Doctoral Dissertation

A Multiple-Case Study Exploring Risk Perceptions and Social Acceptability of Autonomous Vehicles: Japan to Israel

(Summary)

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Abstract

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Autonomous vehicles (AVs) have become one of the core areas of next-generation invention in the technology industry. Although AVs have transformed the future of urban transportation, questions remain regarding the regulations and practical implementation. Understanding the general acceptance of AV technology is crucial for various stakeholders but remains limited in the literature. Across three studies, we aim to assess how risk perceptions and public acceptance of AVs are affected by dread, unfamiliarity, and culture. In Study 1, we conducted an experiment in Japan in 2017 to assess what composes AV risk (dread, unfamiliarity) and how different AV risk factors (system error, hacking, unexpected events) influence risk perception and public acceptance. In Study 2, we extended our work by comparing the residents in Japan between 2017 and 2020 to evaluate changes in risk perception and acceptance after the Japanese were exposed to two well-publicized AV demonstrations in 2018 and 2019. In Study 3, to better understand cultural differences, we conducted a cross-country comparison study between Japan and Israel, two countries that drastically differ in culture but are similar in terms of their leading position in the development and implementation of AV technology. Following the Fischhoff et al. (1978) and Slovic (1987) method, perceived risks were categorized into dread risk, unknown risk, and people-affected risk. We developed a survey measuring these three risk factors with 9 specific items in Study 1-2 and 6 specific items in Study 3: (1) voluntariness of risk,(2) immediacy of effect, (3) knowledge about risk (by those exposed to it), (4) knowledge about risk (by professionals), (5) control over risk, (6) newness, (7) chronic—catastrophic, (8) common—dread, and (9) severity of consequences. Taking all three studies together, we demonstrated that, although residents in Japan were initially unfamiliar with the AVs technology and expressed substantial perceived risks, the level of risk perception (especially risk of unfamiliarity and dread) significantly decreased after exposure to the significant AV demonstrations. We also provided evidence showing that the Japanese are more risk-averse than Israelis, seeking more assurance of AV safety before expressing acceptance. Our findings provided two critical insights into how policymakers should prepare for the coming revolution in AV technology: (1) there should be significant planning and other infrastructure updates before the mainstream rollout of autonomous vehicles; and (2) public acceptance of AVs will benefit from ensuring the safety, security, and privacy of AVs before full implementation.

DEDICATION

To the memory of my dearest, loving,

wonderful

Baba

you gave me the strength and

encouragement to never give up and

conquer the world

With the growing popularity of autonomous vehicle (AV) technology, the global automotive industry has engaged in an extremely rapid and sustained research and development process with the aim of creating reliable self-driving cars for everyday use. AVs have the potential to bring numerous social and economic benefits, including shorter travel times and reduced environmental impact. These benefits will only increase as the technology advances over the coming years. However, the successful implementation of AVs at a large scale depends on public acceptance and understanding. Efforts to improve public acceptance and convey accurate information to the public depend on first assessing where opinion currently lies.

This dissertation presents a multi-nation comparative study of public acceptance of AVs with a primary focus on Japan. As of 2022, current Japanese law allows for self-driving vehicles operating at levels 1-3 of autonomous self-control, as described in the classification scheme developed by SAE International (formerly the Society of Automotive Engineers). Level 3 AVs have "environmental detection" capabilities and can make informed decisions for themselves; current commercial vehicles are already equipped with functions up to this level. But more advanced alternatives are immanent, with the government aiming to achieve public use of level 4 AVs by 2025. These vehicles go beyond level 3 capabilities in several ways, the most critical of which is that they can intervene if things go wrong or there is a system failure. They will therefore not require human control in most circumstances, although a human operator will retain the ability to override the system manually. The change from level 3 to level 4 AVs thus has two components. One is technological, with more advanced self-regulating systems required to implement level 4 vehicles, but the other is social. Human drivers and pedestrians must accept the new systems and must trust AVs to act correctly and safely when facing mechanical failure dangerous driving conditions, and collisions. For the government's goal of implementing level 4 AVs to move forward, general public risk tolerance for these vehicles must exceed a minimal level of acceptance. However, studies evaluating the risk perception and general acceptance of AV technology remain limited, and do not provide sufficient information to determine whether this minimal level has been reached.

