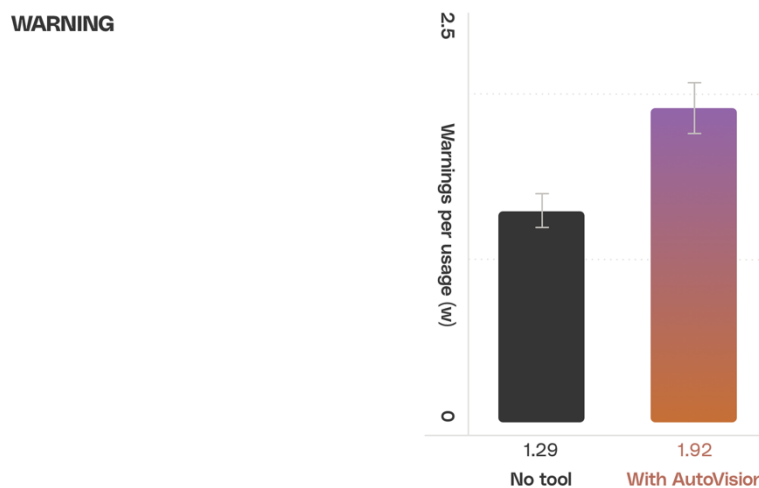


Figure 98. Mean and standard error for the WARNING variable without tool and with tool.

We used a one-tailed T-test to analyze the impact of the tool on the number of warnings per usage issued by participants. The WARNING variable ( $w$ ) was used here among the 28 participants. We obtained  $t(27) = 5.1$  and a corresponding p-value of  $p < 0.01$ . Since this p-value is less than our significance level  $\alpha = 0.05$ , we rejected the null hypothesis.

We used a two-tailed between-subjects T-test to compare the laboratory and company groups. The differences between the two groups were not significant ( $p = 0.20 > \alpha = 0.05$  and  $p = 0.41 > \alpha = 0.05$  respectively). Please refer to Figure 99.

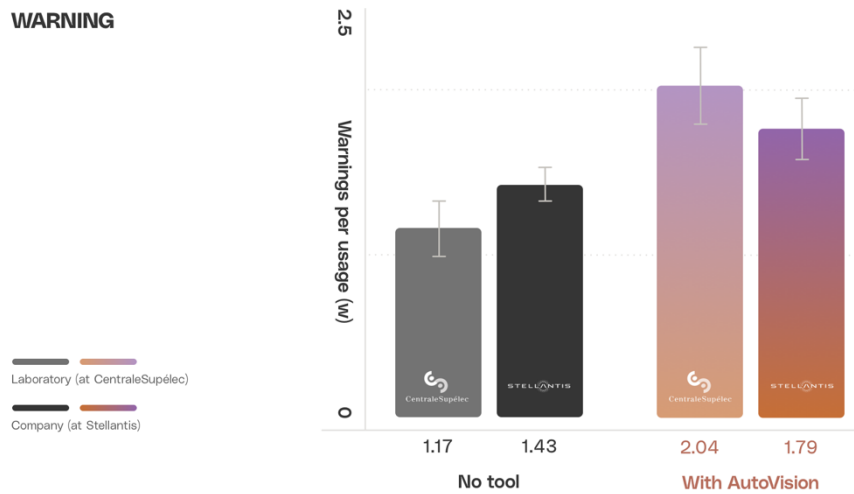


Figure 99. Mean and standard error for the WARNING variable without tool (1) and with tool (2), separating laboratory and company participants.

The participants estimated a medium influence of the tool of around 45% regarding warnings (Figure 100).

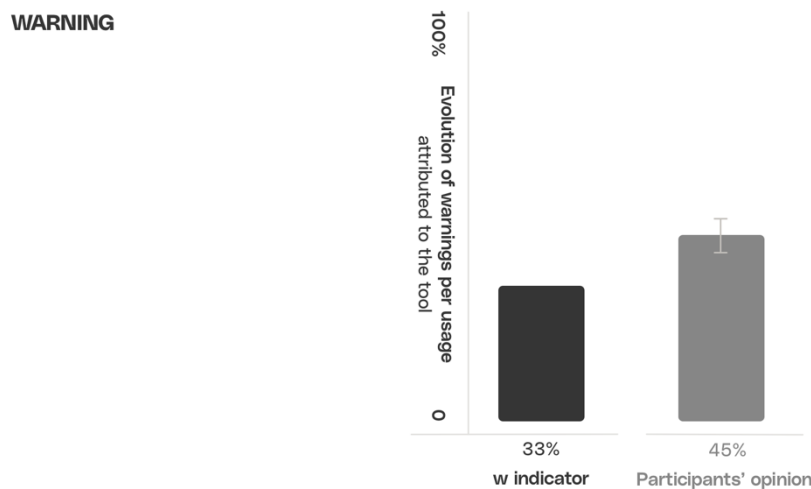


Figure 100. Mean and standard error for the percentage of justification attributed to the tool (according to the WARNING indicator and participants respectively).

A large majority of participants agreed or completely agreed with the statement: "The use of the tool helped you better inform about the risks of your proposals." The results are presented in Figure 101. The only participant who disagreed did not justify his choice.

### WARNING

Participants' opinion about: "The use of the tool helped you better inform about the risks of your proposals."

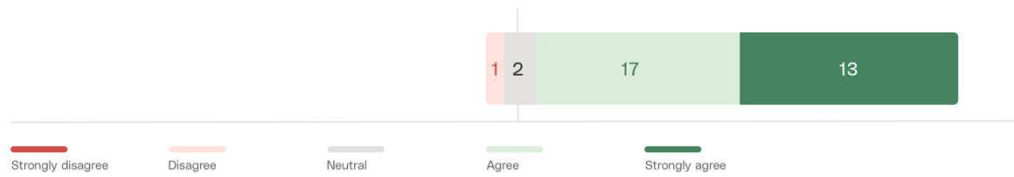


Figure 101. Values reported on a 5-point Likert scale regarding the tool's influence on the number of warnings, according to participants.

### 3.3.5. Responsibility of the design briefs

A large majority of participants agree or strongly agree with the statement: "Using the tool allowed you to build a design brief that is likely to generate fewer undesirable impacts" (Figure 102). One of the participants in disagreement explained that there was a lack of in-depth analysis of the impacts. Another participant did not understand the question, and the last one did not justify his answer.

#### Responsibility

Participants' opinion about: "Using the tool allowed you to build a design brief that is likely to generate fewer undesirable impacts."

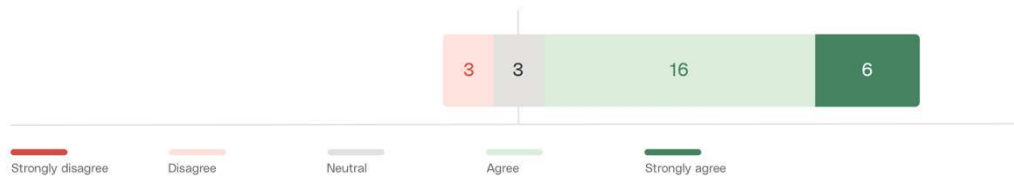


Figure 102. Values reported on a 5-point Likert scale regarding the influence of the tool on generating a more responsible design brief, according to participants.

### 3.4. Findings and feedbacks

The four tested hypotheses show significant results. This means that the null hypothesis is rejected each time. However, the opinions of the participants are not always in line with these conclusions. Figure 103 allows visualisation of the agreement rate (corresponding to "agree" and "strongly agree") of the participants for the questions asked in the feedback section.

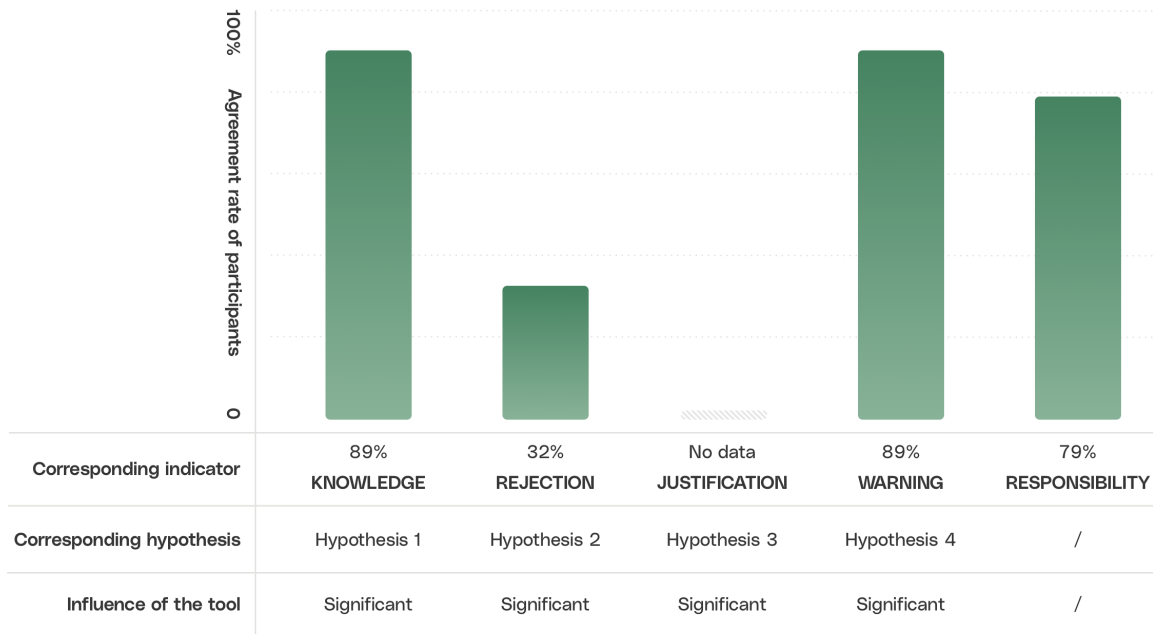


Figure 103. Agreement rate (“Agree” and “Strongly agree” of participants for each Likert scale of the feedback).

As we have seen in the previous sections, it is clear to the participants interviewed that the tool allows for acquiring more knowledge (hypothesis 1) and enables the formulation of more warnings (hypothesis 4). This aligns with our quantitative results. As for the rejection of usages, the participants are very mixed, which tends to confirm our caution regarding the results of hypothesis 2 and hypothesis 3, considering that only 7 participants rejected more usages with the tool. Finally, participants believed that the tool allows for the generation of more responsible design briefs. This result is promising, although it has not been tested quantitatively.

## 4. Discussion

### 4.1. Interpretation of the results

#### 4.1.1. Hypothesis 1: Knowledge acquisition (KNOWLEDGE)

The results of the KNOWLEDGE variable show that the tool had a significant impact on the number of impacts imagined by the participants (about twice as many impacts were imagined). Additionally, almost 90% of participants reported that the tool helped them acquire new knowledge about the impacts of autonomous vehicles, which supports this finding. Therefore, we conclude that hypothesis 1 is validated: The use of the tool enables users to gain knowledge about the likely impacts of autonomous vehicles.

It should be mentioned that we determine someone's level of understanding by asking questions related to a specific AV concept. Keep in mind that our assessment is not an exact measurement of their knowledge; it is an estimate. To calculate the progress rate using our tool ( $k_2$ ), we combine the imagined impacts with and without the tool. However, this calculation is still an estimate and may not accurately reflect reality. We assume that this combination represents what impacts participants can anticipate by using both their own imagination and AutoVision, which could have been directly tested in a between-subject experiment (see Section 2.1 for the explanation why this type of experiment was not used).

#### **4.1.2. Hypothesis 2: Rejection of usages (REJECTION)**

Regarding usage rejections, we found that without the tool an average of 8% of rejections were obtained, while with the tool, this increased to 15%. The number of rejections increased significantly. Participants also estimated that 26% of rejections were due to the use of the tool. However, participants had mixed opinions about the tool's usefulness for rejecting usages. Only 32% of them believed that the tool helped them, while the other 68% thought that the tool did not help them or did not know whether it had an influence. It's worth noting that 43% of participants did not reject any usage, with or without the tool, and that 75% of them did not add more rejections with the tool. Therefore, the tool had an impact on only 7 participants (25%). In consequence, one can wonder if some users may be more inclined than others to trust the tool. No major differences were found in the opinions of the participants from the laboratory and the company. And among the 7 participants who experienced a change in the number of rejections, no specific profile was found. In other words, we did not find any characteristic that promotes the trust of participants in the tool when it comes to rejecting usages.

Based on the elements mentioned here, we cannot reach a definitive conclusion even though the results on the REJECTION variable are significant. The tool can have a moderate impact on the number of rejections, but it has no effect for a large majority of participants (75%). Therefore, the hypothesis 2, which states that the use of the tool allows for more usages to be discarded, especially those likely to generate undesirable impacts, is partially validated.

During each of the five sessions, we observed that participants asked at least three clarification questions regarding the rejection of usages, which could indicate that some participants did not fully grasp this aspect of the experiment. They did not question the act of removing usages, but instead questioned the rationale behind it. Some individuals grappled with establishing criteria for determining whether to remove usages. Some participants also found it challenging to establish objective criteria for rejecting usages. The positioning of the cursor can be challenging at times,

and it is not uncommon for projects with known risks to be executed due to various reasons, which may be more or less acceptable. As a result, the subjectivity of the participants in determining whether a usage is acceptable or not may have played a significant role in explaining the significant differences.

However, we observed a significant difference in the number of rejections between participants from the lab and those from the company during the phase without the tool. On average, lab participants rejected more usages. However, this difference disappeared when participants used the tool. These findings suggest that lab participants who lack expertise may exhibit more cautious decision-making. This could be attributed to the tendency of researchers, who are trained to justify their choices rationally. Alternatively, the difference could also be due to unclear or inconsistent instructions provided during the experiment.

#### **4.1.3. Hypothesis 3: Justifications for rejections (JUSTIFICATION)**

On average, when users did not have access to the tool, there were 0.41 justifications for each rejected usages. When they used the tool, there were 0.57 justifications on average. Although this difference is small, we found that the tool had a significant influence on the increase in justifications. However, the standard errors overlap. Additionally, it is important to note that 43% of participants did not reject any usages (see Section 4.1.2), which reduces the statistical power for this variable. Similar to the REJECTION variable, we cannot definitively conclude here on the hypothesis 3: The use of the tool has a positive influence on the number of justifications for rejections related to the risk of causing undesirable impacts.

There was a significant difference in the number of justifications provided by participants in the laboratory compared to those in the company during the phase without tools. Participants in the laboratory provided more justifications on average. We attribute this difference to the same reason as the REJECTION variable (Section 4.1.2).

#### **4.1.4. Hypothesis 4: Warnings about integrated usages (WARNING)**

On average, the design brief had 1.29 warnings per integrated usage without the tool, and 1.93 with the tool. This represents an increase of about 33%, which is significant ( $p < 0.01$ ). Participants estimated that the tool allowed them to generate 45% more warnings, although this number is slightly overestimated compared to the measured average. This confirms the positive influence of the tool on the number of warnings. Additionally, 90% of the participants (25) feel that the tool helped them to better warn about the risks of their proposals. This validates hypothesis 4, which states that the tool has a positive influence on the number of warnings.



When comparing the participants from the laboratory and the company, we observed a notable divergence in the variables REJECTION, JUSTIFICATION, and WARNING when the participants did not have the tool (gray part of Figure 90, Figure 93, and Figure 97). The laboratory participants exhibited significantly higher levels of rejections and justifications compared to the company participants in relation to the REJECTION and JUSTIFICATION variables. However, no disparity was observed for the WARNING variable.

It is important to note that the same participants imagined the warnings with and without the tool (within-subject experiment). Therefore, it is possible that a learning effect contributed to the increase in warnings. It is also possible that thinking about warnings a second time (with or without the tool) could lead to an increase in the number of warnings, following a learning curve. This potential effect could be eliminated by conducting a complementary experiment with two groups instead of one.

#### **4.1.5. Responsibility of the design briefs**

We did not make any assumptions about whether using the tool would result in more responsible design briefs. This is because responsibility is a subjective concept that cannot be easily measured quantitatively. However, we did ask participants about the effectiveness of the tool in creating design briefs that could result in fewer undesirable impacts. Almost 80% of participants agreed that the tool helped them generate more responsible briefs.

The result suggests that the tool helps users gain more confidence in their design briefs. This is a good sign for its potential usefulness in industrial applications.

#### **4.1.6. Sensitivity regarding the design brief**

We conducted eight tests to determine if the user profile and mode of use affected the results as stated in the design brief (Section 3.2). We found no significant difference ( $p > 0.05$ ), indicating that the tool's effectiveness is not - or only slightly - dependent on whether the AV user lives in a rural or urban area, or whether they use the vehicle in shared or private mode. Some participants who had design brief B for the rural user noted that their subject was very different from the Citroën concept shown in the questionnaire section (which is in the city). They felt that this may have limited their acquisition of new knowledge concerning this specific concept. However, as stated before, we found no significant difference in the responses of participants who had design briefs A, B, and C. This also shows that the concept did not - or very little - influence the results. The significant effect of AutoVision on knowledge acquisition or warnings appears to be quite robust, meaning that this influence is not specific to a particular use case of autonomous vehicles.

## 4.2. Limitations

During the experiment, we tested a prototype of the AutoVision tool that did not have all the planned features. We found that some participants had difficulty reading the results because they did not always understand the causal link between a selected usage/validity domain and an impact. This was due to the missing feature that allows users to display justifications for the displayed impact (from experts or studies). Additionally, the prototype did not allow to use alternative modes of the Impact Guesser, which provide access to existing representations of autonomous vehicles. Participants could have better understood certain usages or compared different existing scenarios of autonomous vehicles if they had access to this feature.

The prototype was limited to one domain of validity, which is the mode of use. We removed the geographic deployment area to make the tool easier to use. We believe that this domain of validity was not crucial for measuring the positive effects of the tool.

The prototype had limited data, with only 30 different usages present for the RUI model section. Adding new data would have improved the prototype. On this, some participants expressed a desire for more usages, but they still found the tool relevant for raising awareness of impacts. The prototype lacked visual representations such as graphs, tables, or “Boston matrix”, which some participants requested. Additionally, certain impacts were not clearly defined in the prototype, which made it difficult for some participants to understand.

As the same participants were involved in both parts of the experiment, there is a chance that they may have learned something during the first phase, making it easier for them to perform better in the second phase (with the tool). This could be due to their familiarity with the subject, rather than the tool helping them. While this scenario seems unlikely, we cannot be certain. To remove this uncertainty, conducting an experiment with two separate groups could be necessary, but this would require twice as many participants. Moreover, the control group would not be able to use the tool, making the experiment less interesting for them.

## 5. Conclusion

We tested one of the tool's modes, called Impact Guesser, with 28 participants within the Stellantis automotive group and a French industrial engineering laboratory. The results of this experiment demonstrate that using the tool enables users to gain knowledge about the possible impacts of autonomous vehicles (about twice as much as if they had worked without the tool) and has a beneficial effect on the number of warnings concerning the potential impacts of the participants' proposals (about 33% more warnings on the proposals). This confirms hypotheses (h1) and (h4) stated in the

introduction. Additionally, we showed the tool's potential to help users decline more proposals (here, usages of AV) and provide better justifications for their decisions. However, we cannot be definitive yet because the tool only affected 25% of participants with regards to these rejections. Therefore, additional experiments are required to address hypotheses (h2) and (h3) outlined in the introduction. Furthermore, we did not detect any significant differences in the results among participants who worked on different case studies (with various user profiles and modes of using the autonomous vehicle). This suggests that the tool's effect is not much influenced by a particular use case. This finding shows potential for using the tool in products other than autonomous vehicles.

When interpreting the previous statements, it is important to consider some sources of error. First, we used the same 28 participants to compare the results before and after using the tool. While this required fewer participants and made the experiment more accessible, it may have caused learning effects that competed with the benefits of the tool. Additionally, the participants only had access to an incomplete prototype, meaning they could not use all the functions presented in Chapter 5 (for instance, they were not able to conveniently access the details provided by experts to justify a social impact, what many of them highlighted in the feedback). Finally, it is important to note that the various aggregation formulas used by the tool heavily depend on the quality of the data from the RUI and SMI models. Therefore, some impacts, usages, and domains of validity may be given an unfair weight. For this reason, the results of the tool should be taken with a degree of skepticism (see Chapter 5).

Although there were a few issues, we strongly believe that the Impact Guesser mode has a significant potential to assist designers or decision-makers in acquiring new knowledge about the impacts of autonomous vehicles and in being more critical with their proposals. This was verified by 79% of participants who reported that AutoVision helped them develop more responsible proposals (Figure 103). Therefore, we can say that the tool has accomplished its purpose as a "safeguard" by enabling users to comprehend the long-term outcomes of their proposals and modify them as needed.

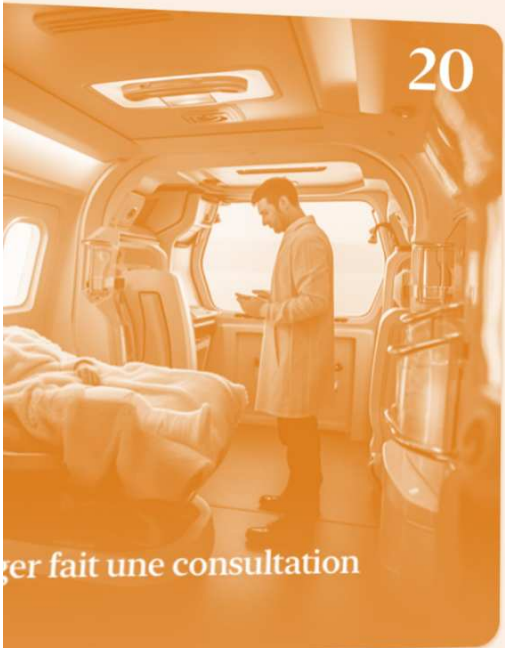




Le passager effectue des tâches personnelles pendant le transport (eg une liste de course)



Le passager ressent des sensations pendant le transport



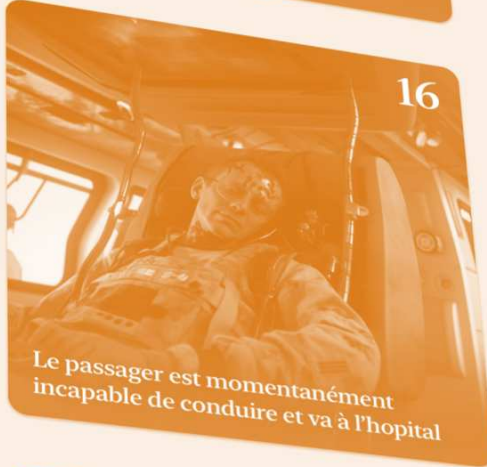
Le passager fait une consultation



Le passager s'immerge dans un contenu multimédia proposé par le véhicule pendant le transport



Les passagers font des activités conviviales / collectives pendant le transport



Le passager est momentanément incapable de conduire et va à l'hôpital



Le passager prend l'avion sans passer par les contrôles de l'aéroport



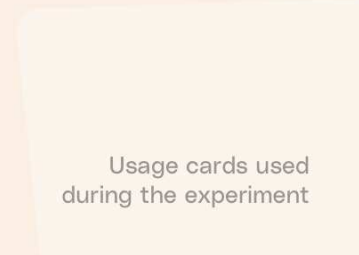
Le passager est mineur et se déplace sur de longues distances



Le passager travaille pendant le transport



Le véhicule propose la visite guidée d'une ville alors que le passager n'est momentanément pas en état de conduire





## CHAPTER 7

# Advisor evaluation

This chapter assesses the Advisor mode of the AutoVision tool. The goal is to determine whether decision-makers perceive the concepts generated with the Advisor mode as compelling for their business strategy. The findings indicate that the tool can assist in developing persuasive concepts. Furthermore, the findings demonstrate that decision-makers in the automotive industry have a genuine requirement for knowledge in this area, despite an apparent lack of awareness.

# 1. Introduction

In Chapter 5, we described the AutoVision tool, which is designed to assist decision-makers and designers in developing autonomous vehicles. This tool has two modes: the Impact Guesser mode and the Advisor mode. The Impact Guesser mode generates a list of potential impacts based on a given autonomous vehicle concept or scenario, while the Advisor mode provides guidance in defining a concept that aligns with a preferred or non-preferred impact strategy. In chapter 6, we conducted a test of the Impact Guesser mode with 28 participants and demonstrated its usefulness in helping users gain better knowledge about the possible impacts of autonomous vehicles and raising awareness about specific impacts related to their proposals for autonomous vehicle concepts.

In this chapter, we focus on the Advisor mode. The Advisor mode allows obtaining suggestions for usages, modes of use, and deployment areas based on an impact strategy (for example, aiming for a reduction in greenhouse gas emissions, and to a better health condition). This is known as generativity (Masson et al., 2016). To respond to this strategy, the tool can for instance suggest a shared vehicle that allows passengers to sleep. It has been defined to be used in the early stages of design when decision-makers or designers lack ideas and need guidance. This way, AutoVision Advisor competes with ideation methods often used to boost creativity in companies (Bilal-Deroussy, 2015). However, unlike these methods that allow designers to diverge and imagine many different (and sometimes atypical) concepts, the Advisor mode constrains ideation by discouraging certain usages from the beginning, which can limit creativity (Shah et al., 2000, 2003). Thus, it is difficult to compare it to ideation methods based on the criterion of the number of generated ideas. Therefore, we assumed that the tool provides ideas of better quality. That is, ideas that guide designers towards more responsible concepts right from the start. Given the timeline for autonomous vehicle deployment, it is naturally impossible to verify the accuracy of the Advisor's suggestions through an experiment. However, since the tool is based on scientific findings and expert opinions, we have postulated that the tool helps for the imagination of more responsible concepts. Based on this assumption, we wanted to verify whether a concept generated using the Advisor could be at least as convincing to decision-makers as a concept they would have traditionally envisioned. So, for this chapter, our goal is to examine how this mode can help establish an autonomous vehicle concept that aligns with a company's strategy and effectively persuades strategic decision-makers within the company. Additionally, we want to explore if the AV concepts envisioned by the participants produce favorable outcomes when inputted into the Impact Guesser.

We start this chapter by describing the experimental protocol used to test our hypothesis (Section 2). We then present the results (Section 3) and analyze them in a

discussion section (Section 4). Finally, we conclude on the potential of the Advisor mode of AutoVision to help a company define a future product.

## 2. Experiment design

In this section, we detail the experimental protocol that we have defined to conduct an exploratory test of the Advisor mode.

The experiment was designed for participants to collaborate in groups on an autonomous vehicle concept. In a project chronology, it is conducted prior to the design phase of a new product, where it is crucial to establish strategic directions. The objective of each group was to define a preliminary concept for an autonomous vehicle. A preliminary concept includes a list of usages to promote or to avoid for the AV, as well as one or more modes of use. It is like a design brief (explained in Chapter 6), serving as a reference for design teams to provide guidance. An example is illustrated in Figure 104.

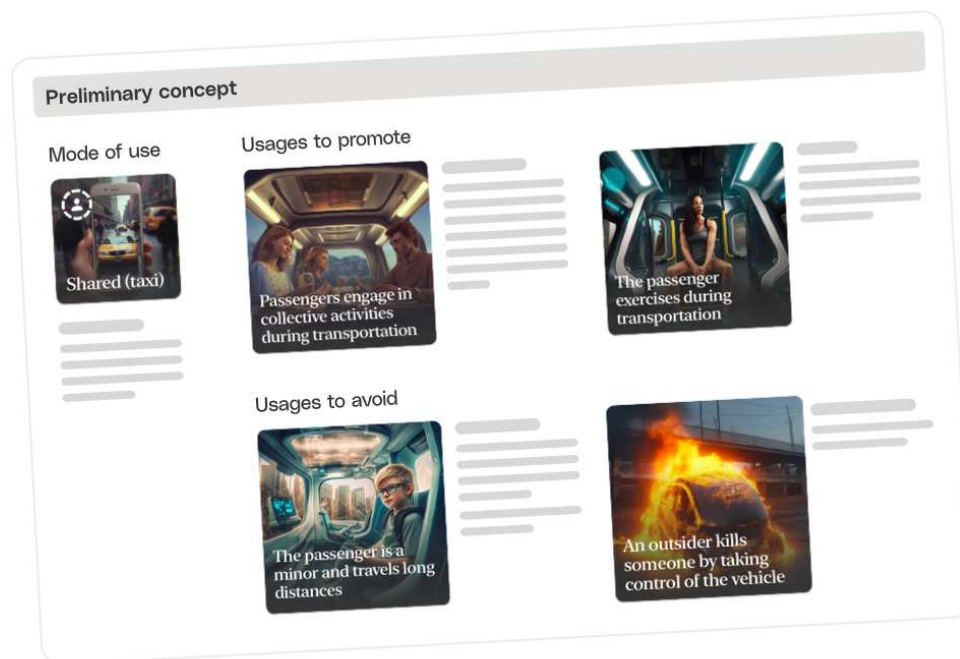


Figure 104. Example of a preliminary concept.

The hypotheses we want to test in this experiment are:

- h1.** A concept generated through the tool is perceived by strategic decision-makers as being at least as convincing as a concept they would have imagined themselves. The term "convincing" referring to the compatibility of a concept with an impact strategy.
- h2.** Designers do not have enough knowledge to accurately assess whether one autonomous vehicle concept is more responsible in the long term compared to another.



**h3.** Experts verbatim can advantageously justify a concept evaluation.

The sections below provide details about the experimental protocol, the evaluation criteria used to test the hypotheses, and the calculation of results.

## 2.1. Protocol

The experiment described in this chapter was conducted with a limited number of participants who had numerous responsibilities within a company working on AVs – kept confidential in this document. As this experiment occurred at the end of the PhD, we designed it to be exploratory, aiming to provide initial insights into the relevance of the Advisor mode within a company, instead of solid quantitative results, statistically validated.

The first characteristic of the experiment is that participants do not directly use the tool. We made this choice to shorten the session, as becoming familiar with the tool takes a significant amount of time (see Chapter 6). This is especially true for the Advisor mode, which we believe is more challenging to understand than the Impact Guesser mode.

The experiment takes place over a period of 2 hours and 10 minutes (Figure 105). Participants are divided into groups (they were 8 in total). They are instructed to mix with individuals whom they do not usually work with. The first 20 minutes are dedicated to explaining the context and details to the participants (supporting slides are available in the supplementary material 23. This phase terminates with the presentation of a general impact strategy (impacts to avoid or promote). The experiment is divided into two parts: Design and Evaluation (Figure 105).

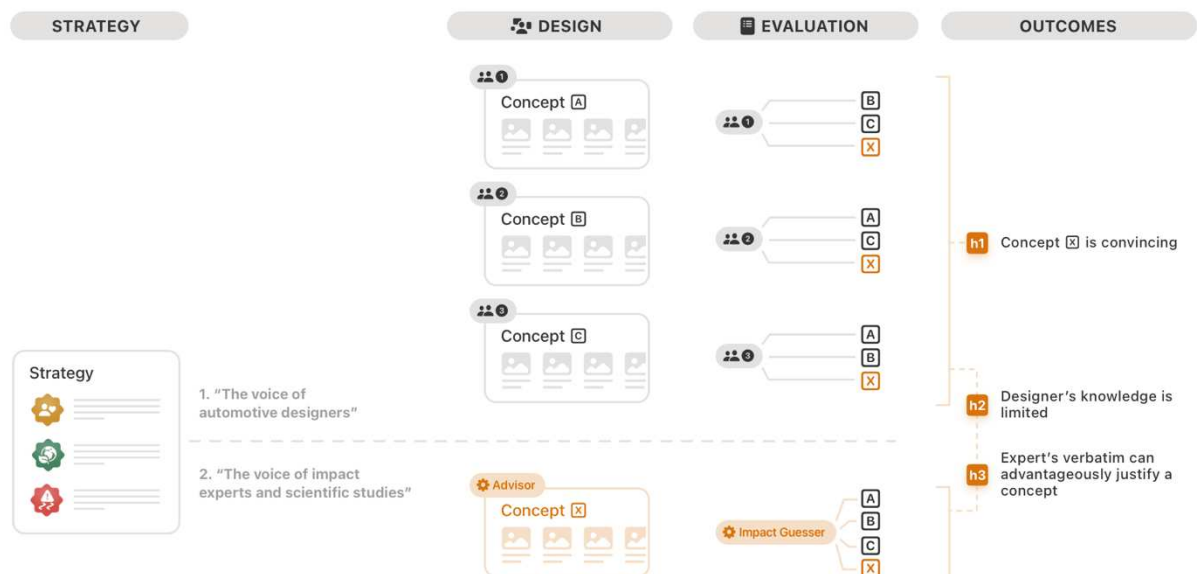


Figure 105. The experiment procedure.