1.1 BACKGROUND

The rapidly aging society of Japan requires a high-quality transportation system that provides expanded and more robust mobility services to all residents. Current systems of public transport do not meet this need, at least in their present state, and autonomous vehicles (AVs) offer one possible path toward allowing ageing Japanese adults to move about more freely. An important milestone in the development of these new capabilities was achieved relatively recently in Hiroshima, Japan, when international researchers, including Professor Akimasa Fujiwara and his team at the University of Hiroshima, tested the integration of autonomous buses (AB) into the local light rail transit (LRT) system. The pilot study was successful in demonstrating the feasibility of autonomous public transport systems. More importantly, over 70% of residents reported intending to use the ABs, and other public acceptance measures also indicated that the combined AB-LRT system was feasible for permanent implementation.1 For example, residents expected fewer accidents after experiencing a test drive in an AB (i.e., their judgment of the risks involved in AB operation were reduced by exposure to the technology). This promising preliminary result showed that there is significant value in clearly understanding the perceived risks before fully implementing AV technologies within any given community. This is especially true when considering large-scale implementation at the national or international level. For these more complex projects, larger datasets are needed. In particular, beyond what can be learned from single-timepoint data collection within specific communities, examining both temporal changes within a country and cross-cultural differences between countries has the potential to reveal valuable insights for various stakeholders. For example, if we see how risk perceptions evolved between 2017 and 2020 in Japan following exposure to major public demonstrations of AVs, we can glean insights into how the educational effects of such pilot programs influence risk perceptions associated with unfamiliarity and novelty. At the same time, by comparing Japan and Israel we can start to see how culture

influences expectations around safety and risk, potentially paving the way for a general understanding of public attitudes toward AVs across cultural and social contexts.

In the present study, Israel was selected as a comparison country for Japan because of the two nations' similar levels of development and usage in AVs, as well as their sharply contrasting levels of cultural priority afforded to AV projects. Japan is a risk-averse society, and relative to many highly developed countries, it is not accepting of autonomous vehicles. It is therefore possible that Japanese leaders may not be taking full advantage of either the enormous economic opportunity AVs represent or the potential for global environmental leadership that innovation in the field might offer. Israel, by contrast, is less risk-averse and has been rapidly developing technological prowess in a wide range of economic sectors. Of particular relevance here, over the last decade Israel has created one of the world's most active and appealing legal and financial ecosystems for automotive manufacturing. With both countries racing to establish themselves as leaders in the AVs industry, comparing Japanese citizens' attitudes toward the technologies to those of Israeli citizens, it may be possible to draw useful conclusions with more general relevance.

However, the implementation of AVs has not been without drawbacks and stumbling blocks. For instance, during the 2020 Tokyo Olympics, an accident occurred involving a visiting athlete. A number of other severe crashes have been reported globally.2-4 Given these incidents and the media coverage they have engendered; it is important that we pursue further studies of risk perception and social acceptability for evolving AV technologies. Such events may have the potential to tarnish the reputation not only of self-driving cars and buses, but of the nation's leading the charge for their implementation.

1.2 THEORETICAL FRAMEWORK

The theoretical framework we adopt for assessing risk perception and social acceptability of AVs is grounded primarily in the work of Slovic and colleagues.[5-7] We propose a two-factor model to capture risk perception, based on the idea that when people encounter a new concept or entity, they tend to assess risk based on two sets of negative emotions: those related to unfamiliarity, and those related to dread. Unfamiliarity-related risks were characterized as follows: 1) the entity is unable to be observed, 2) the risk situation is unknown, 3) the risk effects are delayed, and 4) the risk is new or novel. The more closely these characteristics describe a concept or thing, the greater its perceived unfamiliarity-linked risk. For example, people tend to perceive high unfamiliarity-related risk for new technologies that could potentially break or malfunction (i.e., system errors, hacking, unexpected events that would have happened in AVs). Dread-related risks, meanwhile, are linked to these four circumstances: 1) the risk situation and outcomes are uncontrollable, 2) the consequences of the risk situation appear fatal, 3) getting into the risk situation involuntarily, and 4) the risk not being easily reducible. For example, people are afraid of fatal consequences if AVs go uncontrolled that are resulted from system errors, hacking, or unexpected events.