The first part is dedicated to imagining a concept for each group. It lasts for 30 minutes. A list of usages and modes of use is given to each group. They are then asked to select at least 5 usages to promote and 5 usages to avoid. They are also asked to select one or more modes of use. For each choice, they are encouraged to provide at least one justification. The concepts generated are denoted A, B, and C.

The second part is dedicated to the rating of the concepts by the groups. It also lasts for 30 minutes. Each group is asked to evaluate the concepts of the other two groups, as well as a complementary concept - denoted X - that is generated using the Advisor mode of the AutoVision tool. This rating is done with a questionnaire related to the impact strategy (see Section 2.2.1). The concepts are anonymized so that the participants do not know their origins (group or tool).

After a brief intermission, the results are presented to the participants in the form of a ranking, which reveals the best concept among A, B, C, and X according to the participants. The concept generated by the Advisor (X) is also disclosed to the participants. To provide participants with a glimpse of the AutoVision tool, we then suggest taking the concept with the highest overall score (among A, B, and C) and inputting it into the Impact Guesser to assess its potential impacts (as a demo shown on a projector for all participants). This approach aims to demonstrate to participants that, despite having a higher score than the others, the tool may still reveal significant unexpected impacts for the concept they imagined.

### 2.1.1. Strategy

As we defined in the Advisor mode of the tool (Chapter 5), a strategy (or impact strategy) is a list of impacts desired or not. It is from a strategy that the Advisor can then indicate to the user different usages or modes of use. Depending on the interests of stakeholders, strategies can be very different. For example, an automotive group could prioritize impacts that allow them to sell more vehicles, while a local community would rather reduce the number of vehicles to alleviate traffic congestion. Other impacts are more consensual, such as wanting to reduce the risk of accidents or wanting to reduce carbon impact.

In this experiment, different concepts are imagined and evaluated in relation to a strategy. The question is therefore to define an appropriate strategy for the experiment. As we are conducting this thesis within the Stellantis automotive group, we decided to define an impact strategy based on the group's latest – publicly available – strategic plan: "Dare Forward 2030" presented in 2022 (Stellantis, 2022) and already mentioned in Chapter 1.

The Dare Forward 2030 strategic plan is based on three main branches: CARE, TECH, and VALUE. CARE primarily focuses on aspects related to the planet, customers, and employees; TECH focuses on technical and innovation aspects such as electrification,

software, artificial intelligence, autonomous driving, and investment funds; VALUE focuses on sales-related aspects. The branch that interests us for the experience is the first one: CARE, as it relates to the ethical and responsible aspects of the company. The most highlighted element of the CARE branch is Stellantis' environmental responsibility. The company aims to reduce its carbon footprint by 50% between 2021 and 2030 and wants to promote circular economy (4R strategy: Recycle, Repair, Reuse, Remain). The other two elements of the CARE branch are customer satisfaction and employee well-being. The company mentions its commitment to ethical responsibility but struggles to provide specific examples regarding individuals who are not customers or employees of the company. In general, the company does not present a clear long-term vision at the societal level (as we showed in Chapter 1). It simply mentions the ambition to "transform all facets of mobility for the betterment of our families, communities, and the societies in which we operate." Lastly, Stellantis emphasizes safety, particularly "safe mobility." Safety has been a priority for the company for years. Based on this analysis, we have identified three topics at the intersection of AutoVision's impact themes and the strategic plan (Figure 106). These are the strategic topics that were distributed to the participants to guide their choices.



Figure 106. The three strategic topics distributed to the groups to help them generate and evaluate concepts of autonomous vehicles.

For the first topic, we added additional clarifications for participants. It should be noted that these clarifications are our interpretations and do not engage the group. We have only provided these three points without delving into too many details. This approach allows for a significant level of interpretation on the participants' part. In our opinion, this approach is more aligned with reality, because it seems optimistic for designers to strictly adhere to a detailed strategic plan. It is this interpretation from the participants that is sought to determine whether they believe the concept proposed by the Advisor aligns with the strategy or not.

To be able to generate a concept with the Advisor from the previously described topics, we then defined a strategy by listing impacts to promote and avoid (see supplementary

material 24). Figure 107 shows the strategic topics and the strategy during the experiment.

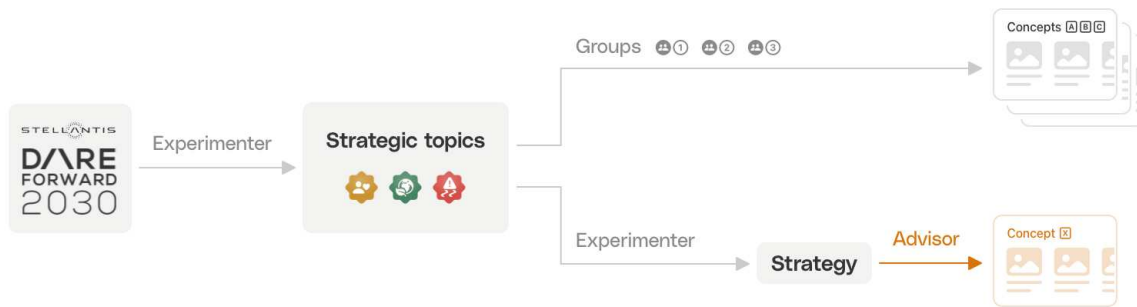


Figure 107. Using strategic topics and strategy to generate the 4 concepts A, B, C, and X.

### 2.1.2. Concept imagination dashboard

To assist participants in defining a concept, we established a digital dashboard using a numeric tool named Mural. Each group assigns one person to display this dashboard on his laptop. Although the Mural platform allows collaboration, we enforced the use of only one computer per group to encourage communication and prevent each individual from filling out the dashboard separately. Figure 108 provides an overview of the dashboard, which is divided into 5 different areas. The first area (1) serves as a reminder for participants about the three strategic topics they should consider. The second area (2) is dedicated to the selection of usage modes and the accompanying justifications. Participants are asked to systematically justify their choices in relation to the strategic topics. Text fields are available on the dashboard for this purpose. The third area (3) allows participants to identify and prioritize between 5 and 8 usages that they believe should be emphasized to promote the three strategic topics. They can drag the illustrated cards representing the usages of area (5) and drop them in area (3). The fourth area (4) functions similarly to area (3), but this time focuses on usages to avoid. Participants should justify their choices of usages as much as possible. Examples of dashboards are available in the supplementary material 25 (in French).

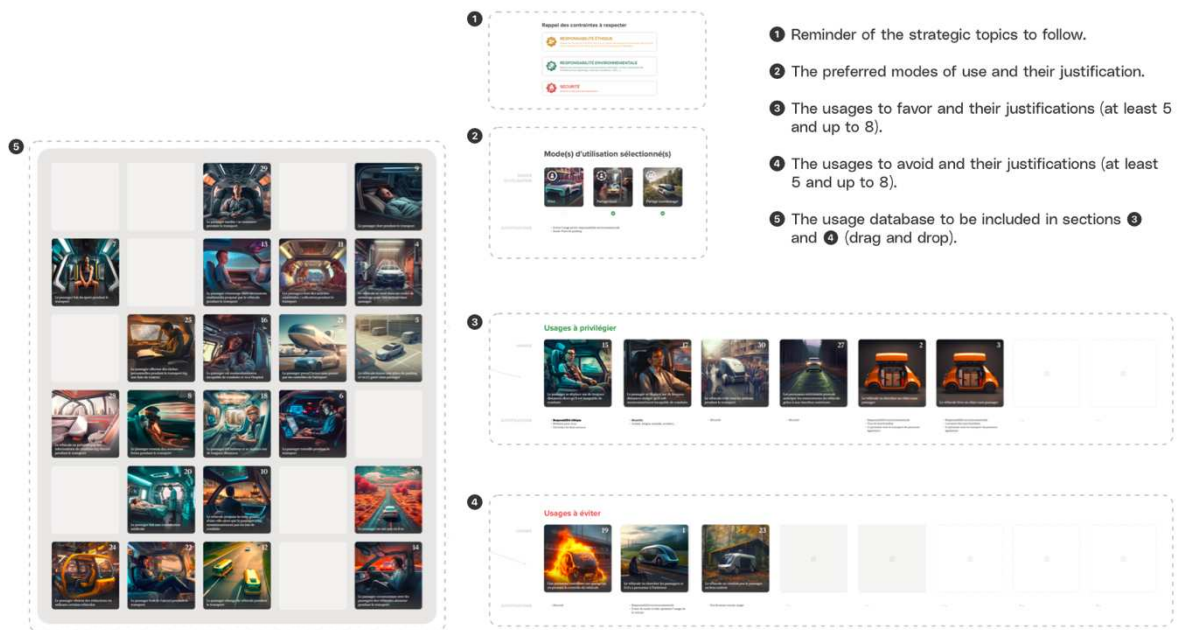


Figure 108. The dashboard provided to the groups to imagine their concept based on an existing database of usages.

In addition to this digital support, we also distributed paper materials to the participants (Figure 109). Since there is only one computer, this allowed participants without access to the computer to read about the different usages and remember the strategic topics.

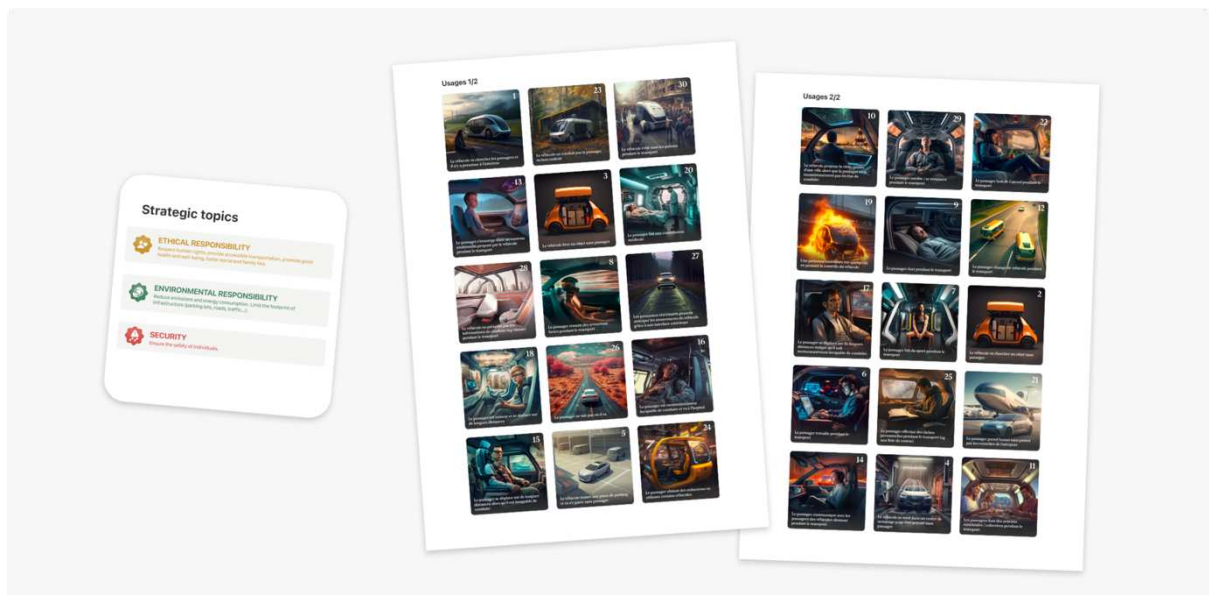


Figure 109. Sheets distributed to participants to remember the strategic topics and to go through the 30 usages without having to look at the computer (see supplementary material 23).

It is important to note that we suggest 30 usages to the participants, which align with the 30 usages of our AutoVision prototype. We made this choice to ensure that the concepts imagined by the participants and those generated by the Advisor were based on the same material. Additionally, in the first experiment (Chapter 6), we observed that

when participants were asked to imagine usages for autonomous vehicles, many of the usages did not align with those of the tool (due to their limited number of 30). This difference would have made it challenging to use the Impact Guesser to compare the concepts (refer to Section 2.2).

### **2.1.3. Generation of concept X with the Advisor**

Based on the strategy defined in Section 2.1.1, we consulted the Advisor to assist us in generating a concept. The Advisor provided a list of usages to promote and avoid, as well as modes of use to promote or avoid. The Advisor has given us 12 usages to promote, 16 usages to avoid, 2 modes of use to promote, and 1 mode of use to avoid (these results from the Advisor are available in the supplementary material 26).

To meet the experiment's constraints (selecting between 5 and 8 usages) and create the impression that the concept was imagined by a group of humans in under 30 minutes, we did not include all the usages provided by the Advisor into the concept. Instead, we divided the number of usages by two, selecting 6 usages to promote and 8 usages to avoid. To select the usages, we used the sorting function (presented in Chapter 5), which ranked usages based on their impact and conflict coefficient. However, we sometimes prioritized usages with lower conflicts, even if their ranking was higher. We also considered the justifications provided by the experts to selected usages that appeared more coherent to us. We believe that this process of concept creation in collaboration with the Advisor mode is like what a designer or decision maker would do. The concept X thus generated is visible in the supplementary material 25.


### **2.1.4. Evaluation form**

After the concept imagination phase, each group is invited to rate 3 concepts within a 30-minute time limit. Two concepts come from the other two groups, and one of them is the concept X created with the help of the Advisor. Of course, when a group rates a concept, it has no indication to identify its origin.

The access to three anonymous Mural dashboards is given to each group. They are then invited to fill out an online questionnaire for each of the concepts. Figure 110 presents an extract of this questionnaire and the supplementary material 23 presents the complete questionnaire (in French).

You need to evaluate the concepts based on the choices of the participants, as well as the number and quality of their justifications.

---



**ETHICAL RESPONSIBILITY**

Respect human rights, provide accessible transportation, promote good health and well-being, foster social and family ties.

**In your opinion, to what extent does this concept meet the objective of ethical responsibility?**

0
1
2
3
4
5
6

- 0 : The objective is not respected at all
- 1 : The objective is hardly respected
- 2 : The objective is somewhat respected
- 3 : The objective is moderately respected
- 4 : The objective is fairly well respected (there are still some areas of uncertainty)
- 5 : The objective is generally respected
- 6 : The objective is fully respected

**Justifications, important points, discussed elements related to your choice**

At least 100 words

Figure 110. Part of the evaluation questionnaire related to the strategic topic of ethical responsibility (translated in English).

For each concept, the group must assign three ratings, one for each strategic theme: Ethical responsibility (shown in Figure 110), Environmental responsibility, and Security. The rating should range from 0 (the objective is not respected at all) to 6 (the objective is fully respected). The correspondence for each intermediary number is shown in Figure 110. Each rating should be justified with a text field requiring at least 100 words.

## 2.2. Criteria

This section outlines the criteria used to address the hypothesis. Following the experiment, the assessments of concepts A, B, and C are compared against concept X to analyze the impact of the tool on concept quality. The concepts are also recorded using the Impact Guesser's interpretation aid, providing an overall score for each concept.

### 2.2.1. Participant evaluations

During the evaluation, each group assigns three scores to each concept. Each score corresponds to a strategic topic: Ethical responsibility, Environmental responsibility and Security. The three concepts proposed by the participants are evaluated by two

groups, while the concept created using the Advisor is evaluated by all three groups. This approach ensures that groups do not evaluate their own concept. Consequently, it is possible to calculate an average score for each concept in relation to each strategic topic. These results can also be combined to provide an overall score by averaging the scores from the three topics.

We aim to test hypothesis (h1), which suggests that a concept generated through the tool is perceived by strategic decision-makers as being equally or more convincing compared to a concept they would have imagined themselves (regarding a specific strategy). We want to reject the null hypothesis (h0) that the concept generated by the tool is perceived as less convincing than others. However, due to the small number of groups (3 groups) in this exploratory experiment, it is not possible to conduct a statistical test like ANOVA to reject this hypothesis. Replicating the experiment would be necessary for such analysis. Nevertheless, we believe that analyzing the averages and standard errors can already provide some insights.

### 2.2.2. Impact Guesser evaluations

In addition to the evaluation by participants, the experiment has been designed to inject the different concepts into the Impact Guesser mode of the tool (presented in Chapter 5 and tested in Chapter 6). Our objective here is to assign scores to each concept based on AutoVision’s knowledge. This allows for comparing the scores given by participants with a score based on expert opinions and scientific studies.

We therefore used the interpretation help of the Impact Guesser, which provides a score for each of the 19 themes of the tool (Chapter 5, Section 5.3). We copied the strategy (defined in Section 2.1.1) into the interpretation help evaluation grid (see Chapter 5). From there, we could input usages and modes of use to obtain a score for each concept according to each impact theme. It should be noted that the usages to avoid cannot be added as input of the Impact Guesser. Therefore, the scoring is only done for the usages to be promoted (Figure 108, area 3). In addition, unlike the evaluation of participants, the score given by the interpretation help can be negative if the situation of a theme is considered worse compared to today.

As the scores are calculated for each theme, they need to be converted into scores for each strategic topic. To do this, we assigned each theme to a topic (Table 30).

Table 30. Matching between impact themes and the three strategic topics.

Strategic topic of the experiment	Impact themes of the AutoVision tool
Ethical responsibility	Education; Employment; Family; Gender; Health and welfare; Human rights; Identity and cultural heritage; Stratification
Environmental responsibility	Energy; Environment
Security	Conflict and crime



Strategic topic of the experiment	Impact themes of the AutoVision tool
None	Networks and communication; Population change; Distance; Speed; Time; Traffic; Transport share; Parking

The calculation of scores for each strategic topic is done by calculating the average score for each theme corresponding to the topic, weighted by the number of impacts considered for each theme.

It should be noted that this calculation includes approximations. We could have defined a specific function inspired by the score provided by the interpretation help, but that directly gives a score for each strategic topic (instead of linking an impact theme to a strategic topic, each impact is directly linked to a strategic topic). We did not make this choice to avoid adding heavy additional calculations to the tool. Considering that the difference in the result would be very small. In addition, we preferred to use the Impact Guesser as it would be used in a real case, rather than introducing a new specific calculation method for our experiment only.

## 3. Results

### 3.1. Participants

We conducted the experiment during a single session involving a total of 8 people from a company working on AVs. Out of these 8 participants, 5 individuals were product owners, product managers, or specialists working on navigation or driving experience. One person was working on the cross-product, another person on customer and marketing intelligence, and one last person was a designer. Most of these individuals had the authority to make decisions and were accountable for entire projects. As a result, they play a strategic role in the company.

To divide themselves into three groups, the 8 participants were instructed to mingle. That is, to mix with people belonging to different teams. The objective was to promote various perspectives and avoid effects that are tied to a specific population. The alternative objective was to give them the opportunity to meet new people from the group. The Table 31 summarizes the number of participants.

Table 31. Number of participants per group.

<b>Group 1</b>	3
<b>Group 2</b>	3
<b>Group 3</b>	2

## 3.2. Evaluation distribution

During the evaluation phase, the different concepts were randomly assigned to three groups. Table 32 provides a summary of this distribution. The participants who had a laptop received the links to the concepts that needed to be evaluated via email.

Table 32. Distribution of evaluations of the four concepts among the groups. The numbers in parentheses correspond to the identifier that participants saw.

<b>Group 1 – Concept A</b>	C (11)	X (21)	B (31)
<b>Group 2 – Concept B</b>	X (12)	C (22)	A (32)
<b>Group 3 – Concept C</b>	B (13)	A (23)	X (33)

Example of reading Table 32: Group 1 evaluates concept C, which was imagined by Group 3. From its perspective, the group is given a concept identified as number 11, without knowing that it corresponds to concept C.

## 3.3. Data

### 3.3.1. Participant evaluations

Figure 111 presents the evaluation results for the three strategic topics, as well as an overall average. Concepts A, B, and C were rated by two groups, while concept X was rated by all three groups. The raw results and detailed calculations can be found in the supplementary material 27.

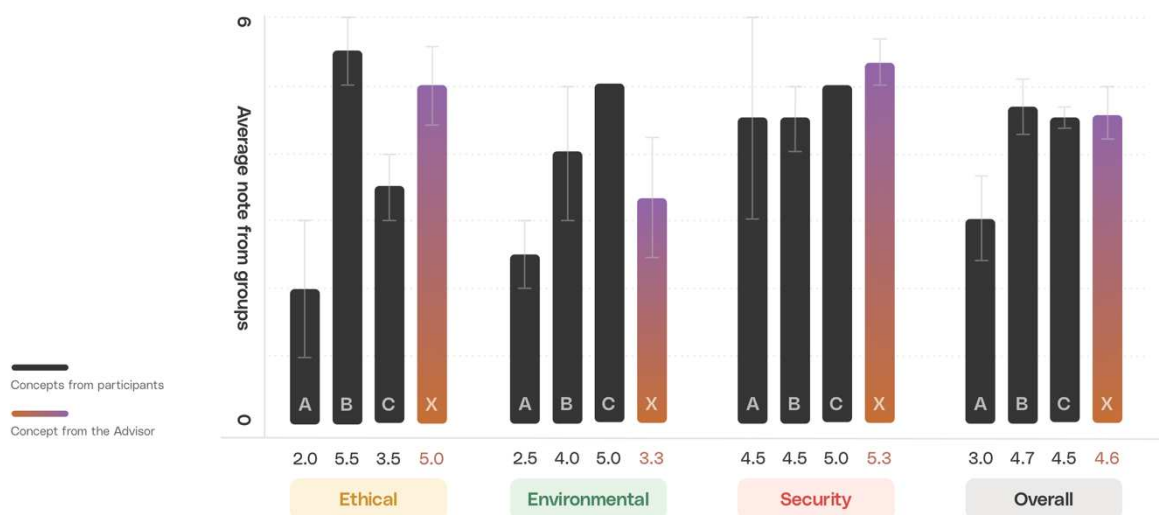


Figure 111. Means and standard errors for the evaluation of each concept by the three groups.

When it comes to ethical responsibility, concepts B (5.5) and X (5.0) outperformed concepts A (2.0) and C (3.5). One group stated that concept B took into account both individual needs and collective usage modes, providing well-supported arguments for

each aspect. The groups evaluating concept X praised its emphasis on health, well-being, and family connections. However, one group expressed concern about the absence of first aid options for transportation to the hospital, which was chosen as a usage to promote in concept X. The groups evaluating concept A stated that only one usage was related to ethics, without any argumentation. Specifically, there were no considerations for social or family connections, leisure, work time, or optimization of travel time. One of the groups evaluating concept C explained that there was no consideration for accessibility, health/well-being, or human rights.

Regarding environmental responsibility, concept C dominates the others with an average score of 5.0. One of the groups stated for concept C that the strategic topic had been respected with an emphasis on the optimization of routes and resources. Concept B positions below with an average score of 4.0. One of the groups explained that environmental aspects seemed less present in the justifications for usages compared to concept C. Concept X obtained a score of 3.3. The three groups that evaluated it do not agree with each other. One of the groups deemed the proposal as good as the others (rating of 5). Another group explained that there were few arguments regarding the environment, except for the argument of shared vs private use (rating of 3). The last group criticized the choice of a usage that allows for sports, which could lead to additional weight carried in the vehicle (rating of 2). Finally, concept A obtained an average score of 2.5. The groups justified their ratings by saying that there were only 2 or 3 usages related to the environment, without elaborate justifications.

Regarding security, the four concepts have close and fairly high scores. Concept X is the highest with a score of 5.3. The groups that evaluated this concept found that it proposed many arguments about security: alcohol consumption, places posing risks to passengers, risks of hacking/terrorism, airplane, unaccompanied child, lost car. One group considered the topic respected but expressed concern about the absence of first aid options for transportation to the hospital (they re-used the same argument as for the ethical responsibility). Concept C obtained a score of 5.0. One of the groups explained that safety was emphasized for vehicle users as well as for the external environment and other users of the infrastructure. Concepts B and A both scored 4.5. For concept A, one of the groups explained that security was fairly well represented in the usages chosen, but the arguments were less developed than for ethics. Finally, for concept A, one of the groups stated that the safety aspect was overwhelmingly dominant in the formulated choices (rating of 6), but another group nuanced it by saying that there was too little justifications (rating of 3).

In terms of overall averages, concept A (score of 3.0) is overshadowed by the other three, which are all very close with each other: B with 4.7, X with 4.6, and C with 4.5. The standard error depicted in Figure 111 suggests that we cannot definitively rank the top three concepts. However, it is evident that concept A is falling behind the others, primarily due to its lower scores on ethical and environmental topics.

For technical reasons, it is important to note that group 1 did not provide any justification for the scores given to concepts B and C, regardless of the strategic topic.

### 3.3.2. Impact Guesser evaluations

The Figure 112 presents the ratings delivered by the Impact Guesser for the three strategic topics as well as an overall average. The raw results and detailed calculations can be found in the supplementary material 27.

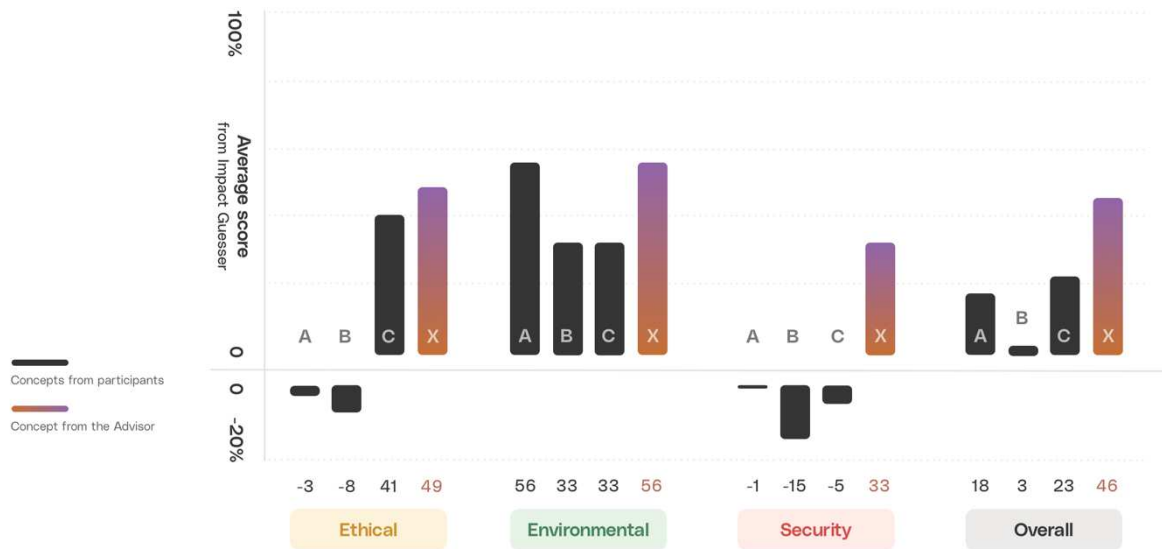


Figure 112. Means for the score given by the Impact Guesser of each concept.

The predominance of concept X is, of course, expected, as our models have indicated a set of appropriate usages for the impact strategy in defining concept X. However, we have been surprised to find that concept X is globally much superior to the others.

Our goal here is to compare the score of concept X relative to the scores of other human-generated concepts, from the viewpoint of the Impact Guesser, which involves assembling the opinions of the consulted experts to consolidate our databases.

Regarding ethics, two concepts received a positive score (C and X). Concept X is superior to the others with a score of +49%, primarily due to high scores on the themes of health and welfare and employment. Next, concept C obtained +41%, thanks to a very good score on employment. Concepts A and B received scores of -3% and -8% respectively, indicating that they may reduce ethical responsibility in the future. The low score of concept A is due to a very poor score on employment but offset by positive scores on human rights and identity and cultural heritage. The low score of B is explained by a poor score on health and welfare and a score close to zero for all other themes.

Regarding the environmental topic, all four concepts received relatively high scores. Concepts A and X scored +56%, while concepts B and C scored +33%. The two themes

of the environmental topic were energy and the environment, and their scores were consistently similar across the four concepts.

Moving on to security, concept X stands out as it was the only one to receive a positive score (+33%). In other words, concept X is likely to improve security, while the other three concepts are likely to degrade it. Concept A received a score of -1%, concept C: -5%, and concept B: -15%. The topic of security was exclusively represented by the theme of conflict and crime.

Overall, concept X surpassed the other three concepts with a score of +46%. Followed by concepts C (+23%), A (+18%), and B (+3%). Concept B was mainly impacted by its low scores in security and ethics.

### **3.3.3. Qualitative comparison of participants' justifications and expert opinions**

To further our analysis and test hypotheses 2 and 3, we qualitatively compared the justifications provided by the participants to justify their concepts with the expert opinions from the Impact Guesser.

We did not consider the impacts to avoid, as we did not use the Impact Guesser on them. We also did not consider concept X, as the justifications provided by the Advisor align with the opinions of the experts. It should also be noted that no expert opinion concerns the environmental strategic topic, as it deals with quantitative impacts drawn from the literature (SMI model).

On average, participants justified their choices with 250 words. While expert opinions from Impact Guesser provided an average of 1200 words per concept. Almost 5 times more details. To improve readability and reduce redundancy, we have synthesized the expert opinions to approximately 600 words per concept. The comparison is shown in Figure 113. Supplementary material 27 provides more details on this comparison and allows for a more suitable reading experience.



Figure 113. Qualitative comparison between the justifications provided by the groups for their choices, and the summary of expert opinions provided by the Impact Guesser (number of words reduced by two times).

To facilitate comparison, we have established four color codes. Firstly, elements that are common between participants and experts are highlighted in green. Elements that are similar but lack sufficient detail among participants to determine a definitive commonality are highlighted in yellow. Disagreeing elements are highlighted in red. The non-highlighted portions represent elements with no common points between participants and experts.

The first thing that stands out is the difference in the accuracy of rationale provided by the participants and the experts. The participants generally did not seek to explain the rationale behind their justifications. Concept A is particularly striking in this regard, as some of the justifications are limited to a few words like "safety" or "environmental responsibility". This was obviously too broad to find any points of comparison with the experts, as highlighted in yellow in Figure 113.

Another notable aspect is that many of the topics discussed by the experts are not reflected in the justifications provided by the participants. In fact, some elements used to justify a concept are even contradicted by the experts. For example, Concept B justifies the usage of "working in the vehicle" by claiming that it allows for more working

time. The experts acknowledge that working in the vehicle can provide flexibility, but it also carries the risk of burnout (highlighted in red).

This last example illustrates another point: the lack of nuance in the participants' justifications. Overall, they did not engage in deep reflection to anticipate the consequences that their choices could have. Instead, they settled for immediate and obvious justifications that are always positive. Resulting in depicting rather utopian concepts of autonomous vehicles. And that was despite the fact that two out of three groups finished before the deadline.