The two kinds of perceived risk can both be mitigated, but they require different approaches. Making people aware of human-originated errors in AVs such as system errors and hacking, for instance, might reduce unfamiliarity but increase dread, making them less accepting toward AVs. Alternatively, exposing people to an AV testing environment and offering education regarding AVs' safety is likely to increase familiarity and thereby increase acceptance. To reduce dread, one possibility is to make people more familiar with the things that can go right during AV operation, helping them build trust in the vehicles and , and decreasing the perceived likelihood of improbable or fatal events.[8]

1.3 AN OVERVIEW OF RELATED LITERATURE

In this section, we present the pre-existing literature on risk perception and acceptance of AVs. The broad domain reviewed here includes (1) the potential benefits of AVs, (2) concerns regarding AV risks, (3) risk perception factors (e.g., system errors, hacking, and unexpected events), (4) effects of prior experience with AVs, (5) perception of risks related to the unfamiliarity of technology, and (6) social and cultural differences. First, regarding the potential benefits of AV technology, numerous studies have highlighted benefits such as improved traffic safety and decreases in travel time, both of which are likely to affect decisions related to travel behavior. With respect to traffic safety, widespread use of AVs could dramatically decrease the number of vehicle crashes that take place, especially those caused by human error, as in cases of drunk driving and speeding. To assess likely changes in travel behavior, Dannemiller and colleagues used latent construct analysis to demonstrate that the introduction of AVs significantly impacts five dimensions of short-term travel-activity choices: (1) more additional local area trips, (2) increased trip distance to shopping or eat-out activities in the local area, (3) increased trip distance to leisure activities in the local area, (4) additional long-distance road trips beyond the local area, and (5) decreased travel time during commuting.[9] From a financial perspective, the major social impacts of AVs would come in the form of savings from reduced collision rates, travel time reduction, fuel efficiency, and parking benefits. Together, these are estimated to approach $2,000 per year per AV, and may approach nearly $4,000 per vehicle when comprehensive crash costs are accounted for.[10]

The second topic reviewed was the presence of clear concerns about AV safety. Self-driving technology is seen as potentially unsafe due to the absence of human control. Research has also found that public perception of risk is influenced by several technology-related factors, such as privacy—being under surveillance, being tracked, and having security from hacking.[11] One study of Twitter user behavior, for example, suggests that public perception of AV-related events is a major driver of public acceptance of AVs. The authors analyzed 1.7 million tweets using sentiment analysis, and reported that tweets about AVs were more negative after reporting on a fatal crash that involved a self-driving car.[12] Similarly, in the immediate aftermath of the Tesla Autopilot incident, the most frequent terms on Twitter shifted from "Amazon" and "startup" to "autopilot" and "vehicle," and overall positive sentiment in AV-related tweets decreased.[13] Systematic reviews showed that "safety" is the most frequently occurring word in all published research dealing with AVs; it is, in other words, of primary concern to all stakeholders.[8,14]

The third topic reviewed was a subset of safety issues: the possibility of system errors and the need for technological transparency. One key point here comes from a survey of 552 drivers. The researchers found that the factors with the greatest influence on likelihood of adoption of AVs were trust and perceived usefulness.[15] Other work has reported that individuals' trust in AV systems, and especially trust in their resilience against hacking, are dependent on degree of experience with the technology. For instance, while drivers who experienced unexpected behaviors from their AVs reported lower levels of trust in the Autopilot feature, overall trust increased over time regardless of specific negative experiences along the way. Trust was also correlated with frequency of use, technical knowledge about the systems, and perceived ease of learning. An online survey of almost 1,000 UK drivers found that AVs were generally perceived as moderately low-risk, and reported minimal opposition to their use on public roads.[16] But compared to human-operated vehicles, they found that AVs were perceived to be riskier for passengers than for pedestrians, and also as being riskier than existing autonomous trains. An important gap in this area of the literature is that previous studies have not examined the attitudes of other drivers, those not riding in AVs but who would nonetheless need to interact with them on the road.

This brings us to the fourth area of this literature overview, which is the effects of prior experience with AVs. Although providing respondents with information about the vehicles significantly affects their risk assessments, their level of acceptance may also be affected by information they have received in the past. Existing studies have examined the results of AV risk information relayed through various channels, including texts, pictures, and videos.[17-20] However, there had been no substantial exploration of how AV risk perception and acceptance may have changed after the public AV experiment in Hiroshima. It is

essential that we better understand the factors that affect AV acceptance, and how attitudes change over time and over the course of exposure via public transport and other everyday travel. Both manufacturers and policymakers rely on these findings to make decisions about how best to develop and integrate these technologies into public life. This particular need for further research is the primary motive for the present study, which explores perception of risks related to unfamiliarity of technology, as well as social and cultural differences in acceptance of AVs.

A crucial piece of the background to this study is therefore the aspect of perceived risk that is related to the unfamiliarity of a given technology. In a technological context, risk is defined as "the likelihood of physical, social, and/or financial harm/detriment/loss as a consequence of a technology aggregated over its entire life-cycle."[21] Although directly observable risks play an important role in the public's perception of risk and subsequent acceptance of AVs, the extent to which unnoticeable risks influence behaviors has been less discussed and remains under-studied. Risk characteristics that consumers are not necessarily aware of, such as social, emotional, and symbolic significance, can act as hidden drivers in favor of or against a specific technology.[22,23] This general finding suggests that both noticeable and unnoticeable risk factors are likely to influence acceptance of AVs.

Other evidence reinforces this conclusion. In one mixed-method study, researchers found that risk perceptions were significantly smaller for conventional driving as compared to connected/autonomous driving.[24] Users showed a tendency to perceive the use of self-driving cars as giving up control of the vehicle (rather than, for instance, using a different form of technologically advanced control), a perspective that has negative associations and may elicit concerns about safety.[25] In addition, several studies have directly examined public perceptions of the risks posed by AVs with different degrees of automation for audiences of different demographics. Across studies, two of the most significant factors are security from outside control of the system (i.e., safety from hacking) privacy (i.e., how much control owners would have over the car's movements, whether their movements could be tracked, and whether owning the cars would subject them to additional surveillance).[11,18] Concern about either factor consistently predicts higher perceived risk of AVs.

The findings with respect to acceptance—rather than risk perception—are similar. A number of recent studies have examined both social and technological aspects of the link between vehicle/system safety and public acceptance. While technological problems can be solved by a combination of innovative new technologies (on the manufacturer side) and amending or introducing relevant laws and regulations (on the government side), dealing with social uncertainty remains challenging because of the novelty of AVs and the level of risk associated with driving in general. Therefore, further examination of the public acceptability of this new technology is crucial, especially prior to greater AV market penetration and full adoption.

As discussed earlier in this chapter, cultural differences can also influence risk perception. Following the lead of other cross-cultural comparison studies, we defined a non-exhaustive list of essential elements for the comparison of two cultural settings: religion, economics, education, policy, and military involvement. Japan and Israel lie at the extreme opposite ends of the spectrum defined by these five traits (see Table 1).

Table 1. Cultural differences between Japan and Israel

Country	Religion	Economics (long-term debt-equity ratio)	Education	Political sensitivity to costs of belligerence[§]	Military supportive
Japan	Unaffiliated with any religion[*]	Low[¶]	Community focused	High	Weak
Israel	Jewish[*]	High[¶]	Western (individualism)	Low	Strong

*Notes: *: Most but not all Israelis see themselves as Jewish. In Japan, a minority of citizens see themselves as religious; this group is predominantly Buddhist. [§]I.e., willingness to threaten (and act on) the use force as a political tactic. [¶]The two countries' per capita GDP are comparable, with Israel's per capita GDP standing at $42,120 and Japan's at $40,850 in 2018 real terms. The divergences in their long-term debt-equity ratios thus reflects a significant economic contrast.*

In short, the two countries present drastic differences in core cultural dimensions. Israel is predominantly religious, individualist, has a high debt-equity ratio, is willing to use political force, and strongly supports its military. Japan is largely non-religious and non-militaristic, with a strong focus on community. These contrasts predispose those living in Japan and Israel toward very different levels of risk-tolerance, with Japan being the more risk-averse of the two cultural environments.[26-28] It was expected that these differences in overall risk-aversion would translate directly into differences in the perceived risk of unfamiliar technology—here, AVs—in terms of both unfamiliarity-related risk and dread-related risk.