### **3.3.4. Observations during the experiment**

The experiment lasted longer than expected. The concept imagination phase lasted 50 minutes (instead of 30), and the evaluation phase lasted 46 minutes (instead of 30). Since we had announced a 3-hour experiment to the participants, we were still able to conduct the experiment without any issues. This shift in time was mainly due to the absence of a preliminary experimentation test.

Some participants expressed confusion regarding the overall objective of the experiment. It appears that they have not grasped the importance to anticipate long-term impacts. For some, they do not even imagine it can be important; here, the "let us practice business as usual" prevails. Additionally, several participants found the evaluation process to be challenging. Furthermore, some had concerns about the requirement to provide a minimum of 100 characters of text to justify their evaluations.

Before the end of the experiment, all groups were able to identify the concept generated using the tool. One of these groups noted that the concept was more detailed compared to the others. This is corroborated by the number of words used to justify, which is significantly higher than for the other concepts (731 words compared to 244 for the second concept; see supplementary material 27). Another group felt that the justifications for the concept resembled those that could have been generated by a Large Language Model like *ChatGPT*. They described the justifications as "generic" and sometimes even absurd, which we, of course, do not share as these justifications were generated by carefully selected experts and the arguments are causally related to specific use modes. Importantly, at this point, none of the participants were aware that the data used to generate concept X came from experts or scientific studies.

At the end of the experiment, we used the Impact Guesser in a plenary session on Concept B (the one that received the highest score from participants) to show Group 2 that their concept was still far from being responsible. We specifically demonstrated that by removing the private mode of use from a scenario, the environmental score increased significantly. Surprisingly, some of the participants questioned the tool's capacity to deliver accurate information. Time elapsed, and we were frustrated not to be able to go further with a deepened auto-analysis of participants' evaluations. A

meeting between participants and the Impact Guesser experts would have been relevant to reveal if the concept evaluations by participants were finally trustworthy.

## 4. Discussion

### 4.1. Interpretation of the results

The Figure 114 overlays ratings delivered by the participants (Figure 111) and the results of the Impact Guesser (Figure 112).

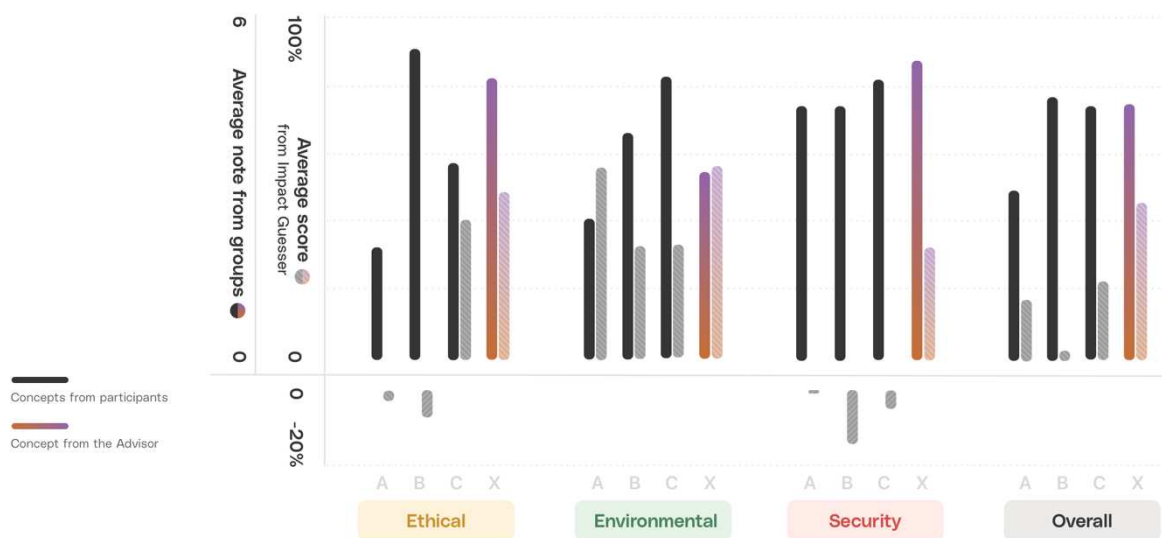


Figure 114. Results overlayed.

The evaluation results indicate that the Advisor can generate a concept that is at least as convincing as a concept envisioned by decision-makers. Although these results do not provide statistical validation for our hypothesis (h1), they still serve as a promising indication. Moreover, the results suggest a weakness in the participants assessment of the long-term impacts of AV.

The very low score of concept A can be explained by the fact that its justifications were much less developed than those of the other concepts, and that humans seem to need explanations - highlighted several times by groups 2 and 3 who evaluated this concept - to validate their own opinions. Amazingly, the Impact Guesser prefers concept A over concept B on all three criteria. It is also remarkable that the score given by the participants on the environmental topic is the lowest of the four, while the score given by the Impact Guesser is the highest (tied with concept X). This seems to indicate that a concept that adheres to a given strategy will not be perceived as such if the justifications are not convincing enough. It first reveals more than a century of automotive industry thinking that has prioritized the purchase of private vehicles and the use of a cockpit as a private space. But more worryingly, this may also indicate that participants have a



real skills deficit in evaluating concepts, especially in ethical and environmental aspects. For example, none of the participants conducted research on the environmental impact of private vs shared modes of use, even though it is easy to find approximate figures on the internet (plus, it is not necessarily specific to autonomous vehicles). This is alarming and seems to be part of a societal trend where the analysis/simulation of environmental impacts is (still) not a priority for decision-makers. To go further, regarding concept B this time, there was another contradictory score between the participants and the Impact Guesser. On the overall average, concept B was considered by the participants as the one that best respects the strategic topics. However, it received the worst score from the Impact Guesser. For example, participants gave this concept a very good environmental score even though it promotes a private mode of use. The AutoVision tool, as well as many synthesis studies (see Chapter 3) clearly showed that this mode is likely to contribute to climate change (more empty trips, more car individualism, etc.). This result is striking and illustrates our previous statement about the participant's deficit into evaluating the concepts accurately. Concept C also has contradictory results regarding environmental and security topics.

What we find particularly interesting is that despite higher scores given by the Impact Guesser - which is based on expert opinions and scientific data - to the concept X (generated using the Advisor), participants considered two other concepts at the same level of compatibility with the strategic topics. More importantly, it was the concept that received the lowest score from the Advisor that was identified by participants as the one that best respected the strategic topics (concept B). We can say that decision makers lack knowledge of AV impacts and thus perceive a concept proposed by the Advisor as equally valid as a concept conceived by a group of individuals without knowledge of impacts. It is particularly striking in Figure 113 that participants missed many impacts and even provided justifications that disagreed with the tool (ethical responsibility) and scientific studies (environmental responsibility). This illustrates the urgency to propose tools like AutoVision — especially the combination of the two modes — to allow decision makers realize the consequences that a concept could have before making any choice. Because counterintuitively, we showed that they do not appear to be the most relevant individuals to assess them.

During the debrief session, we showed to the participants how to use the Impact Guesser to enhance concept B. However, some of them failed to acknowledge their lack of knowledge and instead doubted the tool's ability to challenge their design decisions (e.g., the decision to use private vehicles despite the considerable environmental impact). This seems to indicate a potential barrier to the tool, related to the trust that users place in it. This could also indicate that some participants may have been subjected to an illusion of expertise, as they have been working in the automotive industry for a long time.

## 4.2. Limitations

Despite previous interpretations, it is important to remember that this experimentation is exploratory and does not allow for a statistically determining result.

When calculating scores using the interpretation help of the Impact Guesser, we also made some approximations. We assigned a list of impact themes to each strategic topic and calculated an average score based on the scores of these themes. However, as mentioned in section 2.2.2, implementing a more complex scoring formula (somewhat equivalent of an inverse formula of the Advisor) would not have significantly impacted the results while adding substantial work to modify the AutoVision tool.

Participants quickly realized that concept X had been generated by the tool, primarily due to the more detailed justifications. If we had tested the experiment beforehand, we could have identified this earlier and modified concept X to make it appear more like a concept generated by a group within a 30-to-50-minute timeframe. However, it is important to note that the concept X presented in this experiment was created in less than 30 minutes using the Advisor tool.

An eventual group effect may have also influenced the results. It is not excluded that the most charismatic individuals may have influenced the other participants in their group.

The evaluation of participants for concept X, which received a relatively low score on the strategic environmental topic may have been influenced by the fact that the tool only provided environmental justifications for the modes of use, but not for the usages. This is because this topic is only linked to socio-economic and environmental impacts (energy and environment themes are from the SMI model), which are connected to validity domains (modes of use, continent of deployment) and not to usages (see Chapter 5). In other words, the Advisor mode could not offer guidance on which usages to promote or avoid. This is supported by the comment from group 3, which mentioned that there was limited explanation on concept X except for the justification of modes of use (they rated the concept as 3).

The Impact Guesser score only linked the topic of security to the conflict and crime theme. However, it is possible that participants have provided justifications related to security that are not specific to this theme (e.g. vehicle reliability). This limitation is inherent to the tool, which primarily focuses on the social impacts related to security. This can explain the low security score of concepts A, B, and C.

More importantly, it would have been beneficial to include an evaluation of concepts related to topics other than the three strategic ones. For instance, we could have asked participants to assess the economic potential of each concept or to select the concept they would prioritize for development within their company, providing justification for their choice. Obtaining such results would have been valuable for deeper analysis and for further validation of our observation that participants (products owners) tends to

prioritize concepts based on short-term profitability rather than long-term societal contributions.

Finally, we could have expanded the debrief section, in which we present the limitations of the concepts imagined by the participants using the Impact Guesser. We could have asked systematic questions to assess the participants' sense of knowledge/skill deficiency in the evaluation that was requested. We could have also shown them the comparison in Figure 113 presenting experts' opinions on the concepts, to see if they would question their initial justifications.

## 5. Conclusion

As discussed in previous chapters, predicting the consequences of autonomous vehicles is challenging. The Advisor mode of the AutoVision tool aims to address initial uncertainties by guiding decision-makers towards paths that can minimize negative impacts from the beginning. It should serve as a starting point to not only inspire ideas for autonomous vehicle concepts but, more importantly, to prioritize responsible long-term ideas.

The exploratory experiment described in this chapter was conducted with 8 decision-makers in a company working on AVs, divided into three groups. Despite the lack of statistical representativeness of the results, we were still able to highlight two important elements.

- Our hypothesis 1 seems to be correct: a concept generated using the Advisor mode could be just as compelling, in relation to a given strategy, as a concept generated by decision-makers themselves.
- The capacity of decision-makers to generate and evaluate a concept that is responsible ethically, environmentally, and in terms of safety does not seem to be adapted (hypothesis 2). We have shown that the participants lacked perspective regarding the consequences that autonomous vehicle concepts could have.
- We have also shown that experts can advantageously justify a concept, compared to decision-makers (hypothesis 3).

According to us, the two last result could be explained by three points. First, a possible overconfidence bias related to the fact that decision-makers have accumulated a lot of knowledge about automobiles throughout their careers. It is possible that they apply their knowledge of the current (or past?) automotive world to autonomous vehicles that will be deployed in 30 years. This could explain their lack of willingness to seek information (participants had access to a computer to fact-check information on the internet during the experiment, but never used it). The other possible explanation is the

prioritization of concepts based on criteria other than long-term responsibility. For example, short-term profitability. In a further experiment, it would be interesting to request participants to assess the economic value of concepts during the experiment to test this point. The last, and most concerning explanation could be a form of self-persuasion, or one could say denial about automobiles and AV bad consequences, especially in the context of climate change. We explore this aspect further in the conclusion of the thesis.

Nevertheless, our observations showed that it is urgent to help decision-makers take a step back and consider the long-term consequences of the vehicles they are working on today. This experiment has highlighted the importance of testing concepts without relying solely on the preconceptions and assumed expertise of decision-makers. This validates the interest of both modes of AutoVision: The Advisor mode to save time in the generation and selection phase of the most responsible ideas of AV concepts, and the Impact Guesser mode that can help increase knowledge and promote critical thinking towards concept proposals (see chapter 6).





## CHAPTER 8

# Conclusion and perspectives

This chapter concludes the research by highlighting the expected deployment of autonomous vehicles and the need for responsible consideration of their impacts. It outlines the main contributions of the research, acknowledges the limitations, and discusses future perspectives and potential options for the AutoVision tool.

# 1. Summary

The deployment of autonomous vehicles is expected in the coming years, along with the new forms of mobility they will bring. It is no longer a question of *if*, but rather a question of *when* it will happen. Many automobile manufacturers, such as Stellantis (within which this thesis was conducted), as well as tech companies like Alphabet, are already heavily invested in this field. However, this type of product has the potential to significantly disrupt the way people move by changing existing usages and introducing completely new ones. Therefore, it is the responsibility of companies to anticipate and consider potential consequences from today to mitigate irreversible issues, such as social or environmental problems (Chapter 1, Section 1). An analysis conducted within the Stellantis automotive group has revealed that the company was struggling to define a solid long-term strategy for autonomous vehicles until 2022. Focusing more on technological aspects than potential future usages and impacts (Chapter 1, Section 2).

The field of futures studies shows promise in exploring various future scenarios involving autonomous vehicles. However, it is not well-suited for an industrial context to assist decision-makers or designers in designing future products. Conversely, the engineering design technics commonly used by companies, are not suitable for products with deployment spanning several decades. On the other hand, industrial design could play a crucial role in defining what could be desirable futures with autonomous vehicles. We have merged these three fields of knowledge to construct our research, which aimed to propose a responsible approach to designing a disruptive product that has not yet been deployed (Chapter 1, Section 3).

To foster responsible long-term innovation, we have chosen the approach of anticipating potential impacts of AVs. Through three literature reviews and our analysis of the industrial context at Stellantis, we have formulated three research questions associated with three research axes (Chapter 2).

The first research axis, described in Chapter 3, concerns the acquisition of socio-economic and environmental impacts of autonomous vehicles. This category includes, among other indicators, CO2 emissions, traffic, and transportation speed. Based on abundant scientific literature on the subject, we have developed the Study-Method-Impact (SMI) model, which allows non-experts to obtain information about the impacts of AVs based on several characteristics, such as usage mode (private, shared), or the continent on which the vehicle would be deployed. Here, knowledge was extracted from scientific literature and stored in a database for further interrogation.

The second research axis is described in Chapter 4 and focuses on the acquisition of qualitative social impacts of autonomous vehicles. This category of impacts specifically looks at health status, conflicts, crimes, family relationships, among others. In the absence of solid scientific work on the subject, we have undertaken to build an original

model that allowed us to question experts in sociology, urban planning, medicine, and other disciplines about the potential social impacts of autonomous vehicles. This model, called Representation-Usage-Impact (RUI), thus links the usage of autonomous vehicles to their possible social impacts. Here, knowledge was extracted from impact and sociology experts and stored in a database for further interrogation.

The third and final research axis exploits the models developed in the previous two axes to implement an industrial tool allowing to anticipate the potential impacts of a given concept of autonomous vehicle. This tool is described in Chapter 5 and includes two modes of use. The first mode is a stimulation mode called Advisor, intended to advise decision-makers on autonomous vehicle development paths (for example, prioritizing a shared mode of use over a private one if the company's objective is to limit its environmental impact). The second mode is a simulation mode called Impact Guesser. This mode provides a list of weighted possible impacts based on a concept/scenario of an autonomous vehicle. For example, according to the tool, an autonomous vehicle that allows you to sleep during your commute to work can improve your health. These two modes amount to using, at best, the collection of impact and sociology experts' opinions and scientific literature - mainly based on simulations - to better accompany the responsible choice of AV design concepts.

Both usage modes of the AutoVision tool were tested in the field with a total of 37 participants. These experiments are described in Chapters 6 and 7. The results indicate that the tool effectively helps designers acquire knowledge about the impacts of autonomous vehicles and enables them to be more critical of their proposals. Additionally, the results suggest that the tool can generate concept ideas that are both relevant to decision makers and supported by scientific data. Furthermore, we have also demonstrated that designers/decision-makers are not the most relevant individuals to assess their own concepts in relation to their potential impacts. Based on these initial findings, we have identified the potential of the AutoVision tool to serve as a valuable resource for decision makers and autonomous vehicle designers.

## 2. Contributions, deliverables, and limits

Our initial objective was to propose a responsible approach to designing a disruptive product that has not yet been deployed, focusing on the specific case study of autonomous vehicles. Our research work has led to four main contributions:

- A socio-economic and environmental impact model (SMI) allowing a non-expert (i.e., someone who is not a researcher) to quickly access scientifically sound results about a specific autonomous vehicle concept.
- A social impact model (RUI) allowing to create a knowledge base on the possible social impacts of autonomous vehicles through an expert inquiry protocol.



Then, linking this knowledge base to evaluate the possible social impacts of an autonomous vehicle concept.

- An industrial tool (AutoVision) to help decision-makers and designers envision responsible autonomous vehicle concepts and verify the potential impacts they could generate.
- An on-field validation showing how AutoVision can help decision-makers defining responsible autonomous vehicle concepts using traceable data. And providing them with new knowledge about AV impacts to cultivate a critical mindset when considering their proposals.

For Stellantis, we have provided a functional prototype of the tool based on the online platform *Notion.so* and derived from the prototypes used in the experiments (Chapters 6 and 7). This prototype integrates the Advisor and Impact Guesser modes and the essential functions of the tool.

All these contributions imply certain limits that it is important to mention:

- The main drawback of AutoVision is the need for companies to regularly update its databases, which is a crucial requirement for its usage and effectiveness. Various approaches have been explored, such as leveraging Large Language Models (LLMs) to expedite the inclusion of data from scientific studies or automating expert solicitation questionnaires. In our opinion, if AutoVision is to be implemented on a large scale, these enhancements should be given priority, as they are feasible albeit requiring some time and investment.
- The SMI and RUI models have allowed for the collection of an initial set of data on the impacts of autonomous vehicles, but they are still limited). Ideally, we have set a minimum requirement of 3 impacts per indicator for cross-referencing the results. Currently, the RUI model only has 1.6 impacts, so we would need to involve around 14 more experts. On the other hand, the SMI model has 7.7 impacts, which meets the requirement. However, there is still a shortage of indicators (only 18).
- The models do not allow for establishing complex causal relationships between multiple impacts. They also do not consider combinations of multiple usages that could generate impacts greater than the sum of their parts. Additionally, the models do not account for the probabilistic nature of impacts.
- Participants in the experiments were not always decision-makers from Stellantis. In order to include as many participants as possible, we sometimes had to involve researchers from our laboratory or employees from a company working on AVs who may not exactly match the intended final user profile for AutoVision.

- The AutoVision prototypes lacked important features such as the ability to easily access a scientific study or expert opinions regarding a specific link between an AV characteristic and its potential impact. These shortcomings prevented us from fully testing the tool.

### 3. Generalization and perspectives

The AutoVision tool, currently exists as a functional but incomplete prototype. For it to be fully utilized in an industrial setting, it requires complementary functions that are currently lacking. The first challenge is to overcome the limitations imposed by the *Notion.so* platform. These limitations restrict the deployment of all desired functions and prevent the development of a satisfactory user experience. To address this, it would be necessary to develop the tool as a dedicated application. This would provide the ability to grant specific administrative access to authorized individuals. Additionally, this new architecture would facilitate access to justifications for each impact, allowing users to better understand the results provided. Lastly, it is crucial to include a consolidation mode that enables experts to regularly evaluate the impacts within the model and assign varying degrees of importance to each impact (similar to a "like" feature that enhances search engine results). Similarly to case-based reasoning algorithms (Kolodner, 2014; Leake, 1996; Riesbeck & Schank, 1989). We believe that these functions are necessary for the successful deployment and scalability of the AutoVision tool.

Assuming that the previous functions have been integrated into the tool, we could consider various deployment options, gradually expanding beyond just autonomous vehicles. The tool's consistent results, regardless of user profile or type of autonomous vehicle, suggest its suitability for other innovative products or technologies. The only condition would be for the product to be disruptive and have long-term deployment potential. For instance, the impacts of augmented reality combined with generative AI have already been examined in scientific literature and have the potential to disrupt numerous usages. AutoVision has only a few specific features related to autonomous vehicles, so only few adjustments would be needed to adapt its structure to other product domains. We have identified the following four possibilities, which are not mutually exclusive:

- Deploy the tool internally within the Stellantis group to support decision-making regarding autonomous vehicles and other future mobility systems. The tool could be used as a collaborative platform, enabling company experts to update it with new knowledge regularly (by adding new representations / concepts, new usages, new impacts).

- Offer companies or policymakers the opportunity to use the tool to anticipate the long-term impacts of a future product, in a business-to-business approach. The tool would then be extended to other types of products and hosted by a specific entity (start-up, consulting company).
- Develop an open-source platform that allows a large community to use and update the tool for free. The structure of the tool could evolve based on contributors, and the inclusion of other products would be facilitated. In the long term, it could benefit not only companies but also policymakers at the regional or international level.
- Create an educational version of the tool, which would allow a variety of users to explore cause and effect relationships and thus gain a better understanding of the long-term impacts of a product.

The AutoVision tool has the potential to greatly impact current design decisions and contribute to a more desirable future. In a time marked by climate change and economic uncertainty, AutoVision serves as a safeguard by helping decision makers comprehend the potential consequences of their present choices. This can lead to positive outcomes at all levels. For instance, by assisting in the anticipation of future regulations, it can improve long-term competitiveness. Embracing it would enable making more informed decisions and shape a better future for all.

## 4. Additional reflections

The AutoVision tool has proven its potential in helping designers and decision-makers envision more responsible autonomous vehicles in the long run.

Alongside these results, we have observed the reality on the ground within the complex industrial context of the Stellantis automotive group. We have noticed certain mechanisms and priorities that go beyond long-term responsibility considerations. Our experiments with decision-makers revealed limited interest in projecting oneself 30 years into the future, possibly due to significant constraints that make it difficult to credit uncertain long-term elements. The Stellantis Dare Forward 2030 strategic plan, mentioned earlier, supports this view by projecting the company 8 years into the future. Technical uncertainties and economic issues make it challenging to anticipate the future beyond that. Consequently, social considerations are minimal or non-existent for non-customers or non-employees in the long term. Regarding environmental considerations, the company is committed to reducing greenhouse gas emissions and transitioning towards a more circular economy. It is important to understand that while complying with regulations, the company may face complexities and limitations in reevaluating its approach to ensure a more sustainable future. Nevertheless, notable efforts have been made by certain brands of the group, such as Citroën, to innovate

sustainably and responsibly in their concepts. The introduction of the AutoVision tool aims to accelerate these efforts throughout the organization, highlighting a continuous commitment to improving sustainability practices.

At this stage, there are two main obstacles to using a tool like AutoVision. The first is the ability to easily update databases in an industrial context, which is necessary to ensure accuracy and encourage regular use of the tool. This is mainly a technical issue that can be resolved by allocating resources. For instance, automating the inclusion of data from scientific studies or simplifying the process of adding social impacts for sociologists. One potential solution being explored is linking the databases with Large Language Models (LLMs) to create an interface for adding and consolidating data, making it more user-friendly. Encouraging tests have already been conducted in this area.

The second obstacle, in our view, is the most concerning: *Do designers want to know about potential impacts?* The AutoVision tool focuses on long-term effects and enables a reevaluation of current modes of transportation, promoting responsible perspectives while discouraging ones that lead to negative futures. This might prompt manufacturers to reconsider their conventional approach, which can be daunting for designers and decision makers. We strongly believe that both companies and designers involved in this process have a growing responsibility towards the society they are creating for future generations. It is important for designers to step back and acknowledge that they do not hold exclusive responsibility for making responsible choices. They need support in considering potential outcomes from the outset, moving beyond idealized visions of the future, and anticipating possible failures or consequences.

In reality, the responsibility does not rest solely with the designer or the company. Instead, it is a collaborative effort involving various stakeholders (such as territories or regulators) who must work together to achieve a desirable long-term future. We strongly believe that sharing knowledge, as suggested by AutoVision, is an essential initial step in increasing awareness and fostering large-scale initiatives.



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# **Supplementary materials**

# Supplementary material 1: Videos

## 1. Google ad about the Google car



Click here or scan the QR code to watch the video



## 2. Three videos from PSA group



Click here or scan the QR code to watch the video



Click here or scan the QR code to watch the video





Click here or scan the QR code to watch the video



### 3. Toll crossing (Vinci and PSA group)



Click here or scan the QR code to watch the video



### 4. Toyota e-palette concept



Click here or scan the QR code to watch the video





# Supplementary material 2: Socio-technical analysis at Stellantis

This supplementary material complements the research methodology that was conducted at Stellantis.

## 1. External analysis

We performed a study on the topic of autonomous vehicles PSA and Stellantis. Our objective was to provide external context to the company to better identify areas of investigation for internal analysis. We differentiated between the company's communication and external news. To research Stellantis' public communication, we examined various official websites that were publicly accessible. These included PSA, Stellantis, and several brand sites (refer to Figure 1). After that, we looked for keyword information on YouTube and Twitter platforms to access additional communications on the topic.



Figure 1. Brands from the Stellantis group. Their communication has been analyzed to find information about autonomous vehicles.

We regularly monitored a large number of websites for news using various keywords (see below). We used search engines like Google and Duck Duck Go, switching between the classic search section and the "news" section. We also directly used the search functions of certain international technology journals (such as The Verge and Techcrunch), automotive journals (like futurecar.com), and general news outlets (such as The New York Times). This monitoring continued throughout the first year of the thesis and helped us enhance the information collected in official communications (Figure 2).

🔍 Query examples

- General research in French  
 {"véhicule" OU "mobilité"} + {"autonome"} + {"stellantis" OU "psa" OU "fca"}
- General research in English  
 {"autonomous" OU "automated" OU "self-driving"} + {"car" OU "vehicle" OU "vehicule"} + {"stellantis" OU "psa" OU "fca"}
- Targeted research in English on the brands of the PSA Group  
 {"autonomous" OU "automated" OU "self-driving"} + {"peugeot" OU "citroen" OU "ds automobiles" OU "opel" OU "free2move"}
- Targeted research in French on PSA experiments  
 {"véhicule" OU "mobilité"} + {"autonome"} + {"psa" OU "peugeot citroen"} + {"expérimentation" OU "test"}

```

autonomous_car; autonomous_vehicle; autonomous_automobile; automated_car; auto
mated_vehicle; automated_automobile; driverless_car; driverless_vehicle; drive
rles- s_automobile; self-driving_car; self-driving_vehicle; self-driving_autom
obile; intelligen- t_car; intelligent_vehicle; intelligent_automobile; and aut
omated_driving_system.

```

Figure 2. English synonyms of the autonomous vehicle proposed by Gandia (2018) and alternatively used in our research.

## 2. Internal analysis

As we mentioned earlier, we conducted the internal analysis in a particular department of the company. As this thesis is part of the merger between PSA and FCA, the new organization was not yet established during the field analysis. Therefore, we decided to only interview the actors within the PSA group. This means that our internal analysis heavily relies on the PSA group's perspective on Stellantis.

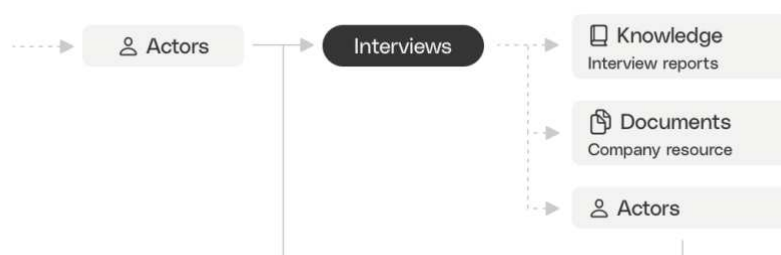


Figure 3. Representation of the interview process designed to converge in identifying new actors at each new interview.

The interviews followed a semi-structured format in which we asked questions based on the interviewee's responses and by using a pre-prepared framework called the "interview guide." This approach seemed appropriate because the interviewees had different profiles, roles in the organization, and levels of knowledge about autonomous vehicles. Due to the Covid-19 pandemic, the interviews were conducted remotely using Microsoft Teams. The process was productive, generating knowledge, providing access

to internal documents, and identifying interesting people for future interviews. The interviews were scheduled for one hour, divided into four phases, allowing for exploration of details without taking up too much of the participants' time and maintaining a consistent format. See Table 1 for a description of the four phases of the interviews.

Table 1. Detail of the four phases of the interviews.

Phase	Phase name	Support	Approximate duration
1	Contextualization, presentation of the thesis and interview objective	Powerpoint	10 minutes
2	Participant presentation	/	10 minutes
3	Semi-directed discussion	Sharing of documents by the interviewee if necessary	35 minutes
4	Debrief (return to the interview objective, sharing of documents, contacts, and other practical aspects)	Powerpoint	5 minutes

An interview guide was created to aid in conducting the interview (Table 2). It was divided into themes, which had objectives and expected outcomes, as well as a set of open-ended questions provided as examples. The four themes corresponded to (1) the company's positioning evolution, (2) various autonomous vehicle projects, (3) skills and actors, and (4) intermediate objects (as defined by Boujut & Laureillard, 2002) for representing the future and AV. It is important to note that for the last point, we intentionally distinguished between (a) representations of the future (the context) and (b) representations of the autonomous vehicle (the object).

Table 2. Interview guide used.

Theme	Objectives	Expected outcomes	Open questions (in French)
Skills / Actors (3)	Identify the actor and be able to position them precisely within the company	Career path, current position, interactions and nature of the links with the VA	<ul style="list-style-type: none"> <li>- <i>Présentation du poste (poste et rôle, activité, localisation, background)</i></li> <li>- <i>Quels liens entre votre poste et le VA ?</i></li> <li>- <i>Quelles interactions internes / externes ?</i></li> <li>- <i>Quels projets en rapport avec le VA ? (+ impacts si possible)</i></li> <li>- <i>Données d'entrées lorsque vous travaillez sur le VA ?</i></li> <li>- <i>Sources d'informations ? D'où vous prenez vos idées pour imaginer vos véhicules de niveau 3-4-5 ?</i></li> <li>- <i>Quelles sont les étapes clés pour un projet type ?</i></li> <li>- <i>Quel est le pourcentage d'un projet qui est repris en série ?</i></li> <li>- <i>Sinon si rien n'a été repris, qu'est-ce qui a été considéré comme un succès ?</i></li> <li>- <i>Est-ce que vos concurrents font la même chose ?</i></li> <li>- <i>Avez-vous mis en évidence des problèmes / impacts surprenants sur le VA ?</i></li> </ul>
Projects (2)	Know about projects / experiments on VA	Examples of projects, input data and information used, positioning vis-à-vis the competition... Technical project details are excluded (sensors, AI, etc...)	<ul style="list-style-type: none"> <li>- <i>Avec qui vous travaillez ?</i></li> <li>- <i>Quelles sont les compétences clés ? (quoi, qui, où) &gt;</i></li> <li>- <i>Réseaux d'open lab ? Universités etc...</i></li> <li>- <i>Qui fixe les directions stratégiques sur le VA ?</i></li> <li>- <i>D'autres infos du côté américain (ex-FCA) ?</i></li> </ul>
Skills / Actors (3)	Identify existing skills within the company	Contacts and their skills, devices in place to increase knowledge, who makes strategic choices and based on what.	<ul style="list-style-type: none"> <li>- <i>Avec qui vous travaillez ?</i></li> <li>- <i>Quelles sont les compétences clés ? (quoi, qui, où) &gt;</i></li> <li>- <i>Réseaux d'open lab ? Universités etc...</i></li> <li>- <i>Qui fixe les directions stratégiques sur le VA ?</i></li> <li>- <i>D'autres infos du côté américain (ex-FCA) ?</i></li> </ul>

Theme	Objectives	Expected outcomes	Open questions (in French)
Positioning (1)	Know the company's positioning	Visions, strategic directions and elements on which they are based	<ul style="list-style-type: none"> <li>- <i>Quelle est l'histoire de la vision de PSA / Stellantis sur le VA ?</i></li> <li>- <i>Quelle est le positionnement actuel sur le VA ?</i></li> <li>- <i>Positionnement par rapport à vos concurrents ?</i></li> <li>- <i>Savez-vous sur quoi l'entreprise se base pour prendre des décisions stratégiques sur le VA ?</i></li> <li>- <i>Sur quelles ressources vous appuyez-vous pour imaginer le futur de la mobilité ? Ces ressources sont-elles internes ou externes à l'entreprise ?</i></li> <li>- <i>D'où proviennent les idées / inspirations initiales pour les nouveaux concepts de mobilité ?</i></li> </ul>
Intermediate Objects (4)	List the mediums used to work and communicate on VA	Objects, media and documents, explanations on how we project ourselves into the future at Stellantis	<ul style="list-style-type: none"> <li>- <i>Quels outils utilisez-vous pour vous projeter dans le futur ? (scénarios...)</i></li> <li>- <i>Utilisez-vous des médiums, outils, supports particuliers pour faire passer des idées entre collaborateurs ? Si il existe différentes formes, pourquoi ?</i></li> <li>- <i>Sous quelle forme représenteriez-vous votre processus d'innovation concernant la mobilité du futur ?</i></li> <li>- <i>Qui borne les scénarios ?</i></li> </ul>

To increase efficiency, we prioritized interview summaries over transcripts when generating reports. All summaries were validated by interested parties to ensure data accuracy and confidentiality. We included a broad spectrum of company documents, both formal and informal, private and public, such as internal reports, public reports, emails, advertisements, and physical or digital objects such as diagrams, sketches, texts, videos, and prototypes. We conducted a total of 11 interviews with 10 different people, including nine current Stellantis employees and one former PSA employee. The collected information involved people with different backgrounds, including four technical specialists (including three working on automation and/or ADAS), three user experience and human-machine interface specialists, two strategy and planning specialists, and one regulatory specialist. The plurality of disciplines enabled us to capture different perspectives and shed light on unique points related to certain expertise, such as regulatory aspects.