Taken together, the research summarized here suggests that we need to establish a clearer understanding of the perceived benefits and risks of AVs before the technology is implemented at scale within our communities. That knowledge will also contribute to the wider field of technology acceptance and allow future researchers to gain greater insight into risk perception and public attitudes toward other new technologies. From a practical perspective, the present study may provide useful insights for policymakers developing regulations for AVs and manufacturers working on making AVs safer from external system threats.

1.4 OBJECTIVES OF THE STUDY

Across three studies, we aim to assess how risk perceptions and public acceptance of AVs are affected by dread, unfamiliarity, and culture. Specifically, for Study 1, conducted in 2017, we completed an experiment in Japan in 2017 assessing what whether dread or unfamiliarity contribute more to AV risk perceptions, as well as how different risk factors (system error, hacking, unexpected events) influence risk perception and public acceptance. The purpose of the study was to better define a general profile for public perceptions of AVs in a Japanese setting.

In Study 2, we extended our work by comparing responses over a three-year period, evaluating the 2017 data in light of new data collected in 2020 to evaluate changes in risk perception and acceptance over time. Here, the objective was to address potential changes in public acceptance and risk perception that may have been caused by exposure to AVs. In 2018 and 2019, Japan witnessed two major public demonstrations of AV technology through the Autonomous Bus Pilot Project led by Dr. Akimasa Fujiwara, the first such public integration of autonomous and piloted public transit in the world. This study was designed to assess the project's impact.

In Study 3, to better understand cultural differences in risk perception, we conducted a cross-country comparison study between Japan and Israel, two countries that differ drastically in key cultural traits but are similar in their commitment to the development and implementation of AV technology. We

hoped to provide insight into cultural factors that play a significant role in shaping public opinion around safety, acceptability, and likelihood of use for AVs.

1.5 RESEARCH QUESTIONS

There are five research questions we seek to address across the projects:

1. What are the key barriers to AV introduction in terms of public attitudes and opinions?
2. What role does information and knowledge play in risk perceptions toward AVs in the context of the BUS/LRT integration experiment?
3. What factors affect risk perception for AVs, and why do these matter in solving existing challenges around developing AV technologies and increasing public acceptance of them?
4. Why are the Japanese risk-averse and non-accepting toward AVs (including historical, cultural, and educational context)?
5. Why are Israelis more willing to take risks and more accepting toward AVs (including historical, cultural, and educational context)?

1.6 AN OVERVIEW OF THE METHODOLOGY

To answer these questions, we developed a survey adapted from those used by Fischhoff et al. (1978) and Slovic (1987) and built on the theories of risk perception those researchers helped create. Our survey incorporated three domains: dread risks, unknown risks, and people-affected risks. The "dread risk" factor included the following items: perceived lack of control, potential for catastrophe, inequitable distribution of risks and benefits, and fatal and dreadful consequences. The "unknown risk" factor consisted of the item's observability, experts', and lay people's knowledge about associated risks, immediacy of risk (delayed effects of potential damage), and novelty (a new-old binary). The third factor, "people-affected risk," broke down into three groups of people who might be affected: personally affected, general-public affected, and future-generations-affected.

For the first study (Japan, 2017, see Chapter Two), we evaluated perceptions of AV risk by assessing the two primary factors, unknown risk and dread risk (Slovic 1987). The study employed a novel method for the delivery of risk-related information, using informational videos about AVs that participants were randomly assigned to view. All versions of the video introduced the participant to AVs, but each of three versions then presented different information determining which type of risk the participant was informed about. These elements included: (1) the possibility of system error (e.g., the AV driving off the road under normal circumstances); (2) the possibility of external interference with and control of the car (i.e., hacking); and (3) the possibility of the AV being unable to cope with unexpected events (e.g., atypical human driver behavior, sudden obstacles in the road, etc.). Data were collected through web-based surveys.