We ceased conducting interviews for two main reasons: (1) the information was becoming repetitive, and (2) they were time-consuming. This repetition ensured that the company's image we captured was relevant (as previously explained in the autocatalytic effect). To elaborate, we encountered some difficulties in obtaining interviews with certain individuals and accessing key documents. Some employees had limited availability, while others did not respond to our requests. The Covid-19 situation also hindered our field integration by requiring remote interviews. These two factors impeded our internal socio-technical analysis, which could have been more comprehensive and informed about the role of social interactions among employees.

# Supplementary material 3: AV representations from Stellantis

This supplementary material provides additional information on the representations of autonomous vehicles that were captured during our socio-technical analysis of Stellantis. Table 3 summarizes the 15 identified representations.

Table 3. Representations of AVs used at some point by Stellantis.

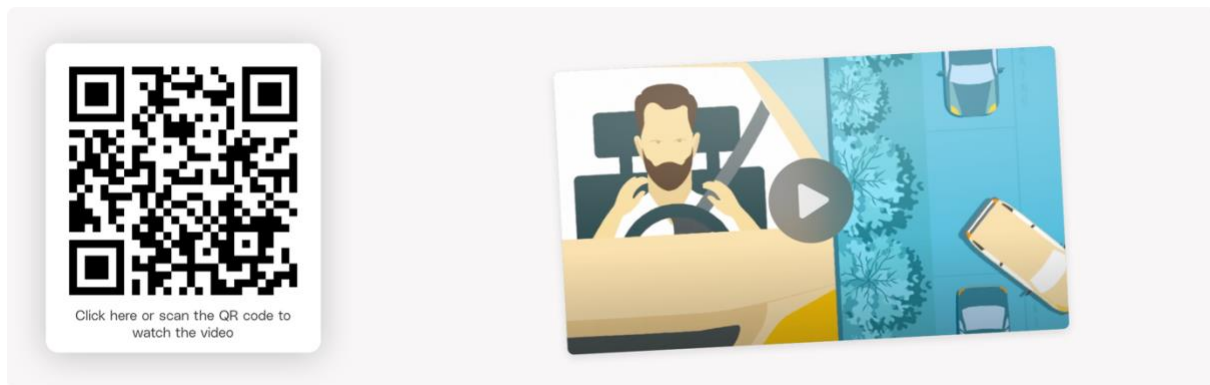
Id	Name
1	GROUPE PSA: towards autonomous vehicles
2	Automated driving: PSA device demonstration
3	Fiction "The City of Lost Drivers"
4	travl-air OpenLab concept
5	SYMBI[au] OpenLab concept
6	Citroën Skate Concept (CV20)
7	BIVAN OpenLab concept
8	Video "The autonomous and connected vehicle seen through the eyes of Generation Y"
9	Mobility Scenarios Singapore 2025+
10	Scenarios Highway Chauffeur (HC)
11	Scenarios Traffic Jam Chauffeur (TJC)
12	Mobility Case Storyboard
13	Ethical Autonomous Vehicles project
14	KO Shuttle
15	Storyboard Open Lab - Serviço - Cenário

Below, we provide examples of representation at varying levels of maturity. Please note that, for confidentiality reasons, we have only included three examples. Figure 4 illustrates the classification of representations based on the classification system presented in Chapter 1.

	Observation and exploration	Conceptualization	Proof of concept
Product		⑥	⑭
Graphic and sensory	⑤ ⑦ ⑧	① ⑨ ⑩ ⑪ ⑫ ⑬	②
Linguistic and semantic	③ ④ ⑮		

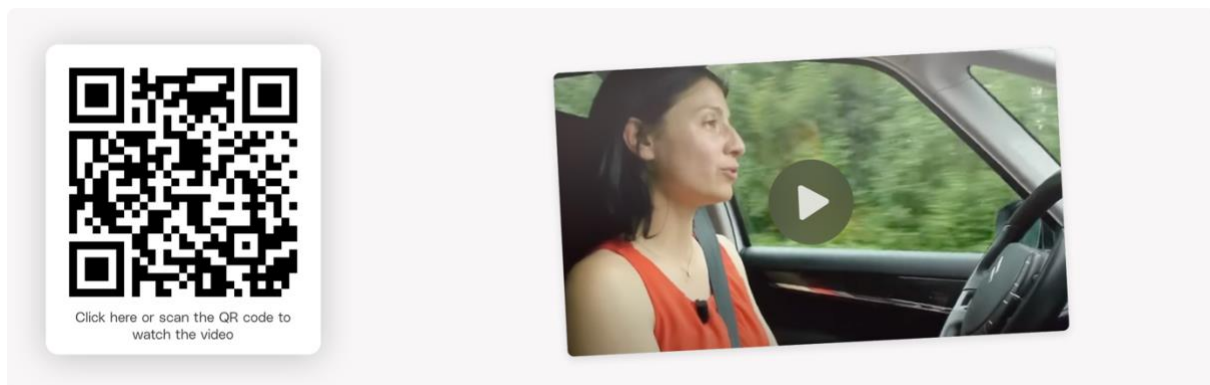
Figure 4. The representations distributed in our classification system.

## 1. GROUPE PSA: towards autonomous vehicles



This video was published in 2017 on the GROUPE PSA YouTube channel. It belongs to the graphic and sensory representation space: It is an animated film commented by a voice-over presenting the future automation functions of PSA vehicles. For example, the park-assist function, hands-off and eyes-off functions, or even automated parking maneuvers from the smartphone. The voice-over concludes the video by saying that "the autonomous vehicle is already a reality." The corresponding maturity level is that of conceptualization because these functions are not yet available and no information is given about their reality (release date, technical characteristics). The video is mainly focused on the user experience in a privately used vehicle.

## 2. Automated driving: PSA device demonstration



This second video was posted in September 2014 on the GROUPE PSA YouTube channel. It belongs to the graphic and sensory representation space: A project manager presents the automated driving system in a video, with a mix of shots inside and outside the vehicle. The corresponding maturity level is that of proof of concept because the demonstration is made with a functional prototype. If we consider only the prototype, the representation space becomes the product space. But we will not detail it here because it is not publicly accessible.

## 3. Fiction "The City of Lost Drivers"



This representation is a fiction that one of the interview participants working on strategy sent to us. It is not internal to the company, but gives an example of external influence for a collaborator. This fiction is a story written in 2016 that imagines mobility in 2050. Therefore, it belongs to the linguistic and semantic space and its level of maturity is exploration.

## Supplementary material 4: Synthesis reviews rejected

List of synthesis reviews selected after phase 2, and explanation of the decision to reject 7 of them (phase 3).

ID	Reference	Title	Decision
Review 1	Narayanan et al. (2020)	Shared autonomous vehicle services: A comprehensive review	✓
Review 2	Milakis et al. (2017)	Policy and society related implications of automated driving: a review of literature and directions for future research	✓
Review 3	Golbabaei et al. (2021)	The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature	✓
Review 4	Acheampong (2018)	Literature review on the social challenges of autonomous transport	✓
Review 5	Soteropoulos et al. (2019)	Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies	✓
Review 6	Faisal et al. (2019)	Understanding autonomous vehicles: A systematic literature review on capability, impact, planning and policy	✓
Review 7	Sun et al. (2017)	Road to autonomous vehicles in Australia: an exploratory literature review	X Does not address socio-economic or environmental impacts – criteria (2)
Review 8	Gandia et al. (2019)	Autonomous vehicles: scientometric and bibliometric review	X Does not address socio-economic or environmental impacts – criteria (2)
Review 9	Duarte & Ratti (2018)	The impact of autonomous vehicles on cities: A review	X Methodology not explained – criteria (3) and (4)
Review 10	Stead & Vaddadi (2019)	Automated vehicles and how they may affect urban form: A review of recent scenario studies	X The focus is on the scenarios and not on the impacts – criteria (2)
Review 11	Becker & Axhausen (2017)	Literature review on surveys investigating the acceptance of automated vehicles	X The focus is on acceptability and not on impacts – criteria (2)
Review 12	Gkartzonikas & Gkritza (2019)	What have we learned? A review of stated preference and choice studies on autonomous vehicles	X The focus is on assessing perceptions / preferences of people and not on impacts – criteria (2)

Criteria are described below:

**Criteria 1.** Is it a synthesis review?

**Criteria 2.** Is the focus on socio-economic or environmental impacts of AVs?

**Criteria 3.** Is the impact collection method described?

**Criteria 4.** Is the impact classification method described?



## Supplementary material 5: Socio-economic and environmental indicators

This supplementary material presents all the themes of socio-economic and environmental indicators.

Theme	Indicator	Description	Number of studies
Distance	Total VMT / VKT	Evolution of total vehicles miles/kilometers travelled (or total mileage): Comparison between a base case (classic use of vehicles: private, not automated) and a described case involving autonomous vehicles. When the VKT measurement is not specified it was assumed to be overall.	29
Transport share	Total number of vehicles	The evolution of the total number of vehicles (TNV) with the arrival of autonomous vehicles for a given area. May be derived from vehicle replacement rate (VRR).	24
Traffic	Road capacity	The evolution of maximum traffic flow obtainable on a given road; usually expressed in vehicles per hour per lane (veh/h/lane) or in vehicles per hour (veh/h).	18
Parking	Parking spaces needed	The evolution of the number of parking spaces required in a specific area.	13
Environment	CO2 emissions	Evolution of the quantity of CO2 rejected by vehicles usage (manufacturing not included) with defined values of comparisons.	9
Energy	Fuel consumption	Evolution of the fuel consumption by one vehicle in %. Comparison between a base case (classic use of vehicles: private, not automated) and a described case involving autonomous vehicles. Can be expressed in km/l or l/h.	7
Time	Intersection delay	Evolution of the delay caused by the passage of a vehicle through an intersection in % : Comparison between a base case (classic use of vehicles : private, not automated) and a described case involving autonomous and/or connected vehicles.	6
Time	Travel time	Evolution of the travel time of a vehicle from point A to point B in % : Comparison between a base case (classic use of vehicles : private, not automated) and a described case involving autonomous vehicles.	6
Energy	Energy consumption	Evolution of the quantity of energy needed for vehicles in %. Comparison between a base case (classic use of vehicles: private, not automated) and a described case involving autonomous vehicles.	4
Traffic	Intersection capacity	The evolution of traffic flow on a given intersection; usually expressed in vehicles per hour per lane (veh/h/lane) or in vehicles per hour (veh/h); may concern the entire intersection or only one lane.	3
Transport share	Total number of taxis	The evolution of the total number of taxis with the arrival of autonomous vehicles for a given area.	3

Theme	Indicator	Description	Number of studies
Environment	GHG emissions	Evolution of the quantity of greenhouse gas rejected by vehicles usage (manufacturing not included) with defined values of comparisons.	3
Distance	VMT / VKT per vehicle	Evolution of vehicle miles/kilometers travelled per vehicle in an area expressed here in %: Comparison between a base case (classic use of vehicles: private, not automated) and a described case involving autonomous vehicles.	2
Speed	Average speed	Evolution of the travel speed / velocity of vehicles in % : Comparison between a base case (classic use of vehicles : private, not automated) and a described case involving autonomous vehicles.	2
Traffic	Space needed for cars	The evolution of space needed for cars in % (road geometry, space for noise barriers and separation, and parking); expressed with a unit of area.	1
Transport share	Total number of vehicles on the road	The evolution of the total number of vehicles with the arrival of autonomous vehicles on the road.	1
Traffic	On-ramp effects on road capacity	The evolution of the local road capacity in an on-ramp area in %; usually expressed in vehicles per hour per lane (veh/h/lane) or in vehicles per hour (veh/h).	1
Distance	Total PKT / PMT	Evolution of miles/kilometers travelled per person in an area expressed here in %: Comparison between a base case (classic use of vehicles: private, not automated) and a described case involving autonomous vehicles.	1

## Supplementary material 6: Identifying common indicators

This supplementary material presents the list of statements made by authors of reviews 7 and 8 corresponding to indicators of the SMI model.

We have added an "Explanation" column that summarizes the condition(s) put forward by the authors of each statement. The last two columns relate to matches found with the SMI model. The first column ("Corresponding indicators") lists the closest indicator(s) to the statement, while the second column ("Corresponding conditions") lists the closest condition(s) to the explanation.

Statement number	Review	Statement	Explanation	Corresponding indicators (SMI)	Corresponding conditions (SMI)
1	8	Emission reductions	Shared mobility	GHG emissions, CO2 emissions	Mode of use: Shared
2	8	Emission reductions	Improved traffic flow, improved safety, increased road capacity, reduced congestion	GHG emissions, CO2 emissions	Conditions on indicators: Road capacity ↑, Intersection capacity ↑
3	8	Increase in emissions	Increased distances travelled	GHG emissions, CO2 emissions	Conditions on indicator: Total VMT / VKT ↑
4	7	Increases the VKT, emissions, and energy consumed	Shared AVs might encourage people to make additional trips	VMT / VKT per vehicle, GHG emissions, CO2 emissions, Energy consumption	Mode of use: Shared
5	7	Increases VKT, emissions, and energy consumed	AVs let passengers do other things during trips, reducing the feeling of lost time. This could encourage people to travel longer distances.	VMT / VKT per vehicle, GHG emissions, CO2 emissions, Energy consumption	Conditions on indicator: Total PKT / PMT ↑
6	7	Potential to significantly reduce the parking demand by 80 to 90%		Parking spaces needed	
7	7	...reduces congestion of vehicles searching for a parking space	Reduce the parking demand	Road capacity	Conditions on indicator: Parking spaces needed ↓
8	7	potential to reduce emissions and energy	Reduction in required fleet size	GHG emissions, CO2 emissions, Energy consumption	Conditions on indicator: Total number of vehicles ↓



## Supplementary material 7: Presentation video showcasing the initial model to experts



# Supplementary material 8: Feedbacks from experts

This supplementary material summarizes all the feedback that experts have provided on the initial version of the RUI model.

Name	Description	Characterization	Solutions	Experts
Inability to generate impacts without context	Sociologists require context to envision impacts. However, the mobility landscape in 2050 is too uncertain to contextualize usage and generate relevant impacts. Therefore, it is necessary to consult experts who can clearly explain the impacts. Some examples include characterizing social demand, determining the area of social relevance (transect), gauging the willingness to use AVs, and measuring the proximity generated between people.	Fondamental	→ Adding context elements on the links between usages and impacts	A, F, E
Why limit to sociologists?	The use of sociologists is limiting. Other experts such as doctors, geographers, road safety experts, psychosociologists, psychologists, managers, lawyers, urban planners, and other experts in social sciences could also be relevant.	Major update	→ Consolidation of criteria for selecting experts	F, G, H, I
Lack of nuances in representations	Current representations of disruptive innovation tend to be black or white (utopias/dystopias).	Minor update	→ Evaluation of the polarization of representations (utopias / dystopias) to verify this remark	C
Forgetting taboos and unforeseen usages	Depending on the representations, taboos, unforeseen/unintended uses may not be present in the uses. For example, a company that expresses a vision of AV in the form of a representation will only present wanted uses.	Minor update	→ Verification that taboos and unexpected usages are taken into account	C
Expert selection bias	By aggregating the opinions, convictions, and arguments of sociologists, there is a risk of experiencing a selection bias.	Minor update	→ Implementation of a minimum number of interviews to limit bias	D
Consent not sufficiently taken into account in interviews	Respect the GDPR, clearly explain what will happen to the experts' data, and explicitly obtain their consent.	Minor update	→ Drafting a detailed consent form for experts	G
New usages focused on the driver	New usages are often related to the absence of a driver. The use is therefore new for the driver but not necessarily for the passengers (e.g., a taxi passenger).	Minor update	→ Being clearer in the definition of augmented usage	I
Open representations to scientific studies	Some scientific results (interview studies) can help generate possible uses from future probable experts or users.	Minor update	→ Adding scientific work to the representations	H
Representations imagined with current mindsets	Representations are necessarily biased by the authors' current (or past) state of mind.	Assumed		C

Name	Description	Characterization Solutions	Experts
New usages emerge during transitional phases	Usages are more likely to emerge during transition phases because innovation will be incremental (i.e., during the arrival of ADAS in vehicles and until the gradual arrival of AVs). This is not taken into account in the method at this stage.	Assumed	C
User constraint field	Usages present in the representations often do not take into account users' constraint field, which weakens the value of the impacts.	Assumed	C
Comparison of AV with personal vehicle	The AV is compared to the personal vehicle and not to buses, taxis.	Assumed	I
Many usages are not imagined	Some uses are systematically less imagined in representations (e.g., business fleets). Some are even completely forgotten at times.	Assumed	F
Multi-factorial and correlated impacts	Impacts can take different forms and come from a complex combination of factors. They are also correlated with each other (complex causal chains).	Assumed	I
Unequal representativeness of representations	Representations are often focused on particular populations/people. In their entirety, they are not representative of the population.	Assumed	I
Prospective ergonomics	An interesting research field that focuses on what people will do with products that do not yet exist.	Advice	H
Avoid talking about the method during interviews	Presenting the method in detail could divert experts from the interview's objective because they could dwell on all the "problems" of the method.	Advice	G

**Fondamental:** The validity of the method is being questioned, and a thorough revision is necessary

**Major update:** Improvement of the model through a significant addition

**Minor update:** Improvement of the model through minimal addition

**Assumed:** Based on our choices and assumptions, we have not envisioned any update.

**Advice:** Tips given by experts

## Supplementary material 9: Experts

Below is the complete list of experts who participated in the development of the model and/or the addition of impacts. They all have been anonymised.

ID	Expertise	Feedbacks on the model	Adding impacts
Expert A	Training in social sciences and management. Runs a research institute on mobility.	Yes	No
Expert B	Sociologist specializing in decarbonized and electric mobility.	Yes	Yes
Expert C	Social responsibility, energy efficiency, energy practices and consumption of households and employees.	Yes	No
Expert D	Sociologist specializing in Urban Planning, Mobility, Controversies, Environmental Assessment	Yes	Yes
Expert E	Sociologist specializing in the social life cycle analysis	Yes	No
Expert F	Specialist in socio-economics of mobility, new mobility services, mobility transitions	Yes	No
Expert G	Sociologist using both qualitative and quantitative methods, while remaining at the interface of complementary disciplinary approaches.	Yes	No
Expert H	Psycho-ergonomist, specialist in mobility innovations.	Yes	Yes
Expert I	Anthropologist and design fiction specialist.	Yes	No
Expert J	Sociologist researcher.	No	Yes
Expert K	Sociologist.	No	Yes
Expert L	Graduated in International Law, Political Science, and Psychosociology. Co-director and founder of a research institute focused on mobility.	No	Yes
Expert M	Retired sociologist researcher.	No	Yes
Expert N	Psycho-ergonomist.	No	Yes
Expert O	Energy specialist sociologist.	No	Yes
Expert P	Research engineer for health and wellness monitoring in the automotive industry.	No	Yes
Expert Q	Urbanist researcher specialized in mobility	No	Yes
Expert R	Ergonomist.	No	Yes
Expert S	Ergonomist specialized in mobility and ADAS.	No	Yes
Expert T	Ergonomist.	No	Yes
Expert U	Specialized in AV and ADAS regulations on safety.	No	Yes



<b>ID</b>	<b>Expertise</b>	<b>Feedbacks on the model</b>	<b>Adding impacts</b>
Expert V	Doctor of law and sociologist, specialized in mobility.	No	Yes
Expert W	Engineer specializing in autonomous vehicle regulations.	No	Yes

## Supplementary material 10: Adding a usage

This document provides an example of how to add usage following the protocol described in **Error! Reference source not found.**

### Adding a usage from a representation

Here we use a representation of an autonomous vehicle in the form of a comic strip proposed by PSA in 2020. We have identified an interesting usage: The fact that the vehicle autonomously picks up the passenger without anyone inside (illustrated in Figure 5).



Figure 5. Illustrated usage.

According to the Table 4, the conditions to add this usage are met.

Table 4. Conditions to add an usage.

Condition	Evaluation
The vehicle is primarily designed to transport passengers with the ability to transport objects.	✓ Verified condition
The vehicle has a seating capacity of 1 to 9 seats (category M1 from United Nations Economic Commission for Europe, 2017).	✓ Verified condition
The vehicle has an automation level of 4 or higher on the SAE scale (SAE International, 2021).	~ Undetermined, but it is used without driver
The vehicle operates in a country with a high human development index ( $\geq 0.700$ ) (Gibbs, 2022; UNDP, 2020).	✓ Verified condition

We estimated that this usage was conditioned by the deployment of AV. Therefore, it is a *new* usage. The action is performed by the vehicle, and the action is *picking up passenger*. This usage is new because the vehicle picks up the passenger while being empty. Therefore, we have added the context: *without passenger*.

We linked usage to the initial representation, adding the following characteristics:

- Author: Robin Lecomte (reminder: this is the author of the link, not the representation)
- Date: 29/09/2022 at 10h45

## Details in databases

### *REPRESENTATION*

<b>Name</b>	Mobility Case Storyboard
<b>Year</b>	2020
<b>Author</b>	GROUPE PSA
<b>Resource</b>	PDF Document
<b>Description</b>	Mobility scenarios by a car manufacturer
<b>Shape</b>	Cartoon
<b>Maturity</b>	2. Projet / Vision

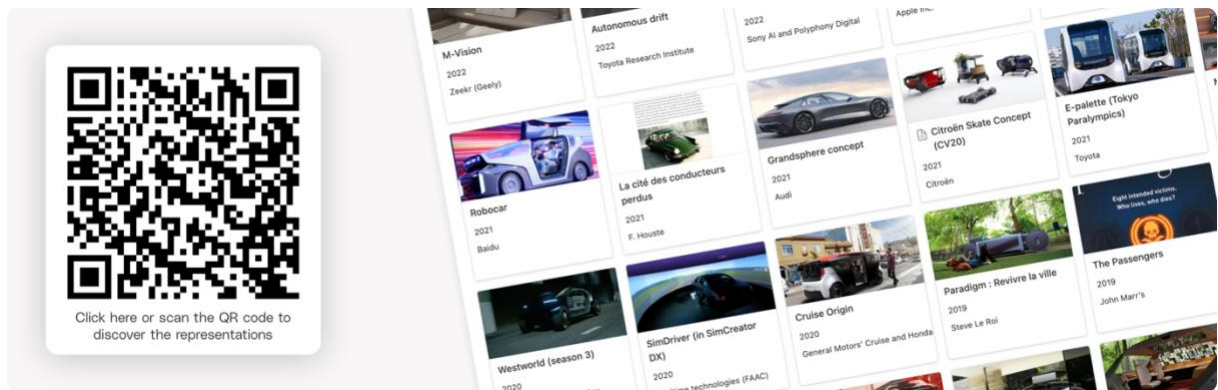
### *EXTRACTION*

<b>Author</b>	<b>Date</b>
Robin L	29/09/2022 à 10h45

### *USAGE*

<b>Type</b>	<b>Subject</b>	<b>Action</b>	<b>Context</b>
New	the vehicle	is picking up passenger	without passenger

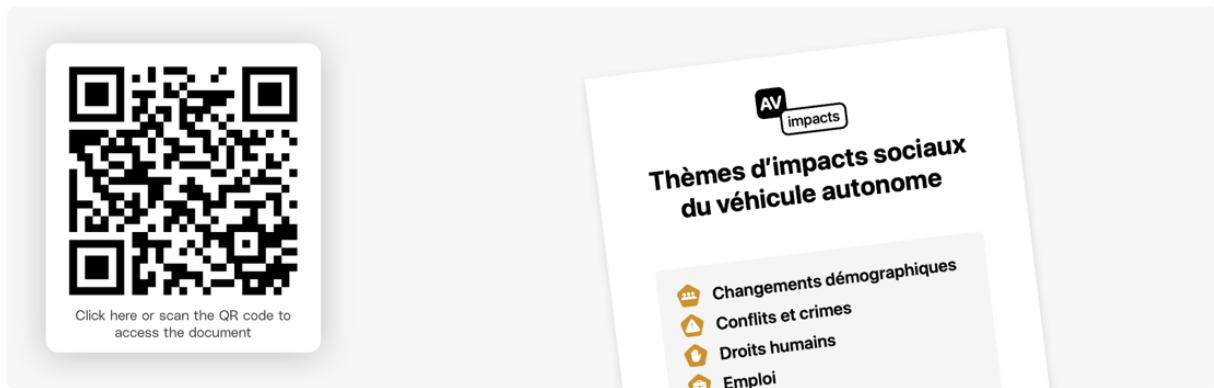
# Supplementary material 11: Extract of Representation database



## Supplementary material 12: Impacts themes sheets

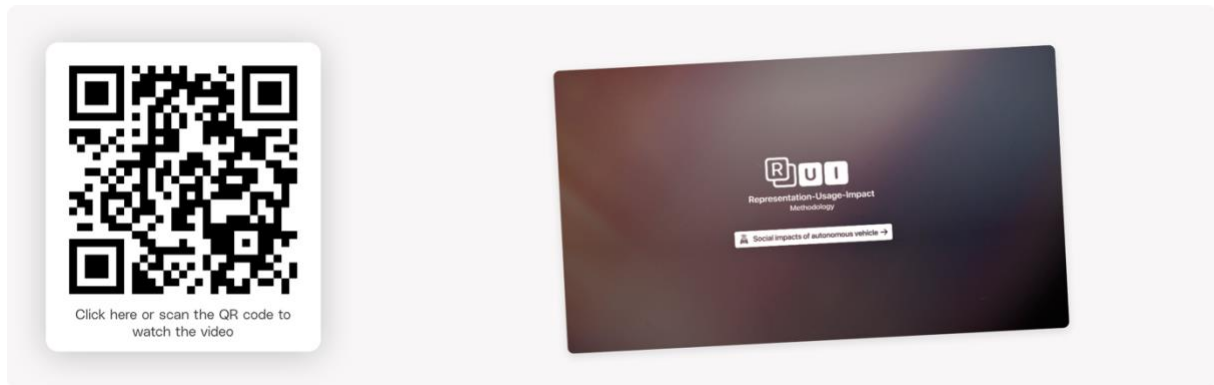
The attached document contains information on all 11 social impact themes. It is intended for experts who have been invited to contribute to the impacts.

The document is in French.



## Supplementary material 13: Graphical user interface for RUI

The following video proposes a graphical user interface that uses the RUI model to help designers gain knowledge about the social impacts of autonomous vehicles.



## Supplementary material 14: GDPR and Data Privacy

Attention has been drawn to consent, use, and protection of data provided by experts.

According to the Commission Nationale de l'Informatique et des Libertés (CNIL), which is the French data protection authority, personal data concerns "any information relating to an identified or identifiable natural person." Within the framework of their collection and/or processing by a private or public entity, the General Data Protection Regulation (GDPR) applies (Ministère de l'économie, 2019).

Expert interviews require the collection of several pieces of information, some of which fall under personal data. In compliance with GDPR, a form specifying the collected data, their retention period, and their use have been presented to the participants. Their agreement were necessary to conduct the interview (Table 5).

Table 5. Collected data.

Category of data	Data	Time until deletion	Use
Interview transcription	Audio Recording; Written Synthesis	Maximum 2 months after the interview	Capture relevant information for the RUI model (categories below) before deletion.
Expert identification	Name; Surname; Company; Expertise; E-mail	Undetermined	RUI use
Knowledge linked to the model	Impacts coded into the databases	Undetermined	RUI use

It may happen that participants refuse to have their personal data stored. If this were to happen, we would consider asking for partial authorization in which the elements allowing them to be identified would be removed (data in red in the table). We did not have to do it for our interviews.

## Supplementary material 15: Impacts synthesis

At the end of each session, a document summarizing all impacts is sent to all participants. This is a way of thanking experts for their participation by giving them access to the data.

The summaries sent to the participants are available below (in French).





# Supplementary material 16: Raw results from RUI

We consider the three examples of usages analyzed in the main document. As a reminder, we selected these usages based on the ratio between the number of usage-impact links and the number of indicators for each usage ( $r = \frac{n_{\text{impacts}}}{n_{\text{indicators}}}$ ). They are presented in the Table 6.

Table 6. Three examples of usage.

Id	Usage	Impacts	Indicators	r
S2U04	The passenger communicates with the passengers of nearby vehicles during transportation	6	3	2
S2U10	The passenger performs personal tasks during transportation (e.g. a shopping list)	3	2	1.5
S1U09	A person from outside the vehicle kills someone by taking control of the vehicle	6	4	1.5

The impacts related to these three usages are presented in the following three tables. These tables include extracts from the output of the RUI model, which was interrogated with the three aforementioned usages.

## Usage ID: S2U04

Table 7. Impacts for the usage S2U04.

Indicator	Trend	Intensity	Occurrence	Depth	Certainty	Expert ID	Theme
Ease of reporting a problem	↑	2	3	2	3	D	Networks and communication
Insults and threats between road users	↑	3	2	2	3	S	Conflicts and crimes
Social interactions	↑	2	3	2	3	D	Networks and communication
Social interactions	↑	3	3	3	3	O	Networks and communication
Social interactions	→	1	1	2	3	V	Networks and communication
Social interactions	↑	1	1	2	1	S	Networks and communication

## Usage ID: S2U10

Table 8. Impacts for the usage S2U10.

Indicator	Trend	Intensity	Occurrence	Depth	Certainty	Expert ID	Theme
Pressure to increase the number of activities	↑	3	2	2	3	Q	Health and welfare

Indicator	Trend	Intensity	Occurrence	Depth	Certainty	Expert ID	Theme
Pressure to increase the number of activities	↑	3	2	2	2	V	Health and welfare
Free time	↑	3	3	3	2	D	Health and welfare

### *Usage ID: S1U09*

Table 9. Impacts for the usage S1U09.