For the second study (Japan 2017 and 2020, see Chapter Three), web-based surveys were again circulated to Japanese respondents. A total of 1,442 responses were collected in March 2017 and 1,035 additional responses in March 2020, all from individuals living in Hiroshima, Japan. As in Study 1, participants watched informational videos about AVs that initially introduced AV technology in general terms and then illustrated one of seven randomly selected AV-related risks associated with one or more incidences of hacking, system error, and unexpected events.

For the third study (Japan 2017 and Israel 2021, see Chapter Four), the dataset collected in 2017 from Japan was compared with a novel dataset collected in 2021 in Israel, using the same web-based surveys. The two groups were the same 1,442 respondents from Hiroshima in March 2017, and 781 respondents in 2021 in Israel. As in the other experiments, all participants watched a 2-minute animated video on AVs. Twelve versions of this video were created (seven for Japan and five for Israel). All twelve videos first introduced AV technology and then either presented or omitted one of several risk elements associated with hacking, error systems, and unexpected events.

The analysis procedure used was identical in all three studies. We first applied descriptive statistics to identify changes in perceived benefits, perceived risks, risk adjustment factors, and acceptable risk levels between groups. Second, the effects of risk information on perceived benefits and acceptable risk levels were analyzed for each of the four AV technologies described in the videos (i.e., AV bus and car, each at

levels 3 and 4 of autonomous operation). Third, cognitive maps of risk perception based on dread and unfamiliarity were developed to assess changes in which types of risk participants were most focused on. Fourth, to explore how the three main types of video-based risk information influenced dread and unfamiliarity risks, ANOVA tests were conducted to compare participants who had received each version of the video. Finally, we checked for differences in the factors that influenced AV acceptability for each group by identifying similarities and differences in their responses about socio-demographic, technological, and risk-related aspects of acceptance. Acceptability can be characterized in both discrete and continuous forms. We could have focused on the discrete choice of whether respondents accept the risks of the technology, but there was an added benefit to the continuous approach. For those who found the current risk level of AVs to be unacceptable, we assessed how much safer they believed AVs should be (or would need to be for them to be acceptable). Tobit models were developed to capture these two aspects of the responses simultaneously. The models included (1) whether a given respondent accepted the current risk level they perceived AVs to possess, and (2) if they did not, how much safer AVs should be to reduce perceived risk to an acceptable level.

1.7 STRUCTURE OF THE DISSERTATION

Motivated by the rapid development of AV technology and a lack of robust, reliable evidence concerning public acceptance of the risks these technologies pose, we analyzed risk perception and public acceptance of AVs in Japan to Israel using theoretical framework originating from the work of Paul Slovic and his collogues. This study contributes to the literature in a significant way, as it is the first experimental evaluation of individual's risk perceptions toward AV technologies, potentially allowing for future experimental work on the effectiveness of marketing and nudging strategies for changing perceptions. We further assessed how risk perception changes both within the same population over time, before and after several major public demonstrations of integrated AV use, and between two culturally distinct national populations. This final section of the chapter will describe the content of each subsequent chapter and highlight the connections between them.

The dissertation consists of five chapters. Chapter One presents an introduction to all three research projects, providing the background and explaining the significance of the problem that is explored. It details the logical and methodological links between the three papers on risk perception and public acceptance of autonomous vehicles, including relevant concepts and the core theoretical framework.

In Chapter Two, the first of three papers present the results of a study on risk perception and social acceptability of autonomous vehicles in Hiroshima, Japan. The paper reports an experiment that was conducted in 2017 assessing the risk type (dread or unfamiliarity) and specific AV-related risk factors (system error, hacking, unexpected events) as influences on risk perception and public acceptance.

In Chapter Three, the second article explores temporal changes in risk perception and public acceptability of autonomous vehicles between 2017 and 2020, using the same population reported on in Chapter Two. This study was motivated by the need to assess any potential changes in public opinion resulting from two well-publicized AV demonstrations that took place in 2018 and 2019.

In Chapter Four, the third and final article assesses differences in risk perception and public acceptance of AVs between groups of participants located in Japan and Israel, to better understand how cultural variation might affect attitudes toward AVs, risk, and considerations for large-scale implementation of these technologies.

Finally, in Chapter Five we summarize the primary findings and implications from all three component studies, discuss the project's limitations, and engage with policy implications and directions for future research.

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