Indicator	Trend	Intensity	Occurrence	Depth	Certainty	Expert ID	Theme
Mobility access	↑	2	2	2	2	U	Human rights, population change, identity and cultural heritage
Ability / Sense of direction	↓	3	2	2	3	S	Identity and cultural heritage, education
Ability / Sense of direction	↓	3	2	2	3	V	Identity and cultural heritage, education
Ability / Sense of direction	↓	3	2	2	3	V	Identity and cultural heritage, education
Movement awareness	↓	3	2	2	3	V	Health and welfare
Risk of kidnapping	↑	3	1	3	2	Q	Conflicts and crimes
Mental health	↓	3	2	2	3	V	Health and welfare

Below are some examples of statements obtained by reading the table.

- If the AV allows the passenger to communicate with nearby vehicles during transport, then it could be easier to report a problem (according to the expert D, sociologist and urban planner who has worked on automobile attachment).
- If the AV allows the passenger to communicate with nearby vehicles during transport, then it could significantly increase insults and threats between road users (according to the expert S, innovation ergonomics and ADAS pilot at Stellantis).
- If the AV allows the passenger to communicate with nearby vehicles during transport, then the number of social interactions could moderately increase (according to the experts D, S, and O, sociologists at EDF). To qualify, the expert V (doctor of law / DEA in sociology) believes that the number of social interactions will not be affected.
- If the AV allows the passenger to perform personal tasks during transport (e.g. a shopping list), then it is likely to significantly increase the pressure on them to perform more activities (according to the experts V and Q, pilot of a study on the place of autonomous vehicles in ecological transition).

- If the AV allows the passenger to perform personal tasks during transport (e.g. a shopping list), then the available free time will be considerably and systematically increased (according to the expert D).
- If an external person can kill someone by taking control of the vehicle, then there will be a significant increase in the number of accidents (according to the expert H, psycho-ergonomist and specialist in mobility innovations).

These statements are given solely based on the attributes *Indicator*, *Trend*, *Intensity*, *Occurrence*, and *Expert*. But it is possible to go much further by taking into account, for example, the level of certainty (*Certainty*), the scope (*Depth*), or the textual details given by the participants (*Change*, *Subject*, *Conditions*).

## Full example

Considering the following statement:

*If the AV allows the passenger to communicate with nearby vehicles during transport, then it could be easier to report a problem (according to the expert D, sociologist and urban planner who has worked on automobile attachment).*

To add details, we can browse the *IMPACT* database by displaying more attributes. The corresponding line for this impact is shown in Table 10 (for the usage: *The passenger communicates with the passengers of nearby vehicles during transportation*).

Table 10. Extract of the *IMPACT* database.

Indicator	Trend	Intensity, Occurrence, Depth, Certainty	Expert ID	What will change?	Conditions	Subject
Ease of reporting a problem	↑	2, 3, 3, 3	D	It is possible that such an application would only be useful in case of emergency (reporting a problem in the vehicle, calling a doctor...)	Technically feasible, there will surely be a demand: talkative people who no longer have the activity of driving to occupy them during the journey, a safety reason may require that the communication system be installed anyway, the autonomous vehicle is communicative by default, might as well use it to entertain passengers.	Passengers of vehicles that can make or receive calls from crews of other vehicles

Expanding on the previous statement, we could thus obtain this level of detail:

*If the VA allows passengers to communicate with other vehicles' passengers during transport, then it could be easier to report a problem regardless of the problematic situation (according to the expert D, sociologist and urban planner who has worked on automobile attachment). He is rather confident that such an application would only be useful in case of a problem (reporting a problem in the vehicle, calling a*

*doctor...). He estimates that this impact would be moderately important and would concern several people among those who would have access to this usage.*

# Supplementary material 17: Complementary objects of AutoVision

This supplementary material presents additional objects that were not detailed in Chapter 5 to avoid overloading it (Figure 6).

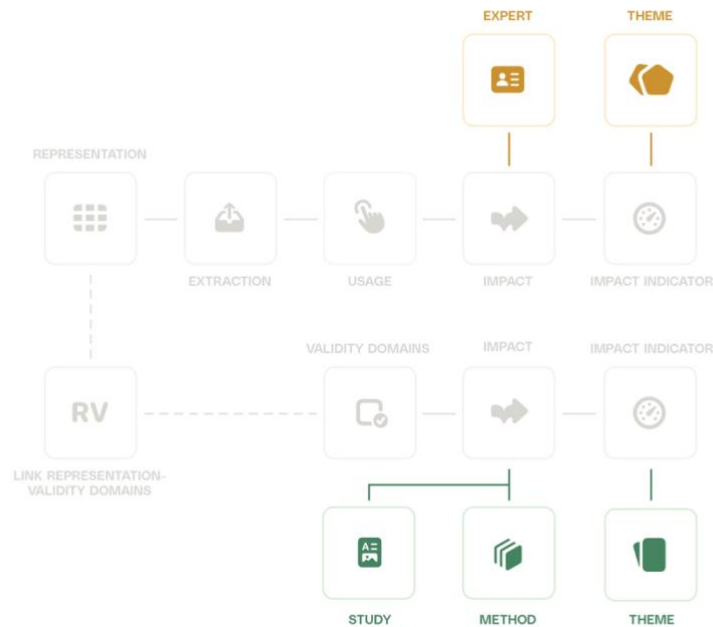


Figure 6. Complementary objects presented in this supplementary material. All other objects are presented in chapter 5.

## 1. Expert

The EXPERT database helps you keep track of all the experts who have imagined at least one impact of autonomous vehicles. Each entry in the IMPACT database is associated with an expert (Table 11).

Table 11. Attributes of an expert.

Name	Description	Modalities
<i>Name</i>	The expert's first and last name	Free text
<i>Expertise</i>	The field and level of expertise	Free text
<i>Company</i>	The employer or organization to which the expert belongs	Free text
<i>E-mail</i>	Email address to contact the expert	Email

## 2. Theme (social impacts)

The social impacts are distributed among 11 different themes, which are listed in the THEME database (Table 12). For more information on the definition of these themes, please refer to Chapter 4 or to the supplementary material 12.

Table 12. Attributes of a social impact theme.

Name	Description	Modalities
<i>Name</i>	The name of the theme	Conflict and crime; Health and welfare; Employment; Family; Human rights; Population change; Networks and communication; Education; Identity and cultural heritage; Stratification; Gender
<i>Definition</i>	The definition of this theme along with concrete examples	Free text
<i>Resource</i>	A set of resources to delve deeper into the concepts of the theme	Free text and/or web-links

### 3. Study

Each socio-economic or environmental impact is linked to a scientific study. Table 13 presents the attributes of an object in the STUDY database.

Table 13. Attributes of a study.

Name	Description	Modalities
<i>Title</i>	Title of the study	Free text (example: Individual Mobility by Shared Autonomous Electric Vehicle Fleets: Cost and CO2 comparison with internal combustion engine vehicles in Berlin, Germany)
<i>Type</i>	Type of publication	Article; Review; Report; Slides; Book chapter; Thesis; Paper (other)
<i>Year</i>	Year of publication	Year
<i>ID (DOI / ISBN)</i>	Identification of the study	Unique identifier (example: 10.1109/ICE.2017.8279909)
<i>Resources</i>	Resource document(s)	Any type of document (example: PDF file)
<i>Data - Citations</i>	Number of citations for the study	Free number
<i>Data - JIF</i>	Impact factor of the journal in which the study is published (if it is a journal article)	Free number
<i>Data - Peer-review</i>	Use of peer-review or not	Boolean

### 4. Method

Each socio-economic or environmental impact was obtained by following one or several methods. The METHOD database lists all identified methods and allows linking impacts and studies to methods (Table 14).

Table 14. Attributes of a method.

<b>Name</b>	<b>Description</b>	<b>Modalities</b>
<i>Category</i>	Category of method used	Simulation; Survey / Workshop; Optimization; Analytical
<i>Name</i>	The name of the method	Free text (example: Microsimulation)
<i>Description</i>	Description allowing to understand the characteristics, specificities and some examples of the method	Free text (example: Traffic (or flow) microsimulation models simulate the behaviour of individual vehicles within a predefined road network and are used to predict the likely impact of changes in traffic patterns resulting from [...])
<i>Deepening</i>	Links to additional resources on this type of method	Free text (example: <a href="https://doi.org/10.1109/SURV.2009.090403">https://doi.org/10.1109/SURV.2009.090403</a> )

## 5. Theme (socio-economic and environmental impacts)

The socio-economic and environmental impacts are distributed among 8 different themes, which are listed in the THEME database (Table O). For more information on the definition of these themes, please refer to Chapter 3 and to the supplementary material 5.

Table O. Attributes of a socio-economic or environmental theme.

<b>Name</b>	<b>Description</b>	<b>Modalities</b>
<i>Name</i>	The name of the theme	Energy; Parking; Distance Environment; Speed; Transport share; Time; Traffic
<i>Definition</i>	The definition of this theme along with concrete examples	Free text
<i>Resource</i>	A set of resources to delve deeper into the concepts of the theme	Free text and/or web-links

## Supplementary material 18: AutoVision User Guide

This supplementary material contains a brief user guide that explains how to use the AutoVision tool. Please note that this guide does not cover addition of new data (usages, impacts, ect), as they are reserved for administrators. This guide could be further expanded in the future, in case the tool is deployed in a company for example.





# Supplementary material 19: Arbitrary grid

This supplementary material includes an example of an arbitrary grid to calculate aggregated scores for the 19 impact themes of the AutoVision tool. It presents all the indicators of the tool. As the name suggests, this grid is subjective and can vary depending on the person defining it. The tool was built so that this grid could be easily changed by the user.

- "↑" indicates that an increase in the indicator will result in an increase in the score of the theme.
- "↓" indicates that a decrease in the indicator will result in an increase in the score of the theme.
- "-" indicates that the indicator has no effect on the theme score (for ambiguous indicators).

An indicator can belong to multiple themes.

## 1. Conflict and crime

Means of managing an unbalanced individual	↑
Reimbursements by insurance	-
Regulation of individuals	-
Various nuisances	↓
Intentional vehicle damage	↓
Blocking of the road	↓
Risk of global pandemic	↓
Number of accidents	↓
Traffic disruptions by pedestrians (demonstration, for fun, ...)	↓
Difficulty stopping criminals	↓
Solicitation of police services	↓
Insults and threats between road users	↓
Malicious acts	↓
Trafficking of prohibited items	↓
Clogging of the judicial system	↓
Number of vehicle thefts	↓
Illegal parking	↓
Terrorist risk	↓
Changes in accident responsibility	-
Substance consumption	↓
Risk of aggression	↓
Risk of kidnapping	↓
Variety of offenses	↓

## 2. Education

Quality of knowledge transmission	↑
Ability to know how to move using different means of transport	↑
Cultural enrichment	↑
Capacity / sense of direction	↑
Driving skills	↑

## 3. Employment

Working time	↓
Number of employees in cleaning centers	↑
New third places	↑
Work requirements	-
Solicitation of police services	↓
Access to employment	↑
Number of employees in the delivery sector	↑
Remuneration of transport workers	↑
Peak hour travel	-
Emergency solicitations	↓

## 4. Family

Quality of family ties	↑
Exposure of young people to inappropriate stimuli	↓
Family interactions	↑
Opportunities for family gatherings	↑
Separation between work and private life	↑
Fulfillment of family obligations	-
Difficulty in finding childcare	↓
Human accompaniment	↑

Quality of family ties	↑
Family spacing	↓

## 5. Health and welfare

Working time	↓
Fears	↓
Well-being	↑
Free time	↑
Speed of medical care	↑
Trust in autonomous driving	↑
Ability to let off steam	↑
Motion sickness	↓
Physical activity	↑
Awareness of travel	-
Separation between work and private life	↑
Flexibility in travel	↑
Health condition	↑
Quality of medical consultations	↑
Quantity of active travel	↑
Commercialization of health	↓
Pressure to increase the number of activities	↓
Stress	↓
Mental health	↑
Substance consumption	↓
Quality of quiet and secure environments (excluding VA)	↑

## 6. Human rights

Population surveillance	↓
Independence of people with disabilities	↑
Personal data leaks	↓
Conditions to meet to own a vehicle	↓
Passivity in the face of a problem	↓
Time spent in places	-
Access to mobility	↑
Changes in accident responsibility	-
Freedom of movement	↑

## 7. Identity and cultural heritage

Parking spaces for disabled persons	↑
Identity significance of the vehicle and driving (virility, self-improvement)	-
Capacity / sense of direction	↑
Access to mobility	↑

## 8. Networks and communication

Intimate activities	↑
Attendance of public space	↑
Access to high internet bandwidth	↑
Ease of reporting a problem	↑
Remote supervision of vehicles	-
Honoring an important appointment	↑
Social interactions	↑

## 9. Population change

Home-to-work distance	↑
Number of trips to the hospital	↑
People's movements	↑
Number of long trips	↑
Access to mobility	↑
Number of activities bringing together people living at a distance	↑
Family spacing	↓

## 10. Stratification

Privileges in travel	↓
Socio-economic inequalities	↓

## 11. Gender

No indicator in this theme.

## 12. Distance

Mileage per vehicle	↓
Mileage per person	↓
Total mileage	↓

## 13. Energy

Fuel consumption	↓
Energy consumption	↓

## 14. Environment

Greenhouse gas emissions	↓
CO2 emissions	↓

## 15. Parking

Parking space required ↓

## 16. Speed

Average speed ↑

## 17. Time

Travel time ↓

Slowdown at intersections ↓

## 18. Traffic

Capacity for merging lanes ↓

Capacity at intersections ↑

Road capacity ↑

Space required for vehicles ↓

## 19. Transport share

Total number of vehicles on the road ↓

Total number of vehicles ↓

Total number of taxis -

## Supplementary material 20: Example of using the tool

In this supplementary material, we provide an example of using the AutoVision tool from the perspective of a decision maker at Stellantis company. The objective is to initiate a project for a responsible autonomous vehicle that aligns with the company's strategy. The end of this walkthrough leads to a design brief to guide the company's design teams in the different phases of vehicle design.

To avoid writer's block and start generating ideas about autonomous vehicles, we have decided to utilize the Advisor mode of the tool. This mode should provide us with guidance to begin shaping our concept (Figure 7).

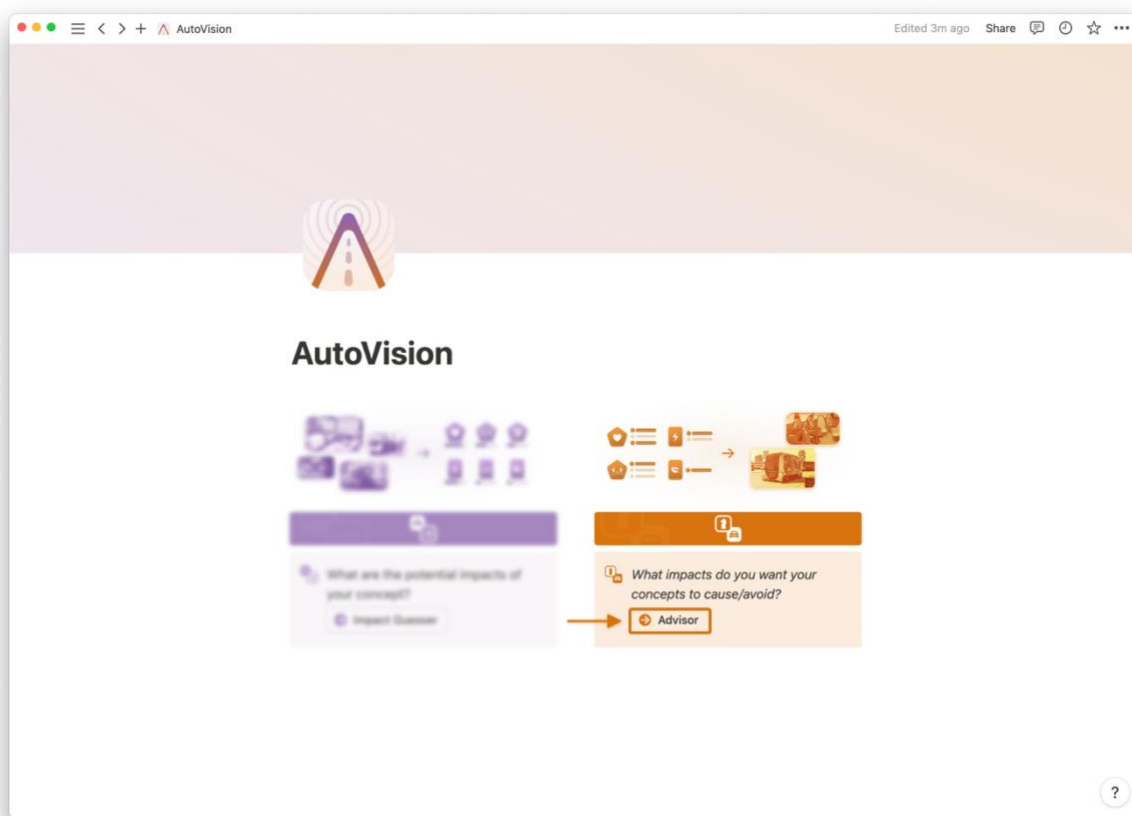


Figure 7. Entering the Advisor mode.

The first step is to define a long-term strategy regarding the desired impacts of autonomous vehicles by the company. In this example, we have chosen to draw inspiration from Stellantis' Dare Forward 2030 strategic plan (Stellantis, 2022). Therefore, we have encoded this strategy using the Advisor mode of the tool (Figure 8). The complete strategy is available in the supplementary material 22, as it was used for the experimentation in chapter 7.

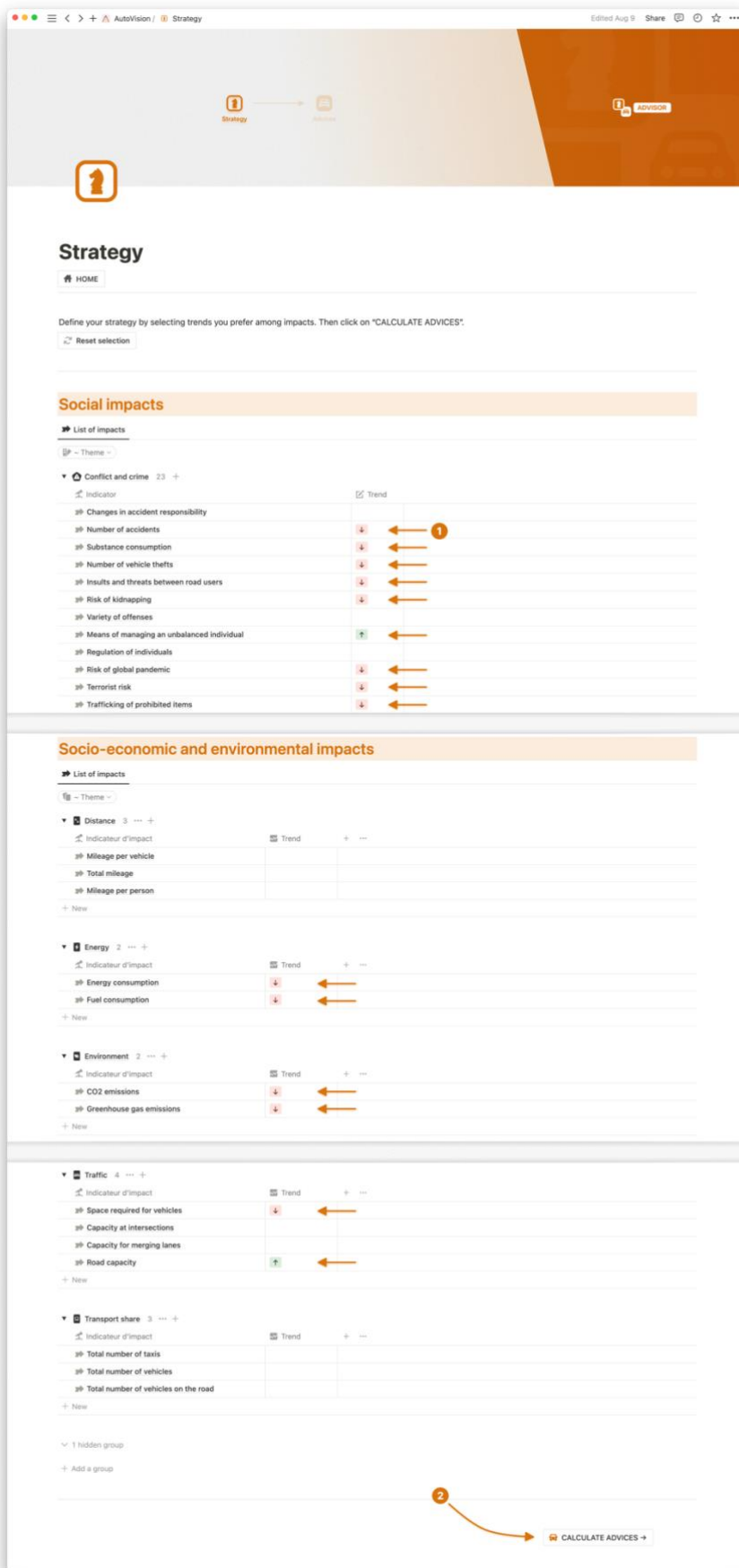


Figure 8. Coding a strategy in the Advisor.

Once the strategy is defined, we clicked on the "CALCULATE ADVICES" button in the Advisor mode (bottom right of Figure 8). This provided us with lists of usage, deployment modes, and continents. Figure 9 presents the recommended characteristics for the AV according to the tool.



Figure 9. Results from the Advisor: To promote.

Figure 10 presents the characteristics of the AV to avoid according to the tool.

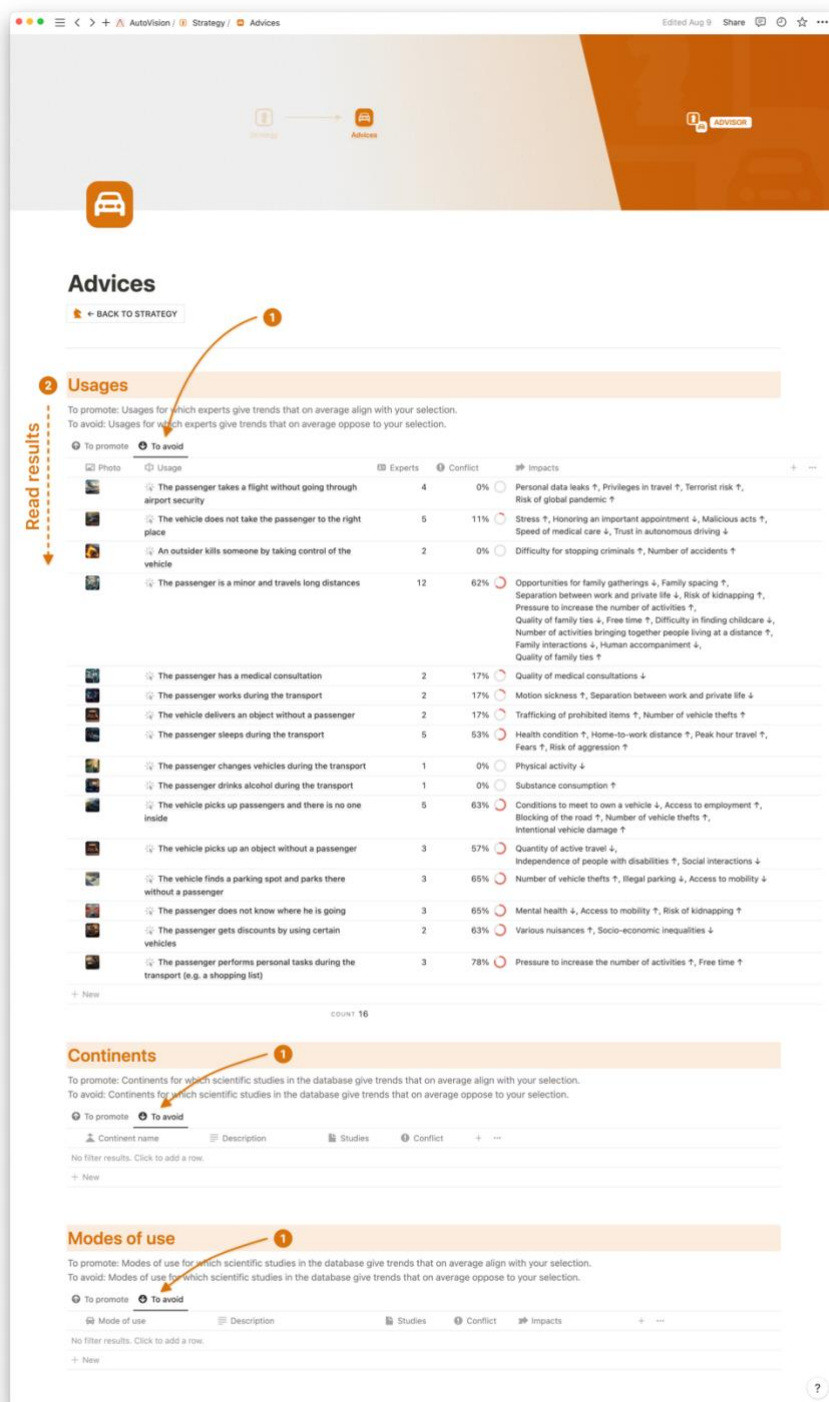


Figure 10. Results from the Advisor: To avoid.

From these results, we have defined an initial concept of an autonomous vehicle by listing its usages and modes of use. At this stage, we have not specified any particular continent.

We have evaluated each proposal from the Advisor results in the order they were presented. When necessary, we consulted expert opinions by clicking on the usages and scientific studies by clicking on the modes of use. This process allowed us to even

consider usages that are not recommended by the tool, and that have strong disagreement among experts (e.g. "The passenger gets discounts by using certain vehicles", and "The passenger performs personal tasks during the transport"). As a result, we have defined a concept called "Concept 1" which is summarized in Figure 11.

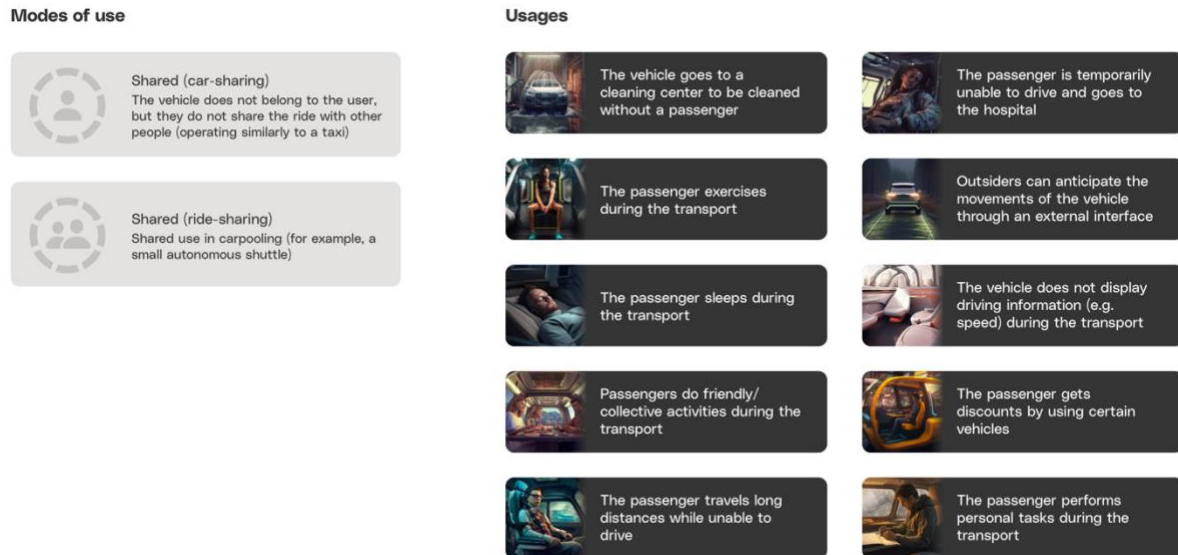


Figure 11. Definition of a first concept by selecting modes of use and proposed usages by the Advisor.

Once we had imagined this initial concept, we wanted to test it to verify that it does not generate too many undesirable impacts. To do this, we utilized the Impact Guesser mode of the tool (Figure 12).



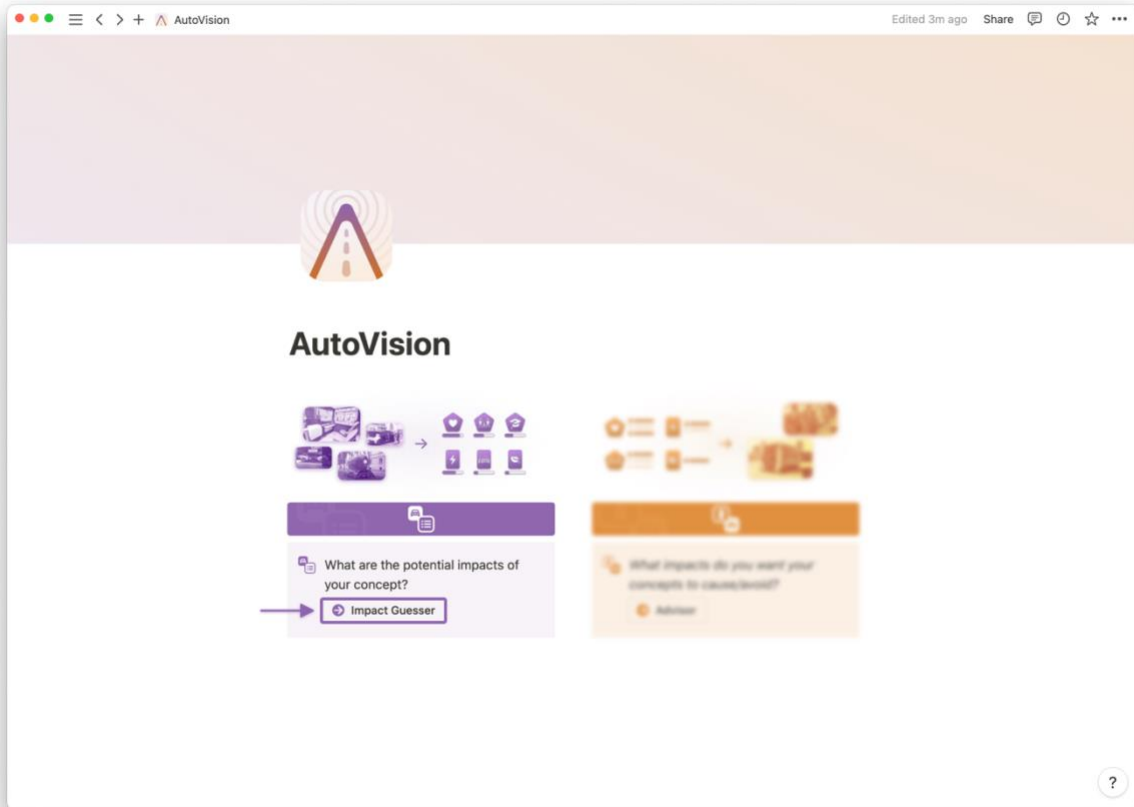


Figure 12. Entering the Impact Guesser mode.

We started by coding our concept in the scenario section of the Impact Guesser mode (Figure 13). Then, we clicked on the "GUESS IMPACT" button to obtain the list of impacts.

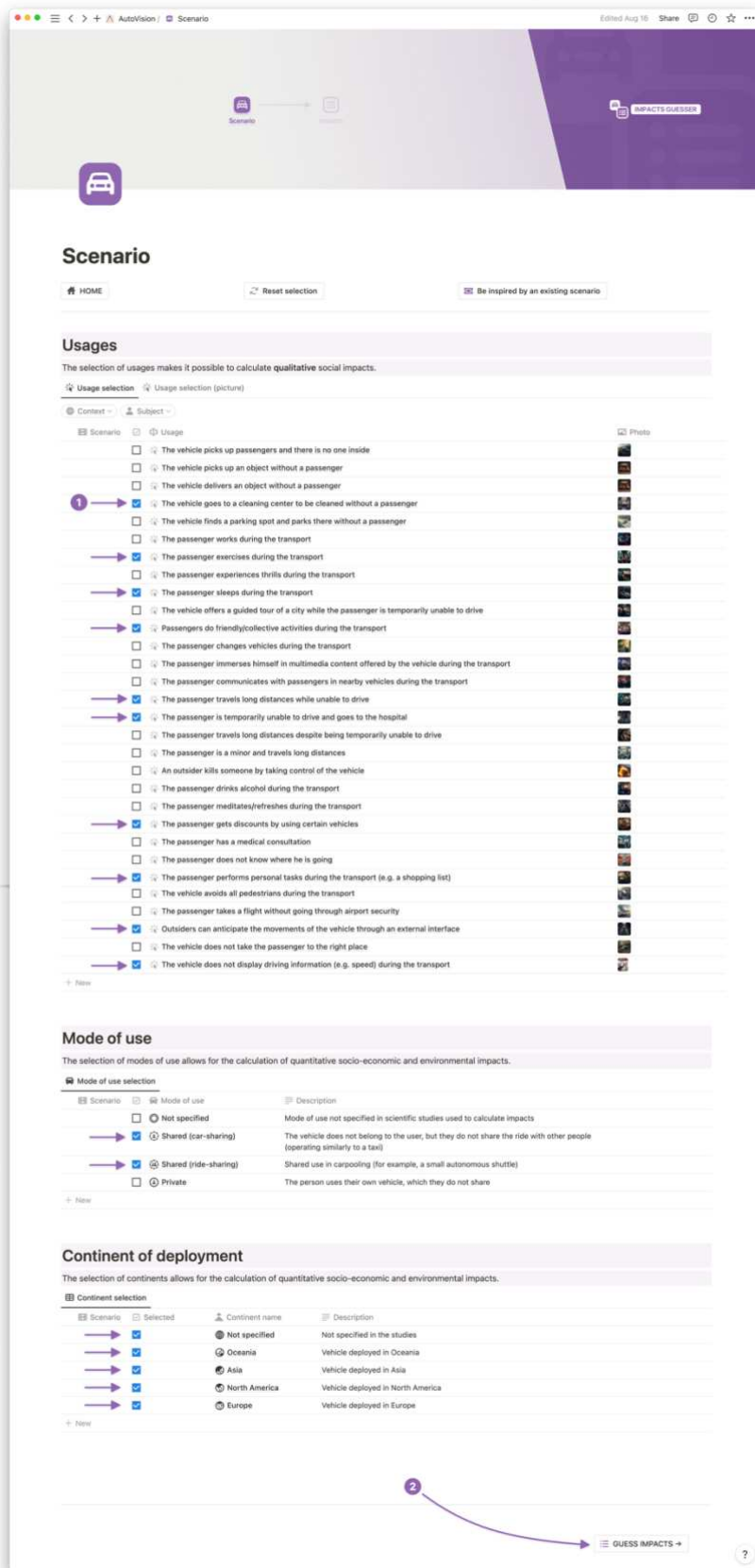


Figure 13. Coding the concept 1 into the Impact Guesser.

The Figure 14 and Figure 15 present the list of possible impacts related to our concept calculated by the Impact Guesser.

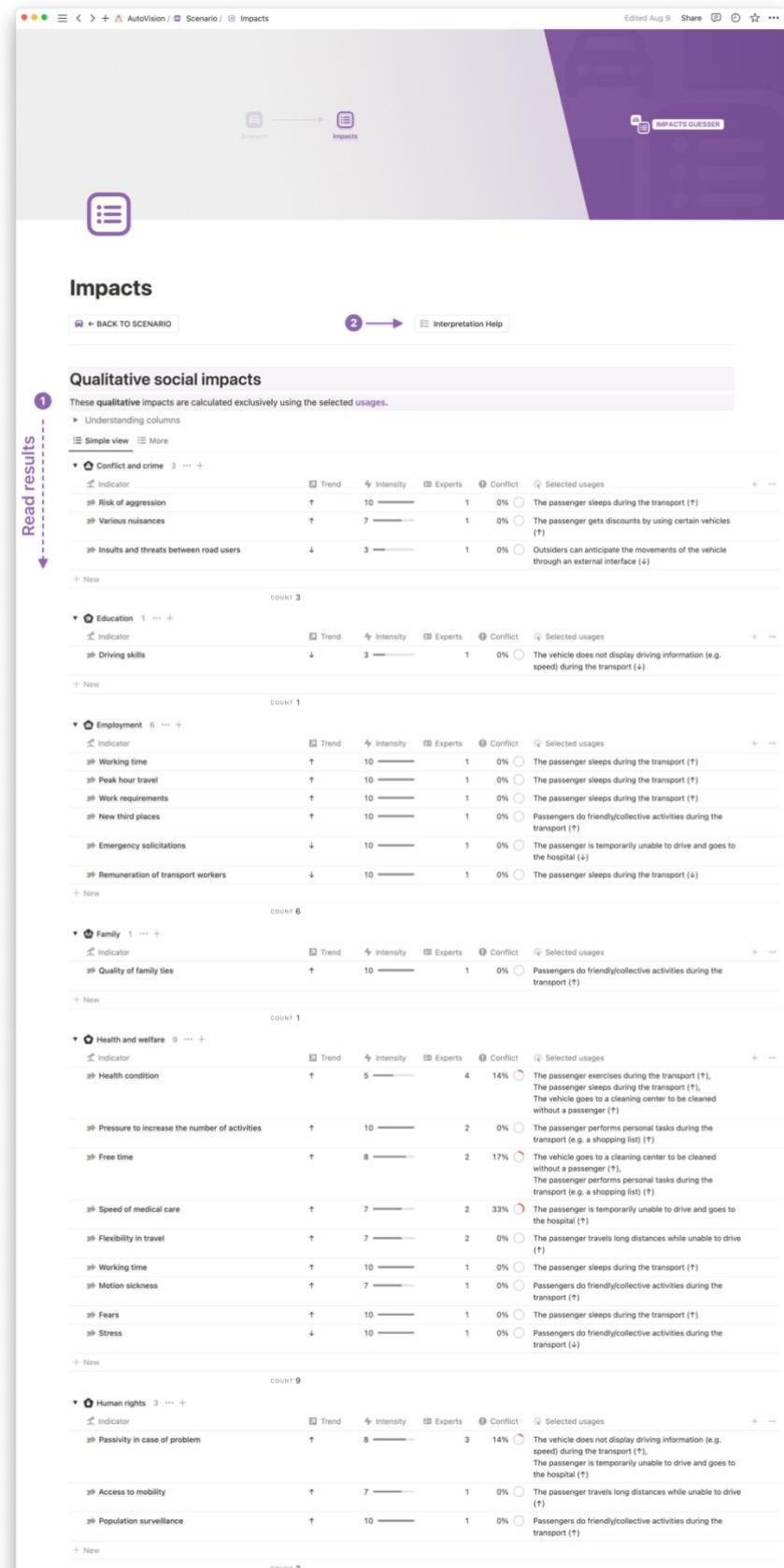


Figure 14. Results from the Impact Guesser for concept 1 (1/2).

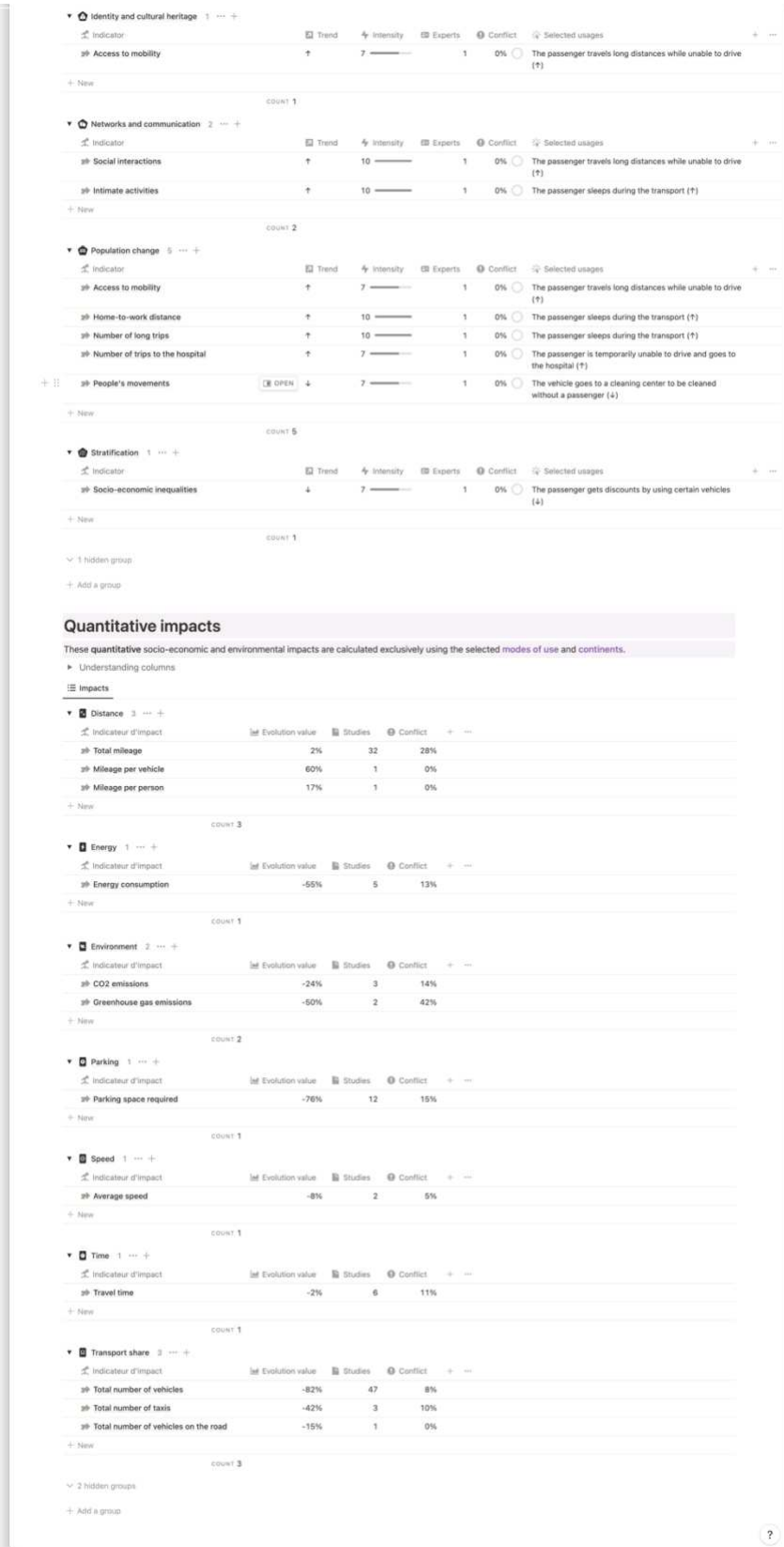


Figure 15. Results from the Impact Guesser for concept 1 (2/2).

To get an overview of these impacts, we then selected the interpretation help (button at the top right). This interpretation help allowed us to obtain a score based on 19 impact themes (Figure 16). These scores are calculated using an arbitrary grid that we have based on the initial strategy presented in Chapter 7 and in the supplementary material 24.

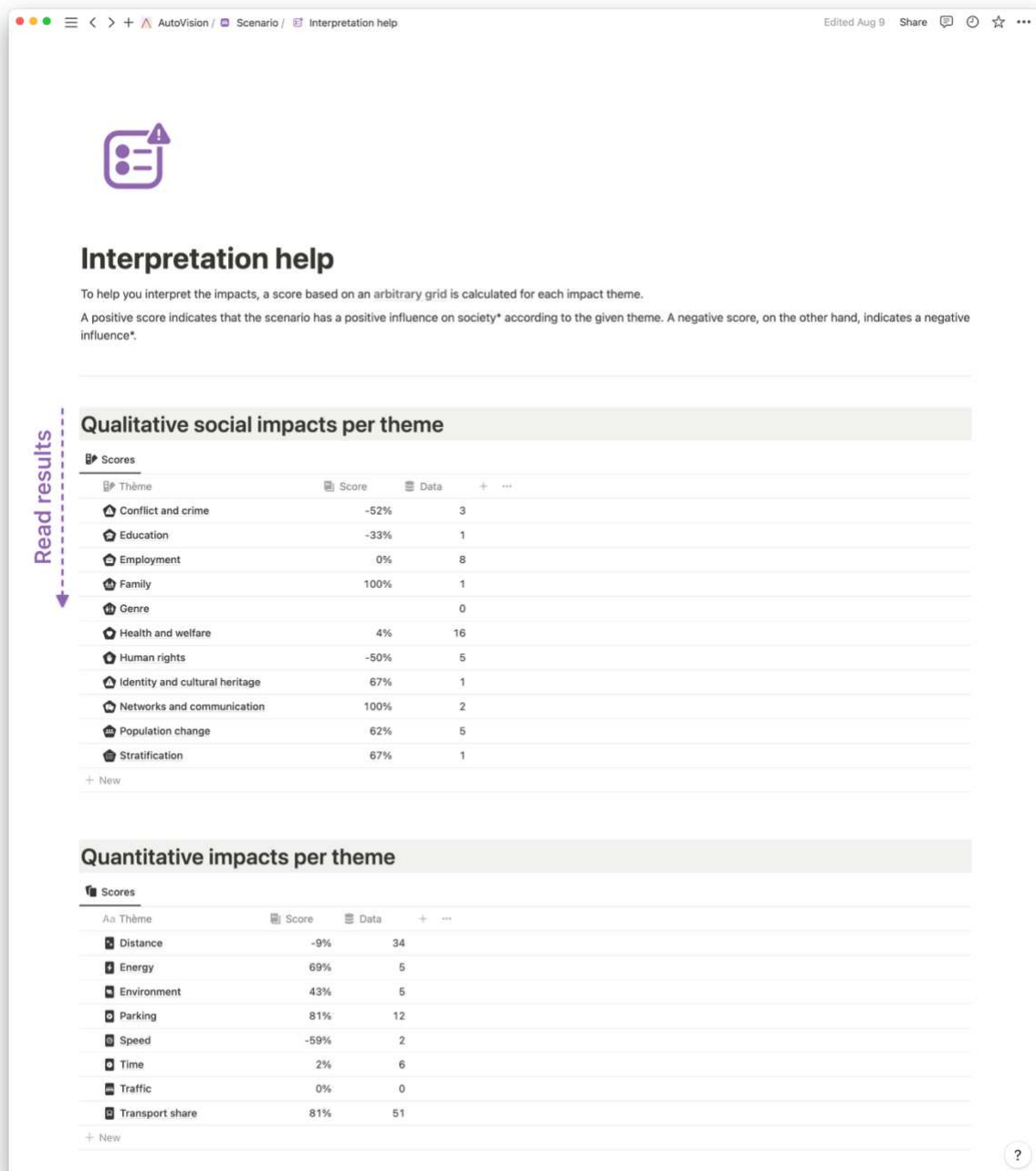


Figure 16. Using the interpretation help of the Impact Guesser to get an overview of the impacts according to different themes.

Combining the results with the interpretation help (Figure 14, Figure 15, and Figure 16), we were able to identify that certain usages were causing undesirable impacts. Figure 17 presents an example of identifying a usage that could cause undesirable impacts. In

this example, we first identified that the Education and Human Rights themes were weak using the help interpretation. We then traced back to the impacts (arrows 1 and 2) that influenced these scores. This allowed us to identify a usage that negatively influenced both themes (arrow 3).

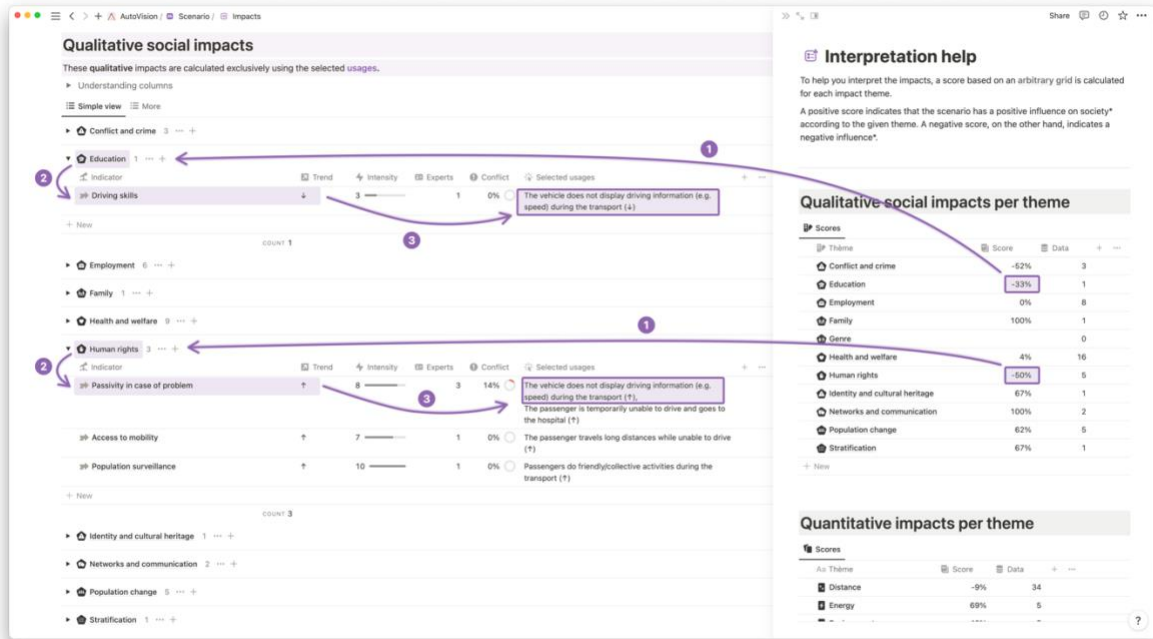


Figure 17. Identifying a usage with possibly bad impacts on Education and Human rights (Figures 129 and 130 combined)

The use of the Impact Guesser has allowed us to question certain choices. Therefore, we have chosen to remove the usage "The vehicle does not display driving information (e.g. speed) during the transport" from our concept (Figure 17). We have also decided to add a clarification accompanying the usage "The passenger gets discounts by using certain vehicles". These modifications can be seen in Figure 18.

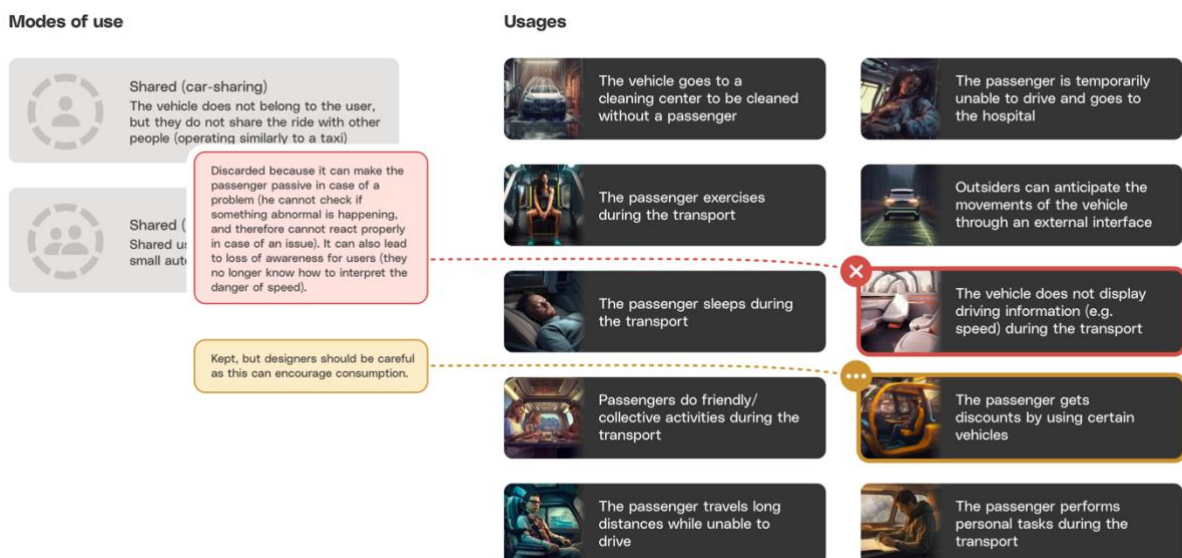


Figure 18. Update of the concept.

Using the Impact Guesser mode again with this new concept, we have achieved better scores on education and human rights.

We have seen how to use the Advisor and Impact Guesser modes together to quickly define a concept of an autonomous vehicle. The Advisor helps generate ideas rapidly, while the Impact Guesser allows for iterative refinement of the concept to mitigate potential impacts and provide better justification for choices. The next step would be to entrust the concept presented in Figure 11 to designers to take it further. It should be noted that the Impact Guesser mode could then be used in subsequent design stages to check the possible impacts of the concept throughout its evolution.

To maximize the understanding of this example, we have shown concepts defined by a set of usages and modes use. In reality, a concept can take many other forms, and the number of possibilities is only limited by the imagination of decision-makers or designers. For example, we could have added a list of impacts to avoid, like the concepts presented in chapter 7.

## Supplementary material 21: Experiment resource (experiment 1)

All resources related to the Impact Guesser experiment are available in this supplementary material. These resources are in French, which is the language in which the experiment was conducted.

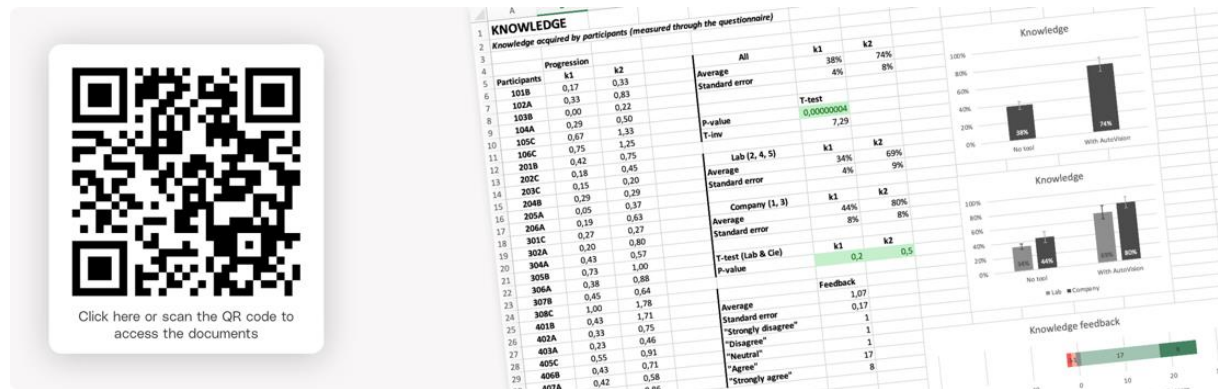
We first provide all the PDF files for printing to conduct the experiment. The final file contains cards on which participants can enter their names. The login information for the tool is given on the back of these cards. However, for confidentiality reasons, this login information has been removed from this document. The experience was conducted using slides to explain things to the participants and show them where they are in the process. These slides are available in PDF format (without animations).





# Supplementary material 22: Raw results and calculation (experiment 1)

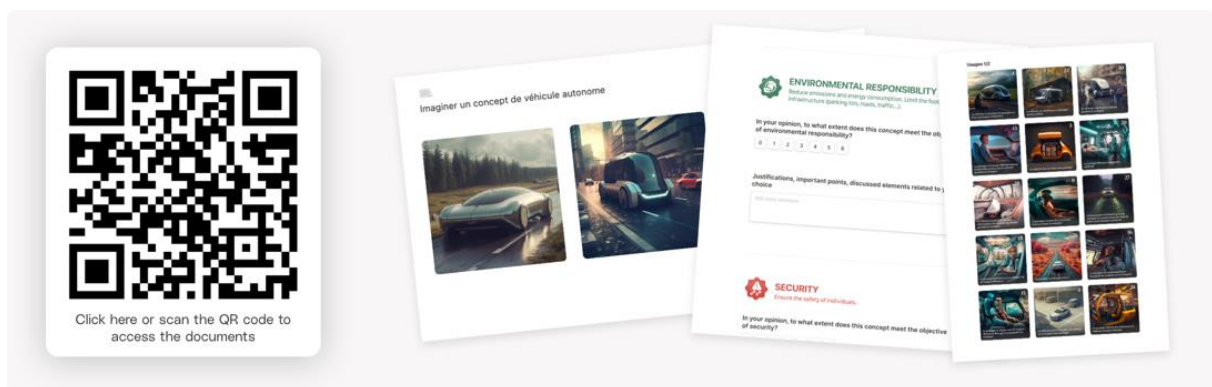
All data is compiled and calculated in the following Excel table. The first tab, labeled "DATA," includes all input data. The next four tabs concern calculations related to the KNOWLEDGE, REJECTION, JUSTIFICATION, and WARNING indicators. The next tab, labeled "Responsibility," concerns participants' opinions on whether the tool helped them generate a responsible design brief. The next tab, labeled "Brief influence," allows for the calculation of the influence of design briefs A, B, and C on the results. The last tab "Agreement" summarizes the favorable opinions of the participants on the various feedback questions. Furthermore, all the responses have been scanned and catalogued in a folder.



## Supplementary material 23: Experiment resource (experiment 2)

All resources related to the Advisor experiment are available in this supplementary material. These resources are in French, which is the language in which the experiment was conducted.

Unlike the first experiment, this one was mainly conducted using digital tools. The experience was carried out using slides to explain and guide the participants throughout its progression. These slides are available in a PDF format (in French, without animations). The questionnaire filled out by the participants to evaluate the different concepts is also available in PDF. It has been translated into English. We also provide all the support PDF files for printing (in French).



# Supplementary material 24: Strategy

In this supplementary document, we present the strategy derived from three strategic topics inspired from the Dare Forward 2030 strategic plan of Stellantis (Stellantis, 2022). These three topics are presented in Figure 19. This strategy was used to query the Advisor and generate concept X for the experiment associated (Chapter 7).



Figure 19. The three strategic topics.

The strategy is available in the following document. For each impact from the list, related to the three strategic topics: ↑ = this indicator should increase (e.g. health status), ↓ = this indicator should decrease (e.g. the CO2 emissions).



## Supplementary material 25: Concepts


We provide here the four concepts resulting from experiment 2. Concepts A, B, and C were imagined by the participants. Concept X was generated with the help of the Advisor tool, based on the strategy described in the supplementary material 24.

These concepts were created using the online whiteboard platform Mural.

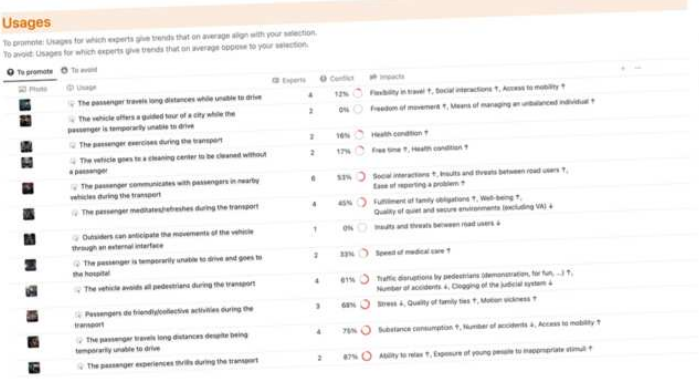


# Supplementary material 26: Output from the Advisor

The document below corresponds to the output of the Advisor from the strategy presented in the supplementary material 24.



Click here or scan the QR code to access the document



**Usages**

To promote: Usages for which experts give trends that on average align with your selection.  
To avoid: Usages for which experts give trends that on average oppose to your selection.

To promote	To avoid	Experts	Conflict	Impacts
<input type="checkbox"/> The passenger travels long distances while unable to drive	4	12%	<input type="checkbox"/> Feasibility in travel <sup>T</sup> , Social interactions <sup>T</sup> , Access to mobility <sup>T</sup>	
<input type="checkbox"/> The vehicle offers a guided tour of a city while the passenger is temporarily unable to drive	2	0%	<input type="checkbox"/> Freedom of movement <sup>T</sup> , Means of managing an unbalanced individual <sup>T</sup>	
<input type="checkbox"/> The passenger exercises during the transport	2	16%	<input type="checkbox"/> Health condition <sup>T</sup>	
<input type="checkbox"/> The vehicle goes to a cleaning center to be cleaned without a passenger	2	17%	<input type="checkbox"/> Free time <sup>T</sup> , Health condition <sup>T</sup>	
<input type="checkbox"/> The passenger communicates with passengers in nearby vehicles during the transport	6	53%	<input type="checkbox"/> Social interactions <sup>T</sup> , Injuries and threats between road users <sup>T</sup> , Ease of reporting a problem <sup>T</sup>	
<input type="checkbox"/> The passenger meditates/relaxes during the transport	4	60%	<input type="checkbox"/> Fulfillment of family obligations <sup>T</sup> , Well-being <sup>T</sup> , Quality of time and leisure amenities (excluding VA) <sup>T</sup>	
<input type="checkbox"/> Outsiders can anticipate the movements of the vehicle through an external interface	1	0%	<input type="checkbox"/> Injuries and threats between road users <sup>T</sup>	
<input type="checkbox"/> The passenger is temporarily unable to drive and goes to the hospital	2	33%	<input type="checkbox"/> Speed of medical care <sup>T</sup>	
<input type="checkbox"/> The vehicle avoids all pedestrians during the transport	4	61%	<input type="checkbox"/> Traffic disruptions by pedestrians (demonstration, for fun, ...), Number of accidents <sup>T</sup> , Clogging of the judicial system <sup>T</sup>	
<input type="checkbox"/> Passengers do friendly/collective activities during the transport	3	69%	<input type="checkbox"/> Stress <sup>T</sup> , Quality of family ties <sup>T</sup> , Motion sickness <sup>T</sup>	
<input type="checkbox"/> The passenger travels long distances despite being temporarily unable to drive	4	76%	<input type="checkbox"/> Substance consumption <sup>T</sup> , Number of accidents <sup>T</sup> , Access to mobility <sup>T</sup>	
<input type="checkbox"/> The passenger experiences thrills during the transport	2	87%	<input type="checkbox"/> Ability to relax <sup>T</sup> , Exposure of young people to inappropriate stimuli <sup>T</sup>	

# Supplementary material 27: Raw results and calculation (experiment 2)

All data is compiled and calculated in an Excel table:

- The "DATA" tab compiles all the raw data.
- The "RESULTS" tab presents the evaluation results from the participants and from the Impact Guesser.
- The "NOTATION DETAILS" tab compiles all the texts provided by the participants in their evaluations.
- The "METRICS" tab counts the number of usages, justifications, and words for the four concepts.
- The "QUALITATIVE COMPARISON" tab compares the justifications of the participants with the opinions of the experts (according to the Impact Guesser).



# Supplementary material 28: Résumé étendu en Français

## 1. Contexte, positionnement et question générale de recherche

### Contexte général

Les transports ont joué un rôle essentiel dans le développement des civilisations, des moyens de transport traditionnels comme la marche aux avancées modernes telles que les chemins de fer, l'automobile, l'aviation commerciale et les transports en commun. Le numérique a également ouvert la voie à de nouvelles façons de se déplacer, avec les services de covoiturage, de VTC et les plateformes de location de véhicules.

L'augmentation des déplacements, notamment grâce à la voiture, a eu un impact environnemental significatif, notamment sur les émissions de gaz à effet de serre. Par ailleurs, les accidents de la route restent un problème majeur malgré les efforts des constructeurs et des gouvernements pour les limiter. La fatigue, en plus de la consommation d'alcool ou de drogues, en est un facteur important. Les accidents de la route ont causé 1,2 million de décès dans le monde en 2019 (Ritchie et al., 2018), ce qui en fait la douzième cause de décès. Ces problèmes, ainsi que la pollution de l'air, les embouteillages et les inégalités croissantes liées au coût des véhicules, nuancent ses nombreux avantages.

Pour répondre à ces problématiques, les véhicules autonomes (VA) semblent être sur le point de révolutionner l'industrie des transports, offrant des avantages tels que la réduction des accidents de la route, ou bien la diminution de la consommation énergétique grâce à l'optimisation des trajets. Mais il est à ce stade difficile de conclure sur ses éventuels bénéfices. Il est donc crucial d'analyser sérieusement, et dès maintenant ses effets potentiels.

Cette thèse examine les effets à long terme des véhicules autonomes (VA) sur la société et l'environnement. Son objectif est d'informer les concepteurs et les décideurs afin qu'ils puissent prendre des décisions responsables et durables dès aujourd'hui, sur le développement des véhicules autonomes.

Le véhicule autonome est un véhicule routier qui peut transporter des passagers et fonctionner sans aucune intervention humaine (état de Californie et Techopedia, 2023). Plus largement, on parle de mobilité autonome, qui est un concept plus large qui englobant non seulement les véhicules, mais aussi l'ensemble de l'écosystème des

services de transport et des infrastructures. La Figure 20 présente les caractéristiques du cas d'étude que nous avons retenu pour la thèse.

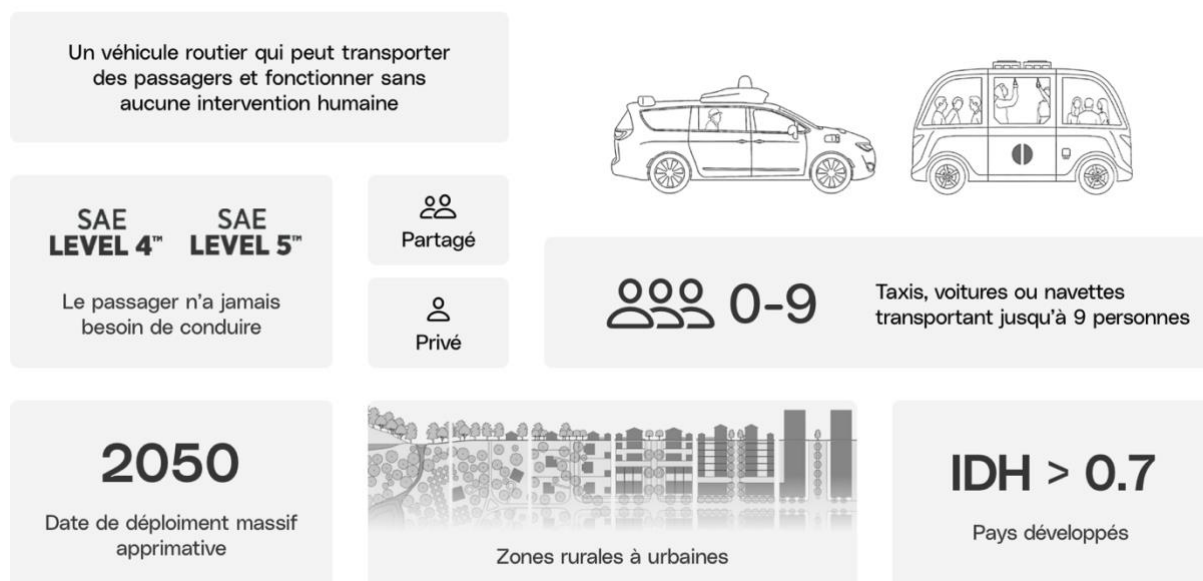


Figure 20. Cas d'étude de la thèse (niveaux d'automatisation d'après le SAE International, 2021).

### Contexte industriel à Stellantis

Cette thèse CIFRE a été réalisée au sein du groupe automobile Stellantis. Plus spécifiquement au sein de l'entité UXLAB, dédiée à l'innovation centrée utilisateur. Ce département intervient dès les premières phases de conception, couvrant l'idée initiale jusqu'à la formalisation d'un premier concept. Ses membres travaillent notamment sur les cockpits de véhicules, réunissant des professionnels de différents domaines comme les ingénieurs, les concepteurs et les ergonomes.

Avec 12 interviews et plus de 50 documents internes étudiés, nous avons analysé comment l'entreprise traitait le sujet du véhicule autonome. Pour cela, nous nous sommes intéressés à quatre scopes : (1) Stratégique, (2) Organisationnel, (3) Opérationnel, et (4) Cognitif et culturel.

Au sein du groupe, nous avons pu mettre en évidence trois phases d'ambition depuis 2010, correspondant au positionnement général de nombreux groupes automobiles travaillant sur le sujet. Ces niveaux d'ambition ont été représentés sur un « cycle de la hype » du cabinet Gartner, visible en Figure 21.



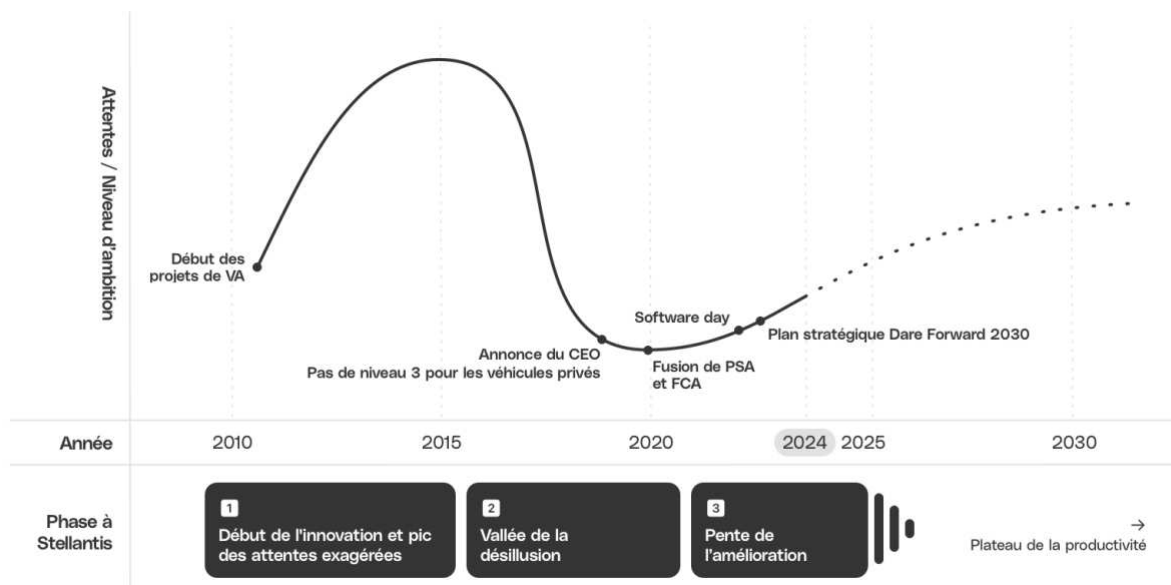


Figure 21. Ambitions de Stellantis depuis 2010.

### Phase 1. Début de l'innovation et pic des attentes exagérées

Pour rester compétitive à long terme, une entreprise doit identifier rapidement les technologies émergentes et les maîtriser (Boly et al., 2016). C'est ce que Stellantis a fait dès 2010 en s'intéressant aux véhicules autonomes et en lançant des projets et des expérimentations.

### Phase 2. Vallée de la désillusion

Dès 2015, la deuxième phase a été marquée par une diminution de l'ambition et l'abandon de nombreux projets en raison de difficultés techniques et financières. Malgré cela, des expériences et opérations de communication ont été menées, notamment avec la présentation du concept car Peugeot e-LEGEND en 2018. En 2019, PSA a suspendu ses projets de véhicules à haut niveau d'automatisation en raison de la fusion avec FCA et de la priorité accordée à la rentabilité à court terme. La pandémie de Covid-19 a également joué un rôle dans cette décision. Seuls les projets de niveau 2 ont été poursuivis, tandis que les projets de véhicules autonomes de niveau 3 ont été abandonnés en 2020.

### Phase 3. Pente de l'amélioration

Dès 2021, Stellantis a développé une nouvelle stratégie axée sur les véhicules autonomes, avec des partenariats avec BMW et Waymo. La société a identifié trois grandes tendances dans la mobilité : l'électrification, les véhicules connectés et autonomes, et la mobilité en tant que service. L'entreprise a aussi établi des partenariats clés pour le développement de logiciels sécurisés et l'automatisation des véhicules. Le plan stratégique "Dare Forward 2030" présenté en 2022 met l'accent sur les niveaux d'automatisation 3 avec BMW et les niveaux 4 et 5 avec Waymo, mais se concentre exclusivement sur la livraison en tant que service pour ces derniers niveaux.

Nous avons mis en évidence des difficultés chez Stellantis dans le développement des véhicules autonomes jusqu'à 2022, à cause d'une diffusion inégale des connaissances entre les différentes équipes du groupe et à l'absence d'une stratégie claire pour l'avenir de la mobilité. Cela a entraîné l'abandon de plusieurs projets en raison d'une conception en boucle ouverte. Cela a également provoqué de la confusion en interne et une communication incohérente envers le public au sujet des VAs.

Même si les objectifs de Stellantis pour 2022 ne correspondent plus complètement à notre cas d'étude, le travail reste pertinent en raison de l'évolution potentielle des technologies d'automatisation. Cette thèse vise donc à contribuer à la diffusion des connaissances au sein du groupe. Cela pourrait aider à mettre en évidence les défauts et les qualités de la technologie des VAs, permettant aux concepteurs de prendre du recul et de considérer des changements plus larges (par exemple, repenser le concept de mobilité). Par conséquent, il doit être suffisamment flexible pour être applicable dans différents processus de conception et avec différents types d'employés de l'entreprise.

## **Contexte de recherche**

D'un point de vue scientifique, nous avons constaté que le domaine des *futures studies* (Bishop & Hines, 2012) permettait d'étudier différents futurs alternatifs. Nous avons aussi étudié la science de la conception (ABET, 2000; Pahl et al., 2007) car elle offre des méthodologies et des techniques largement utilisées pour concevoir des produits et des services. Cependant, nous avons émis des doutes quant à l'efficacité de ces méthodes pour la conception de produits qui seront déployés à très long terme. Nous avons également vu que le design industriel (Icsid, 2015) pouvait apporter de l'empathie (la capacité de voir le monde à travers les yeux des autres) dans le processus de conception de produits, non seulement pour s'adapter aux besoins des utilisateurs, mais aussi pour proposer et créer un avenir attractif et responsable pour la société.

Les *futures studies* peuvent aider à répondre à la question : « Quel pourrait être le futur ? », la science de la conception à la question « Comment construire le futur ? », et le design industriel (ou le design responsable), à la question : « Comment devrait être le futur ? ». La combinaison des trois disciplines semble prometteuse pour étudier le déploiement d'une technologie potentiellement disruptive et clarifier la responsabilité des concepteurs quant à son impact sur le futur.

## **Question générale**

En résumé, le concept des véhicules autonomes a progressé rapidement sur le plan technique et législatif depuis les années 1980, mais les conséquences sur la société n'ont pas été suffisamment étudiées. Les groupes automobiles, comme Stellantis, ont

majoritairement axé leurs efforts sur les aspects techniques plutôt que sur les usages potentiels, ce qui a entre autres entraîné des retards et des changements de stratégie. Les *futures studies*, l'ingénierie de conception et le design industriel sont des approches prometteuses pour essayer de comprendre et à façonner l'avenir de cette technologie. D'où la question générale suivante :

**Question générale :** Comment une entreprise peut-elle anticiper les impacts d'un concept, tel que le véhicule autonome, qui n'existe pas encore mais qui causera sans aucun doute des perturbations importantes ?

## 2. Revue de littérature, questions de recherche et méthodologie générale

### Résumé des revues de littérature et questions de recherche

Pour adopter une approche responsable dans le développement d'un produit déployé sur plusieurs décennies, il est important de considérer ses impacts dès que possible pour éviter de potentielles conséquences irréversibles. Le terme "impact" est utilisé pour capturer les changements ou conséquences notables liés à l'arrivée des véhicules autonomes.

Dans notre revue de littérature sur les impacts des véhicules autonomes, nous avons identifié deux catégories d'impacts : les impacts étudiés, pour lesquels il existe déjà des connaissances quantifiées, et les impacts non étudiés, pour lesquels les connaissances sont pratiquement inexistantes. Les impacts étudiés concernent des échelles spatiales larges, tels que l'évolution des besoins en stationnement urbain ou de la consommation d'énergie, et sont classés comme socio-économiques et environnementaux. Les impacts non étudiés concernent des échelles plus petites, comme les liens familiaux ou la santé des individus utilisant des véhicules autonomes, et sont classés comme impacts sociaux. Il est important de noter que ces deux catégories ne sont pas complètement séparées et que notre distinction reflète principalement la dichotomie existante dans les connaissances actuelles. Ces deux catégories couvrent des échelles de temps allant de quelques années à plusieurs décennies (voir Figure 22).

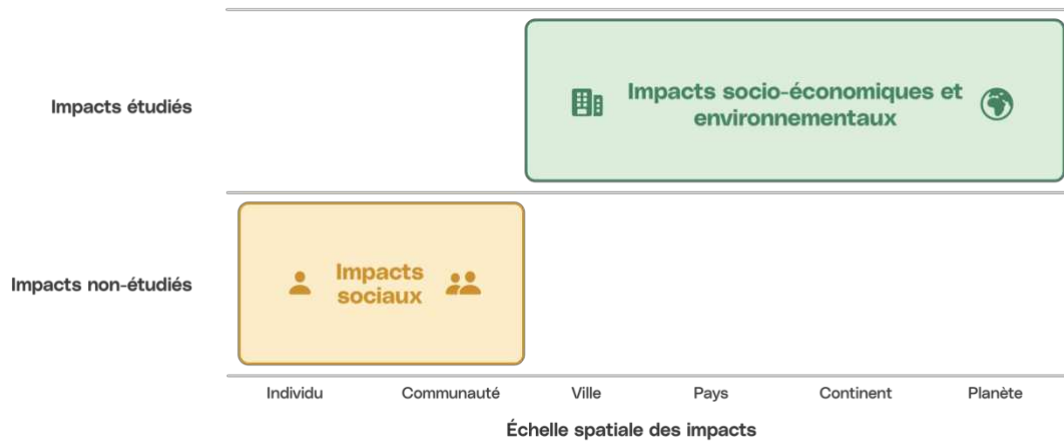


Figure 22. Les deux types d'impacts considérés.

Il existe de nombreuses études sur les impacts socio-économiques et environnementaux des véhicules autonomes, mais il peut être difficile pour les décideurs ou les concepteurs d'accéder à l'information (en vert, Figure 22). Il est crucial pour eux de se familiariser avec les résultats scientifiques, lorsque disponibles, sur les conséquences possibles des véhicules autonomes. Comme l'explique Berman (2009), les concepteurs "ont le devoir professionnel de s'assurer que leurs inventions ne sont pas seulement intelligentes, mais qu'elles sont sages ; qu'ils ne créent pas seulement des choses attrayantes, mais qu'ils sont en accord avec un avenir durable." Ces observations nous ont amenés à formuler la question de recherche n°1.

**Question de recherche n°1 :** Comment permettre aux non-experts d'obtenir des informations de qualité sur les impacts socio-économiques et environnementaux des véhicules autonomes ?

La littérature scientifique ne traite pas des impacts sociaux des véhicules autonomes car les méthodes utilisées pour évaluer ces impacts ne sont pas adaptées aux produits ou technologies qui seront massivement déployés à très long terme (en jaune, Figure 22). Cependant, cela n'absout pas la responsabilité des concepteurs. Cette observation nous a conduit à formuler la question de recherche n°2.

**Question de recherche n°2 :** Comment permettre aux concepteurs d'anticiper les possibles impacts sociaux à long terme des véhicules autonomes ?

Stellantis ainsi que d'autres constructeurs manquent de méthodes intégrées dans leur processus de conception pour anticiper les impacts à long terme de leurs produits. Cette observation nous a conduit à formuler la question de recherche n°3, qui se

concentre sur le processus de conception et se distingue des questions n°1 et n°2, qui sont plus générales.

**Question de recherche n°3 :** Comment exploiter les connaissances sur les impacts des véhicules autonomes dans le cadre d'un processus de conception industriel, afin que les entreprises automobiles puissent prendre des décisions éclairées et éviter des conséquences négatives ?

## Méthodologie générale

Pour formuler les trois questions de recherche et être en mesure d'y répondre, nous avons suivi la méthodologie générale de recherche illustrée dans la Figure 23. Cette méthodologie adopte les principes du cadre méthodologique de la recherche en conception de Blessing et Chakrabarti (2009).

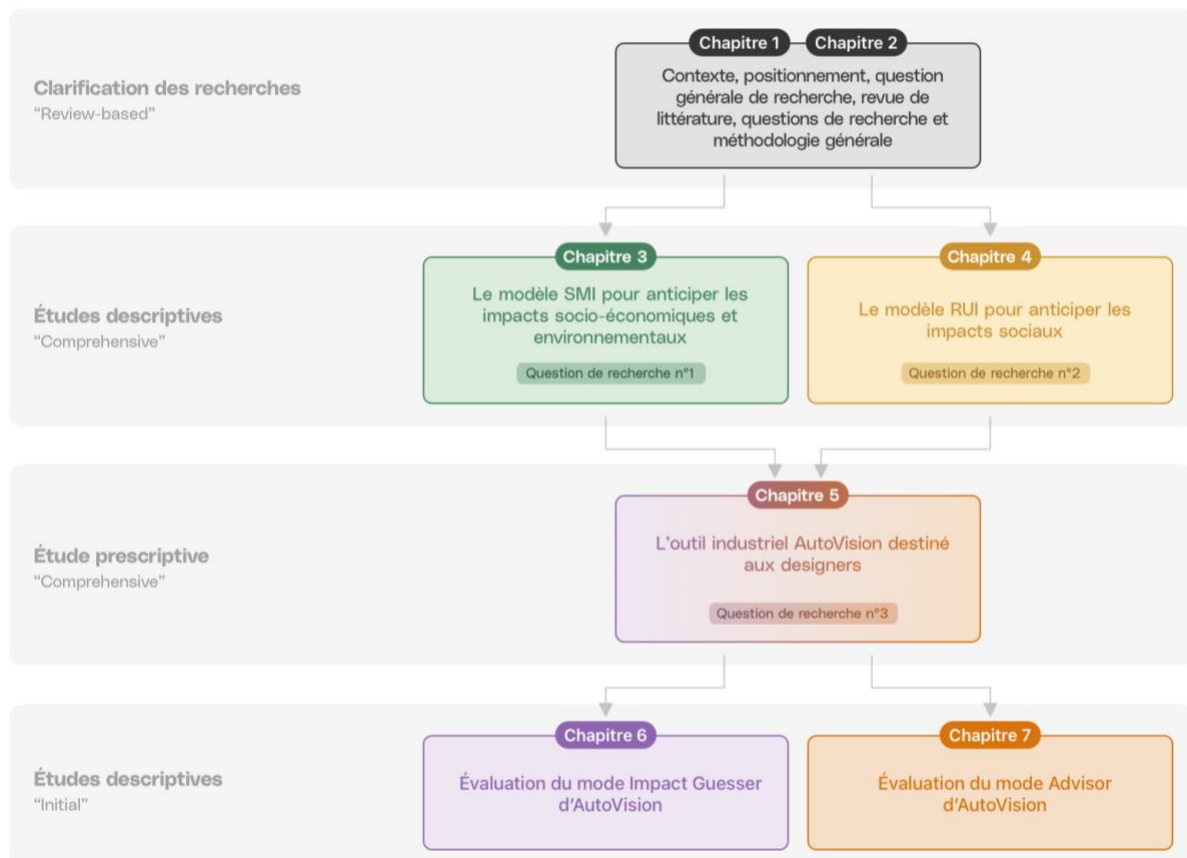


Figure 23. Processus méthodologique de la thèse et les différents chapitres (d'après Blessing et Chakrabarti's DRM, 2009).

### 3. Le modèle SMI pour anticiper les impacts socio-économiques et environnementaux

#### Contexte

Ce chapitre présente le modèle SMI (Study-Method-Impact) destiné à aider des non-experts à comprendre l'état actuel des connaissances sur les impacts socio-économiques et environnementaux des véhicules autonomes. Le modèle fournit une analyse automatisée et structurée des connaissances contenues dans la littérature scientifique en réponse à des requêtes spécifiques. Il permet de centraliser et de structurer les informations dispersées dans la littérature, tout en présentant les résultats de manière compréhensible pour les non-experts. L'objectif de la recherche est de déterminer la faisabilité de créer un modèle pour les non-experts tout en garantissant des informations précises comparables aux résultats des revues de littérature scientifique.

Pour construire SMI, nous avons d'abord effectué une recherche systématique de revues de synthèse relatives aux véhicules autonomes pour nous aider à construire la structure du modèle. Ensuite, nous avons établi quatre bases de données interconnectées qui composent le modèle. Dans la partie suivante, nous décrivons le protocole d'ajout des données et expliquons le fonctionnement du modèle. Ensuite, nous expliquons notre protocole d'évaluation du modèle en le comparant à des études récentes.

#### Fonctionnement du modèle

Le modèle SMI est composé de plusieurs bases de données liées entre elles (Figure 24). La base de données STUDY comprend l'ensemble des études scientifiques utilisées, la base de données IMPACT comprend l'ensemble des impacts extraits des études scientifiques. La base de données METHOD permet de renseigner la méthode utilisée pour déterminer chaque impact. La base de données INDICATOR permet de répertorier l'ensemble des indicateurs d'impacts du modèle.

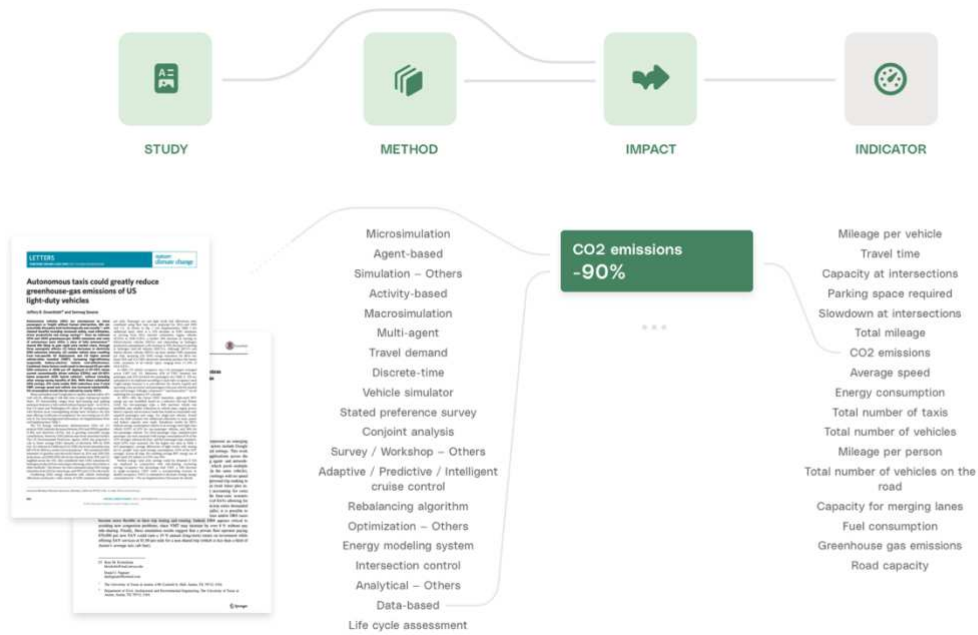


Figure 24. Bases de données constituant le modèle SMI.

Ce réseau de bases de données permet d'effectuer des requêtes auprès du modèle, comme montré dans la Figure 25. L'utilisateur peut sélectionner un indicateur, affiner sa recherche en ajoutant une condition (par exemple, un mode d'utilisation partagé du véhicule), et sélectionner un mode de représentation. Le modèle peut ensuite calculer un résultat sur la base des données correspondant à la requête. En calculant par exemple l'évolution moyenne de l'indicateur choisi d'après les études à disposition.

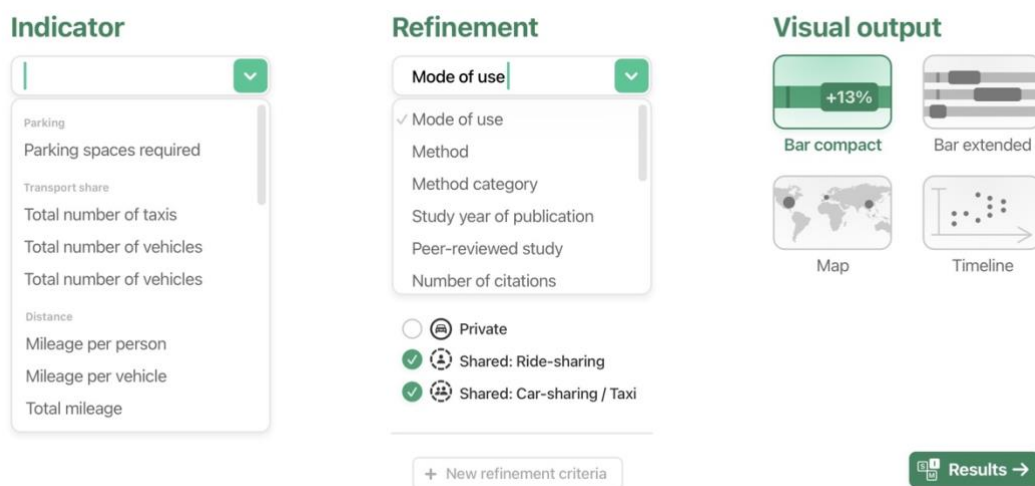


Figure 25. Exemple d'interface permettant d'effectuer une requête auprès du modèle SMI.

Nous avons aussi présenté un protocole de mise à jour de ce modèle, pour ajouter de nouvelles études, et donc de nouvelles données (pas détaillé dans ce résumé).

## Validation

Pour vérifier si le modèle présentait des résultats plausibles, nous les avons comparé à ceux de deux revues de synthèse scientifiques (Othman, 2022 et Silva et al., 2022). Parmi 19 comparaisons, nous avons trouvé une correspondance de 90%, ce qui est prometteur vis-à-vis de l'efficacité du modèle.

Le modèle SMI offre des avantages tels que des possibilités de requête avancées, une accessibilité accrue et la possibilité d'une mise à jour régulière par des non-experts. Il permet également une meilleure compréhension des méthodes utilisées et identifie les zones grises dans la recherche sur les impacts sociétaux des VAs.

## 4. Le modèle RUI pour anticiper les impacts sociaux

### Contexte

Les techniques d'évaluation produit actuelles sont insuffisantes pour prédire les effets sociaux à long terme d'un produit qui n'a pas encore été déployé comme le VA. L'évaluation de produit est utilisée pour prévoir ses performances, en particulier son impact sur les utilisateurs. Elle est couramment utilisée pour les produits déployés dans un avenir proche. D'autre part, l'évaluation d'impact (*impact assessment*) évalue l'effet d'une loi, d'une mesure environnementale ou d'une nouvelle technologie sur la société à plus grande échelle. Cependant, les méthodes utilisées pour l'évaluation d'impact ne sont souvent pas adaptées aux produits individuels et se limitent aux populations connues, ce qui restreint leur utilité à des périodes relativement courtes. Les *futures studies* et la prospective stratégique fournissent des techniques et des méthodes pour explorer les futurs possibles, plausibles et probables à long terme. Bien que ces méthodes ne soient pas spécifiquement conçues pour analyser l'impact social d'un produit particulier, elles sont une autre piste complémentaire. Dans ce chapitre, nous avons cherché à explorer la possibilité d'anticiper les impacts sociaux d'un produit disruptif qui n'existe pas encore sur le marché grâce à une approche originale. Nous utilisons les principes des *futures studies* pour créer des scénarios d'usages crédibles. Ces scénarios sont ensuite utilisés comme contexte pour interroger des experts tels que des sociologues. En d'autres termes, notre principale hypothèse est que ces experts peuvent anticiper les futurs impacts sociaux à la condition qu'ils puissent se projeter dans le futur.

Il convient de noter que les impacts socio-économiques et environnementaux, évalués dans le chapitre 3, font l'objet de nombreuses études, notamment par la modélisation numérique. Ces impacts diffèrent grandement des impacts sociaux que nous explorerons dans ce chapitre, car il y a un manque de recherche sur les impacts sociaux des VA. C'est cette lacune que nous cherchons à combler ici, en tentant de fournir un



modèle d'impact appelé Représentation-Usage-Impact (RUI) qui compile et agrège les connaissances d'experts pour anticiper les impacts sociaux des véhicules autonomes.

## Fonctionnement du modèle

Lors de la construction du modèle, notre principale hypothèse était que les sociologues, habitués à travailler avec des phénomènes passés ou présents, peuvent utiliser leurs connaissances pour imaginer les impacts sociaux à long terme. Le modèle doit permettre aux experts (sociologues, urbanistes, juristes, etc) de se projeter dans des situations futures, de collecter et organiser leurs connaissances, et de faciliter l'accès à ces connaissances via des requêtes spécifiques. Les principaux objets du modèle sont les représentations, les usages et les impacts. Les représentations incluent toutes les ressources qui représentent un véhicule autonome, les usages sont les actions de base rendues possibles par le véhicule autonome, et les impacts sont les conséquences possibles des usages d'après les experts.

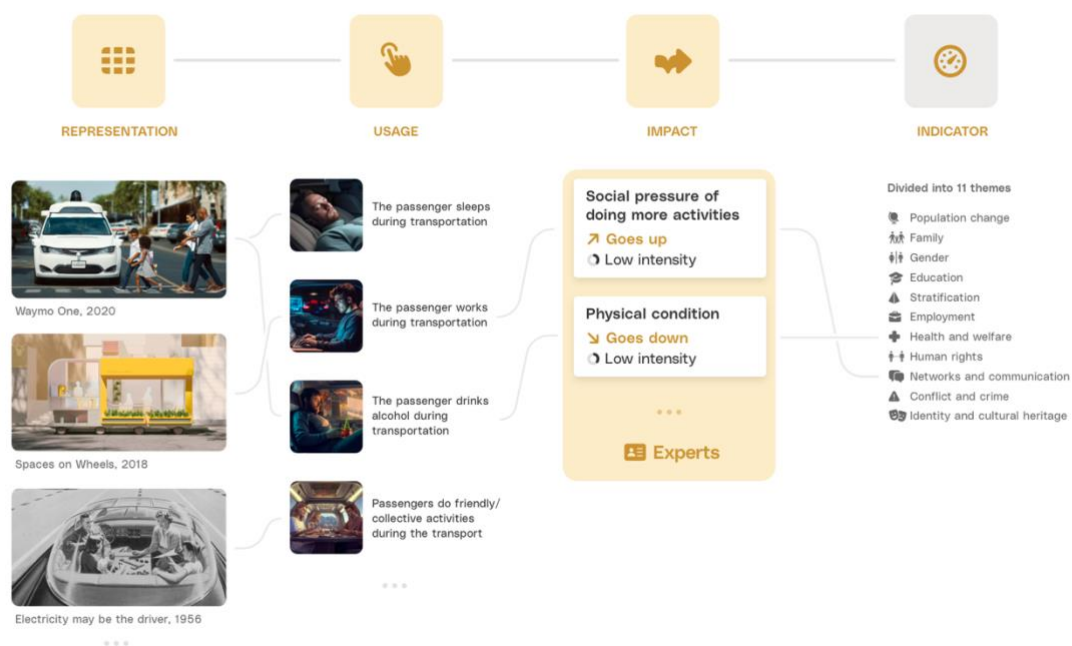


Figure 26. Bases de données constituant le modèle RUI.

Le modèle se compose d'un ensemble de plusieurs bases de données interconnectées (voir Figure 26). La première, REPRESENTATION, est utilisée pour stocker et organiser différentes représentations du véhicule autonome. La base de données USAGE répertorie et caractérise tous les usages extraits des représentations. La base de données IMPACT contient toutes les informations fournies par les experts pour caractériser un impact. Elle est connectée à la base de données INDICATOR, qui stocke et définit tous les indicateurs d'impacts sociaux répartis en 11 thèmes (Rainock et al., 2018).

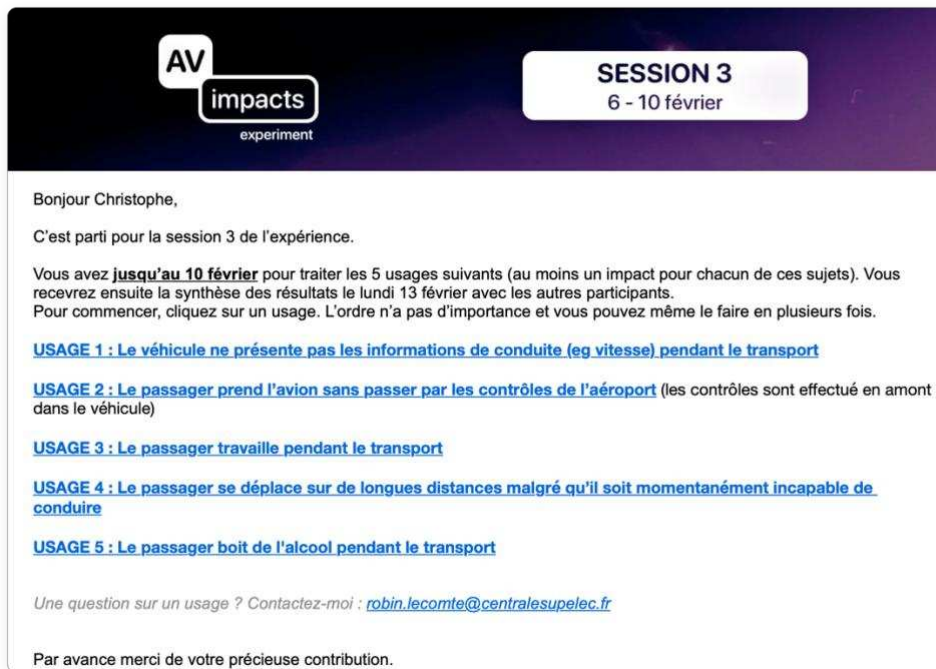


Figure 27. Exemple d'e-mail envoyé aux experts.

Pour ajouter des données, un questionnaire semi-automatisé et rapide à renseigner a été créé. Ce questionnaire, à destination des experts (sociologues, urbanistes, juristes, etc) permet de récolter des impacts rapidement. Un exemple d'e-mail envoyé aux experts est proposé dans la Figure 27. Chaque lien dans cet e-mail est ensuite lié à un questionnaire simple dans lequel l'expert peut renseigner un impact correspondant selon-lui à l'usage sélectionné.

## Premiers résultats

Nous avons sollicité des experts pendant trois semaines, et avons réussi à collecter un total de 139 impacts. Au total, 16 experts ont participé. Sur les 30 usages présentés aux experts, 24 ont été traités par au moins trois experts différents (80%). Parmi les six usages restants, cinq ont été traités par deux experts et un par un seul expert.

Le modèle RUI, inspiré des méthodes d'évaluation produit et des *futures studies*, prend en compte les impacts sociaux à grande échelle et à long terme. Il explore de multiples usages du véhicule autonome et s'appuie sur des experts pour générer des impacts cohérents. Le modèle est prometteur dans l'anticipation des impacts par rapport aux méthodes existantes. Pour la suite, son intégration au sein d'un outil destiné aux concepteurs pourrait faciliter l'accès aux connaissances et s'adapter aux besoins des utilisateurs (Chapitre 5).

## 5. L’outil industriel AutoVision destiné aux designers

### Contexte

L'évaluation technologique (*technology assessment*) utilise différentes approches pour anticiper et comprendre les impacts potentiels des nouvelles technologies. Bien que ces approches ne prédisent pas nécessairement de manière précise les impacts à long terme, elles fournissent des connaissances précieuses et permettent une prise de conscience des impacts potentiels. Le désavantage de ces méthodes est qu'elles sont souvent difficiles à mettre en œuvre et ne conviennent pas bien à un contexte d'innovation industriel. De l'autre côté, les méthodes agiles accordent la priorité à la flexibilité et aux itérations fréquentes dans le développement de produits, mais peuvent ne pas être adaptées aux échelles de temps plus longues.

Nous avons développé un outil appelé AutoVision qui est conçu pour les concepteurs et les décideurs. L'objectif de l'outil est d'éviter le développement de véhicules autonomes susceptibles de causer des problèmes sociaux, environnementaux ou socio-économiques irréversibles. Il n'est donc pas destiné à prédire l'avenir avec précision, est s'apparente plutôt à un "garde-fou". Nous l'avons positionné pour pouvoir répondre à deux questions : (1) Quelles idées de VA devraient être sélectionnées pour éviter/favoriser certains impacts ? et (2) Quels impacts une idée de VA est-elle susceptible de générer ? Ainsi, l'outil propose deux modes d'utilisation distincts : le mode Advisor, qui aide à construire un scénario (ou un concept) de véhicule autonome en fonction des impacts que l'on souhaite éviter ou favoriser, et le mode Impact Guesser, qui, à l'inverse, fournit une liste des impacts possibles à partir d'un scénario de véhicule autonome. Un scénario se compose de différents éléments tels qu'une liste d'usages, des modes d'utilisation (privé, partagé) ou une zone de déploiement géographique. Cet outil est basé sur les deux modèles développés dans les chapitres 3 et 4.

### Fonctionnement de l'outil

L'outil AutoVision combine et agence les bases de données des modèles SMI et RUI, pour lier des scénarios (ou concepts) de véhicules autonomes à des impacts possibles (Figure 28).



Figure 28. Réseau de bases de données d'AutoVision.

## Mode Advisor.

Le mode Advisor se positionne dans la phase d'idéation de nouveaux concepts en fournissant des stimuli créatifs responsables (Howard et al., 2011). Il permet aux utilisateurs de sélectionner les tendances souhaitées. Ensuite, l'outil fournit des listes correspondantes d'usages et de domaines de validité à promouvoir ou à éviter. L'objectif de ce mode est de conseiller les utilisateurs sur les choix à faire concernant un nouveau concept. Il agit comme une boussole pour les concepteurs qui ne savent pas par où commencer lors de la conception d'un véhicule autonome. À la manière des méthodes d'idéation (ateliers, *user journey maps*, routine UX, etc.), mais avec la dimension responsable (Figure 29).

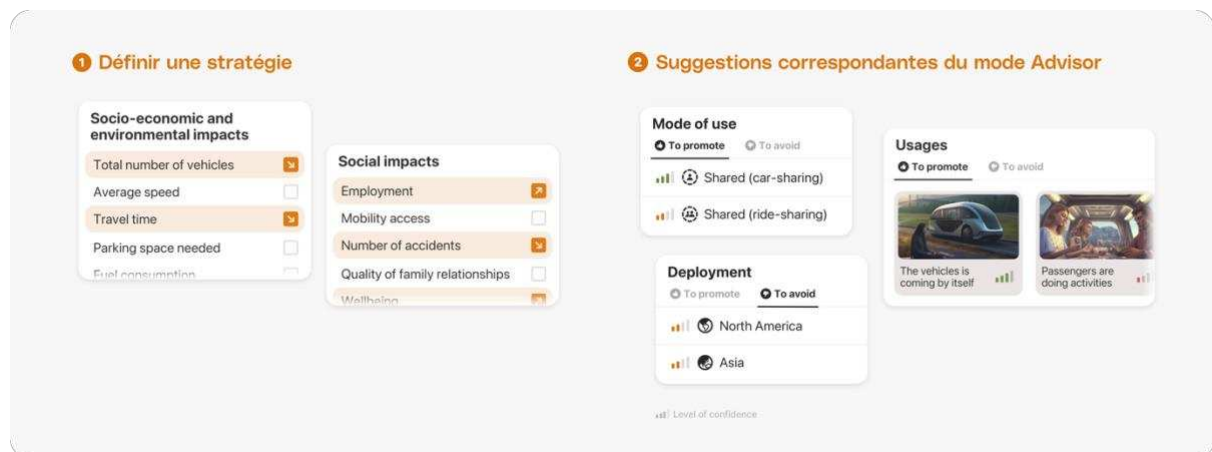


Figure 29. Principe du mode Advisor.

## Mode Impact Guesser.

Le principe du mode "Impact Guesser" est de proposer une liste d'impacts possibles basée sur une liste d'usages et de domaines de validité sélectionnés par l'utilisateur. Il peut servir de garde-fou, permettant l'évaluation et la priorisation des idées les plus responsables dans un processus de conception (Ferioli et al., 2010) (Figure 30).

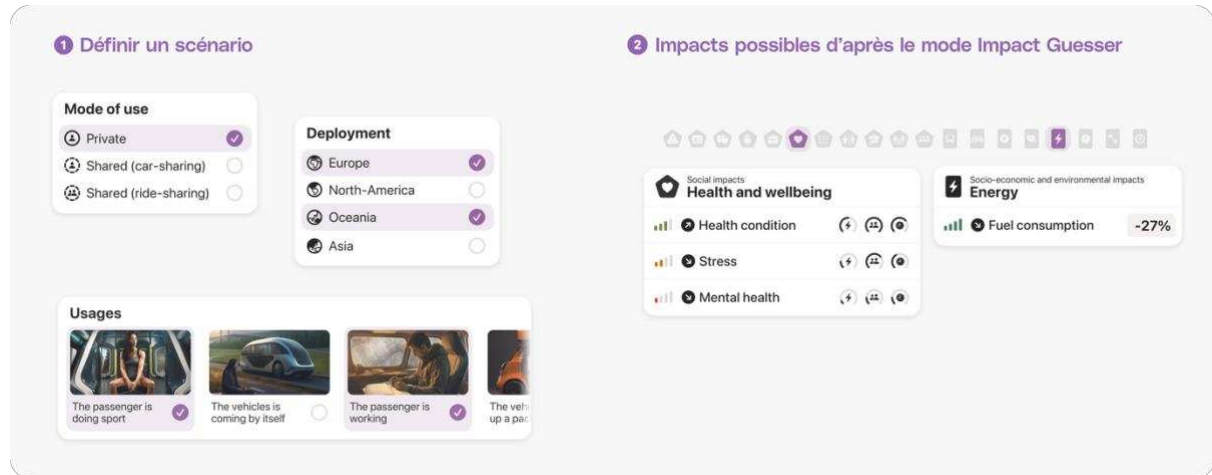


Figure 30. Principe du mode Impact Guesser.

L'une des caractéristiques d'AutoVision, est qu'il est possible pour l'utilisateur de remonter jusqu'aux justifications provenant des études scientifiques (modèle SMI) ou des experts (RUI). Voir l'exemple sur la Figure 31.

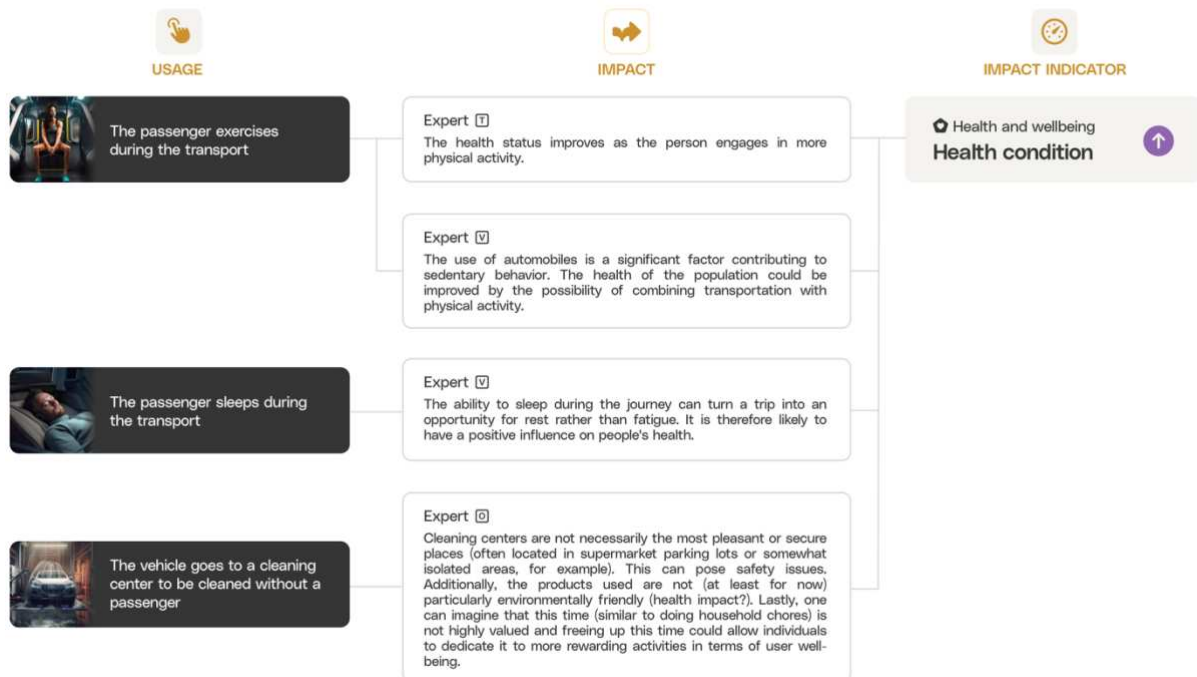


Figure 31. Accès aux justifications liant des usages à un indicateur d'impact.

## 6. Évaluation du mode Impact Guesser d'AutoVision

### Hypothèses

Dans ce chapitre, notre objectif est d'évaluer la pertinence du mode "Impact Guesser". Nous cherchons à tester son efficacité pour fournir des connaissances sur les impacts aux utilisateurs et les aider à devenir plus critiques vis-à-vis des concepts qu'ils proposent pour les véhicules autonomes. Nous commençons ce chapitre en décrivant le protocole expérimental utilisé pour tester nos quatre hypothèses. Nous présentons ensuite les résultats puis nous concluons sur le potentiel du mode "Impact Guesser" pour aider une entreprise à anticiper les impacts à long terme d'un futur produit disruptif.

Nous avons formulé quatre hypothèses :

- h1.** L'utilisation de l'outil permet aux utilisateurs d'acquérir des connaissances sur les impacts probables des véhicules autonomes.
- h2.** L'utilisation de l'outil permet de rejeter davantage d'usages, en particulier ceux susceptibles de générer des impacts indésirables.
- h3.** L'utilisation de l'outil a une influence positive sur le nombre de justifications pour les rejets liés au risque de causer des impacts indésirables.
- h4.** L'utilisation de l'outil a une influence positive sur le nombre d'avertissements.

### Protocole

Pour évaluer les quatre hypothèses, nous avons réalisé une expérience en deux parties consécutives (Figure 32). La première partie a été réalisée sans l'outil AutoVision, et la deuxième partie avec celui-ci. Nous avons conçu cette expérience pour des participants ayant des niveaux et des domaines d'expertise variés. Chaque participant a réalisé l'expérience individuellement. L'expérience consistait à (1) imaginer et sélectionner de usages de véhicule autonome à développer, et (2) imaginer les impacts probables d'un concept de Citroën. Nous avons comparé les résultats des deux parties pour déterminer l'influence de l'outil sur plusieurs métriques : Le nombre d'impacts imaginés à partir du concept Citroën, le nombre d'usages rejetés car perçus comme « non-responsables », le nombre de justifications par rejets, et enfin le nombre d'avertissement ajoutés aux usages conservés.

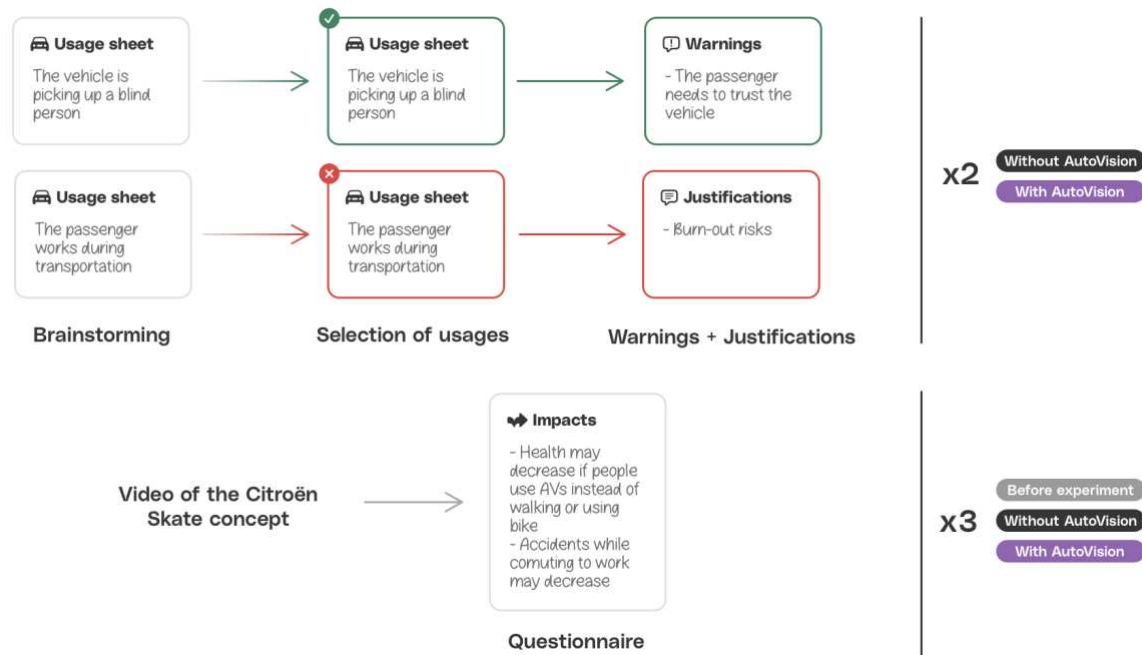


Figure 32. Plan d'expérience pour évaluer l'Impact Guesser.

## Résultats

Nous avons réalisé cinq sessions impliquant un total de 28 personnes. Deux de ces sessions ont eu lieu au sein du groupe automobile Stellantis en France, avec un total de 13 participants. Les trois autres sessions ont été organisées au laboratoire génie industriel (LGI) de CentraleSupélec en France, avec un total de 15 participants.

**Hypothèse 1.** L'utilisation de l'outil a considérablement augmenté le nombre d'impacts imaginés par les participants (deux fois plus) et les a donc aidés à acquérir de nouvelles connaissances sur les impacts des véhicules autonomes. Ce résultat est significatif. L'hypothèse 1 est validée.

**Hypothèse 2.** L'utilisation de l'outil a augmenté le nombre de rejets de 8% à 15%, mais seulement 32% des participants ont estimé qu'il les avait aidés. De plus, l'outil a eu un impact sur seulement 25% des participants. L'outil a donc partiellement validé l'hypothèse 2. Les participants ont eu du mal à établir des critères de rejet des usages, et il y avait des différences subjectives dans la détermination de l'acceptabilité.

**Hypothèse 3.** Lorsque les utilisateurs ont eu accès à l'outil, il y a eu une augmentation légère mais significative du nombre moyen de justifications pour les usages rejetés. Cependant, les erreurs standards se chevauchent et la puissance statistique est réduite en raison d'un pourcentage élevé de participants n'ayant rejeté aucun usage. L'hypothèse 3 n'est donc que partiellement validée.

**Hypothèse 4.** L'utilisation de l'outil a entraîné une augmentation d'environ 33 % du nombre d'avertissements. Les participants ont estimé une augmentation de 45 %, surestimant très légèrement la moyenne réelle. 90 % des participants ont déclaré que l'outil les avait aidé à mieux prévenir les risques. Ce résultat est significatif, validant ainsi l'hypothèse 4. Cependant, un effet d'apprentissage peut avoir contribué à l'augmentation des avertissements, suggérant la nécessité d'une expérience complémentaire avec deux groupes.

## 7. Évaluation du mode Advisor d'AutoVision

### Hypothèses

Le mode Advisor propose des suggestions pour les usages, les modes d'utilisation et les zones de déploiement en se basant sur une stratégie d'impact. Il vise à guider les concepteurs vers des concepts plus responsables dès le début, mais peut limiter la créativité par rapport aux méthodes traditionnelles d'idéation. Les suggestions de l'outil sont supposées être de meilleure qualité, et ce chapitre examine comment le mode Advisor peut aider à établir un concept de véhicule autonome aligné sur la stratégie d'une entreprise, pour ensuite persuader les décideurs. L'exactitude des suggestions ne peut être vérifiée expérimentalement, mais elles sont basées sur des découvertes scientifiques et des opinions d'experts. Nous avons formulé les trois hypothèses suivantes :

**h1.** Un concept généré par l'outil est perçu par les décideurs stratégiques comme étant au moins aussi convaincant qu'un concept qu'ils auraient pu imaginer eux-mêmes. Le terme "convaincant" fait référence à la compatibilité d'un concept avec une stratégie d'impact.

**h2.** Les designers n'ont pas suffisamment de connaissances pour évaluer avec précision si un concept de véhicule autonome est plus responsable à long terme par rapport à un autre.

**h3.** Les experts peuvent avantageusement justifier des choix pour un concept.

Nous commençons ce chapitre en décrivant le protocole expérimental utilisé pour tester nos hypothèses. Nous présentons ensuite les résultats et concluons sur le potentiel du mode Advisor d'AutoVision pour aider une entreprise à définir un futur produit.



## Protocole

L'expérience décrite dans ce chapitre a été réalisée avec un nombre limité de participants avec de nombreuses responsabilités au sein d'une entreprise travaillant sur des véhicules autonomes (AV). Comme cette expérience s'est déroulée à la fin du doctorat, nous l'avons conçue comme étant exploratoire, dans le but de fournir des premiers aperçus sur la pertinence du mode Advisor au sein d'une entreprise, plutôt que des résultats quantitatifs solides et statistiquement validés. L'expérience s'est déroulée sur une période d'environ 2 heures. Les participants étaient répartis en groupes (ils étaient au total 8). Les 20 premières minutes étaient consacrées à expliquer le contexte et les détails aux participants. Cette phase s'est terminée par la présentation d'une stratégie d'impact générale (impacts à éviter ou à promouvoir). L'expérience était divisée en deux parties : Conception et Évaluation (Figure 33).

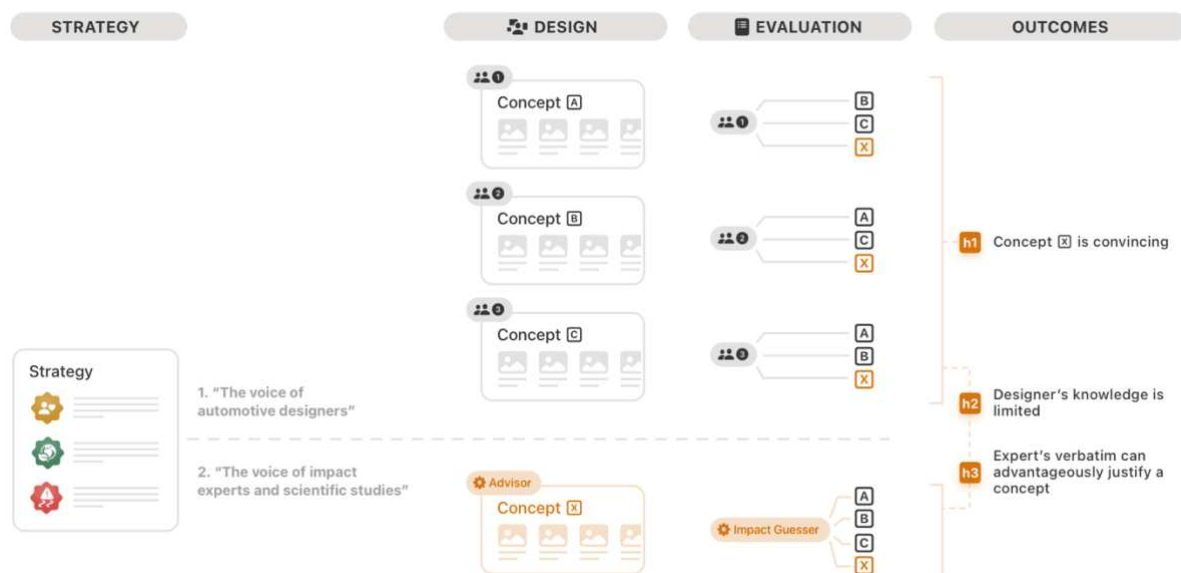


Figure 33. Protocole expérimental pour tester le mode Advisor.

La première partie consistait pour chaque groupe à imaginer un concept. Chaque groupe a reçu une liste d'usages et de modes d'utilisation, et devait sélectionner au moins 5 usages à promouvoir et 5 à éviter, ainsi qu'un ou plusieurs modes d'utilisation en fournissant une justification. La deuxième se concentrait sur l'évaluation des concepts. Chaque groupe a évalué les concepts des autres groupes, ainsi qu'un concept complémentaire (noté X) généré avec l'Advisor. Après une courte pause, les résultats ont été présentés aux participants sous forme de classement, révélant le meilleur concept parmi A, B, C et X selon les participants.

## Résultats

Nous avons réalisé l'expérience lors d'une seule session impliquant un total de 8 personnes d'une entreprise travaillant sur des véhicules autonomes. La plupart de ces individus étaient responsables de projets. En conséquence, ils jouaient tous un rôle stratégique dans l'entreprise.

**Hypothèse 1.** Les résultats indiquent que l'Advisor peut générer un concept aussi convaincant qu'un concept envisagé par les décideurs. Bien que ces résultats ne fournissent pas de validation statistique pour notre hypothèse, ils restent néanmoins une indication prometteuse.

**Hypothèse 2.** Les résultats suggèrent une faiblesse dans l'évaluation des participants quant aux impacts à long terme des véhicules autonomes.

**Hypothèse 3.** Les résultats montrent que des experts (justifications présentes dans l'outil) ont une richesse de vocabulaire beaucoup plus grande que les concepteurs pour justifier les impacts possibles d'un usage de véhicule autonome. De plus, ils ont des propos beaucoup plus nuancés (contrairement aux propos polarisés des participants).

## 8. Conclusion

### Contributions

Notre objectif était de proposer une approche responsable pour concevoir un produit disruptif, en se concentrant sur les véhicules autonomes. Nos travaux de recherche ont abouti à quatre principales contributions.

- Un modèle d'impact (SMI) permettant d'anticiper les impacts socio-économiques et environnementaux possibles des véhicule autonome, d'après la littérature scientifique.
- Un modèle d'impact social (RUI) permettant d'anticiper les impacts sociaux possibles des véhicule autonome, d'après des experts comme des sociologues, urbanistes ou juristes.
- Un outil industriel (AutoVision) pour aider les décideurs et les concepteurs à envisager des concepts de véhicules autonomes responsables et vérifier leurs impacts potentiels.
- Une validation sur le terrain montrant comment AutoVision aide les décideurs à définir des concepts de véhicules autonomes responsables en utilisant des données traçables, et en fournissant de nouvelles connaissances sur les impacts des VA pour cultiver une pensée critique et favoriser la prise de recul.

Pour Stellantis, un prototype fonctionnel de l'outil basé sur la plateforme en ligne Notion.so a été fourni, intégrant les modes Advisor et Impact Guesser ainsi que les fonctions essentielles de l'outil.

Les limites d'AutoVision incluent la nécessité de mettre à jour régulièrement les bases de données, les modèles SMI et RUI ont également quelques limitations, comme l'incapacité des modèles à établir des relations causales complexes ou à tenir compte de la probabilité des impacts.

### **Généralisation et perspectives**

L'outil AutoVision, actuellement disponible sous forme de prototype fonctionnel mais incomplet, nécessite des fonctions complémentaires pour être pleinement exploité dans un environnement industriel. Les défis comprennent la nécessité de développer une meilleure expérience utilisateur, et l'inclusion d'un mode de consolidation pour évaluer les impacts et attribuer des degrés d'importance variables. Une amélioration du protocole de mise-à-jour des impacts est également indispensable. Ces fonctions sont nécessaires pour le déploiement et la mise à l'échelle réussis de l'outil AutoVision.

L'outil peut être déployé au-delà des véhicules autonomes, car il est adaptable à d'autres produits ou technologies innovantes, à condition qu'ils soient disruptifs et aient un potentiel de déploiement à long terme. Les prochaines pistes sont les suivantes :

- Déployer l'outil en interne au sein du groupe Stellantis en tant que plateforme collaborative permettant aux experts de l'entreprise de le mettre à jour régulièrement avec de nouvelles connaissances.
- Offrir aux entreprises ou aux décideurs politiques la possibilité d'utiliser l'outil pour anticiper les impacts à long terme d'un produit futur, dans une approche business-to-business.
- Développer une plateforme open source pour permettre à une large communauté d'utiliser et de mettre à jour l'outil gratuitement, avec une structure évolutive basée sur les contributeurs et une facilitation de l'inclusion d'autres produits.
- Créer une version éducative de l'outil pour permettre aux utilisateurs d'explorer les relations de cause à effet et de mieux comprendre les impacts à long terme d'un produit.

L'outil AutoVision a le potentiel d'avoir un impact sur les décisions de conception actuelles, en aidant les décideurs à comprendre les conséquences potentielles de leurs choix et à anticiper les réglementations futures.

## Réflexions complémentaires

L'outil AutoVision a prouvé son potentiel pour aider les designers et les décideurs à envisager des véhicules autonomes plus responsables à long terme.

Dans le contexte industriel complexe de Stellantis, certains décideurs peuvent avoir un intérêt limité à se projeter à long terme. Par exemple, le plan stratégique Dare Forward 2030 est limitée à 8 ans dans le futur. L'entreprise s'engage à réduire les émissions de gaz à effet de serre, mais on imagine que la vente continue de véhicules peut entrer en conflit avec la responsabilité à long terme des choix. Le défi pour faire adopter un outil comme AutoVision est donc important. Cependant, certaines marques, comme Citroën, font des efforts pour innover de manière durable. L'outil AutoVision est introduit pour accélérer ces efforts.

L'utilisation d'AutoVision est entravée par la difficulté de mettre à jour facilement les bases de données dans un contexte industriel. Une solution potentielle consisterait à lier les bases de données aux modèles de langage de type LLM pour faciliter l'ajout et la consolidation des données, rendant l'outil plus convivial.

L'outil AutoVision met l'accent sur les effets à long terme des choix de conception, encourageant des perspectives responsables et décourageant celles qui mènent à des futurs dystopiques. Les designers ont une responsabilité croissante envers la société et doivent être soutenus pour prendre en compte les impacts potentiels dès le début du processus de conception. Mais la responsabilité ne repose pas uniquement sur le designer ou l'entreprise : Elle nécessite une collaboration entre différents acteurs pour atteindre un avenir souhaitable. Le partage des connaissances est une étape essentielle pour accroître la sensibilisation et favoriser des initiatives à grande échelle.

## Supplementary material 29: Slides from the defense

