Setting the Scene for Automated Mobility: A Comparative Introduction to the Mobility Systems in Germany and Japan

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Abstract This chapter presents a comparative analysis of the mobility systems in Germany and Japan, providing insights into how these systems might influence the implementation of vehicle automation. This comparison begins by exploring the historical evolution of transport in both countries, noting that both have long-established infrastructures shaped by unique geographical and historical contexts. Germany's transport system, for instance, developed within a landlocked nation with extensive rail networks, while Japan's transport was influenced by its island geography and mountainous terrain. The chapter then examines key dimensions of the current transport systems, including demography, settlement patterns, road transport governance, public transport infrastructure, and the automotive industry's role. Comparative statistics are provided, illustrating the differences and similarities

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between Germany and Japan. The analysis highlights how these existing systems serve as both enablers and barriers to the integration of automated vehicles. The chapter concludes that the introduction of vehicle automation will not revolutionize these transport systems overnight but will gradually adapt to existing frameworks. The success of vehicle automation depends on the interplay between technological advances and established transport policies, regulations, and cultural norms. This chapter suggests that understanding the deep-rooted structures of transport systems in Germany and Japan can offer valuable insights into how vehicle automation might unfold in other regions with mature mobility markets. In conclusion, the chapter provides a holistic framework for analyzing the potential impacts of vehicle automation, stressing the importance of considering the existing transport system's legacy and the multifaceted nature of mobility in Germany and Japan.

1 Introduction

Vehicle automation is being discussed as a possible game-changer with the potential to revolutionize transportation. For about a decade, automation has been one of the key topics of transport research, and there have been visions of imminent disruptive changes to the transport system caused by automation [3, 61, 70]. However, automation technologies in transport are not going to be introduced into undeveloped transport systems. Instead, they will be implemented in mature mobility markets with established framework conditions, ranging from infrastructural conditions, through legal foundations for transport, to deeply ingrained mobility routines on the side of travelers [8]. In other words: Implementation of automated vehicles (or AVs) will not all of a sudden establish an entirely new transport system in which they unfold their full potential. Instead vehicle automation technology will have to adapt to existing framework conditions, and most likely successively alter these conditions in order to unfold its potential step by step. In order to understand this process and allow for projections regarding the stepwise implementation and effects of vehicle automation, it is key to understand the pillars that define today's transport system, and their relationship to vehicle automation.

Japan and Germany are predestined mobility markets which are useful case studies to understand the relevant domains of existing transport systems and their consequences for the implementation of vehicle automation. Germany represents a European transport system that has taken a middle way between the strongly car-oriented North American evolution of the transport system, and the less car-oriented eastern Asian experience, for which Japan represents a prototypical path [30, 68]. Assuming that the path of extensive car orientation that North America has taken is unsustainable for many emerging economies, it appears likely that the future of emerging mobility markets in the world falls between the European and the Japanese approaches [107]. Hence, studying the Japanese and German transport systems and the implications for the implementation of vehicle automation will allow for conclusions as to what to expect in other transport systems in the future.

This chapter takes a different approach to the rest of this book, and thus provides both a multifaceted prelude and a complementary methodology. The other chapters mostly focus on specific dimensions of vehicle automation, and often take a quantitative approach. In contrast, this chapter looks at various dimensions of the transport system in a cross-national comparison, and draws multidimensional conceptual conclusions.

After introducing the historic evolution of the transport systems in Germany and Japan, this chapter selects ten topics that are key to how these systems are constituted today. Each topic section presents comparative information for the two countries, and some include comparative statistics. Each section concludes with an interpretation of how these pillars of the transport system have influenced or will influence the implementation of vehicle automation. These discussions of the dimensions of the transport systems in Germany and Japan provide a holistic framework for speculation to identify drivers and barriers of vehicle automation, and how it will change established transport systems in the decades to come.

2 Historic Evolution of Today's Transport System

2.1 Germany

Elements of today's transport system in Germany date back to ancient times, such as Roman or medieval urban street layouts in some city centers [48]. However, much of the foundation of the modern German transport system was laid in the 19th century with the advent of the railway. Plans for long distance rail networks preceded the opening of the first German rail line in 1835 [125]. Specifically, between 1840 and 1880, the German long-distance rail network expanded rapidly, reaching its largest extent early in the 20th century. About 90% of today's long-distance rail lines in Germany originate from that era. From the second half of the 19th century, urban rail networks extended quickly [46]. At first, these were horse-drawn, but from the turn of the 20th century electric catenary tramways took over [47]. This development coincided with rapid population growth, specifically in German cities, which were characterized by extremely high population densities relative to today's standards. However, the increased travel speeds brought about by urban tramways for the first time in history allowed cities to grow substantially in spatial size while keeping total travel times in check. While in the early days long distance and urban rail development was mostly financed and operated by private entrepreneurs, gradually the state took over from the end of the 19th century [47]. There was a mix of motivations to do so, ranging from military strategy considerations to the prospect of generating revenue from railway operations. However, from that time onward, German transport planning and policy was characterized by the notion that the transport system could not be left to market forces but required strong state intervention.

The early 20th century saw the emergence of the automobile as a new mode of transport. At first, automobiles represented a risky leisure activity for tech-savvy and adventurous young, and mostly male, urban elites [69]. While Germany, like other European countries, lagged behind the United States with regard to motorization by several decades, cars started to become more commonplace from the 1920s [68]. Much of the motor vehicle regulation which is in place today in Germany originated in this era, including requirements to register and insure vehicles, and rules regarding driver education and vehicle taxation. Due to effective automobilist lobbying, in the early days vehicle tax revenue was hypothecated for road construction, providing substantial funding for roads and fueling road construction from the 1920s [47]. Contrary to popular belief, the first federal Highway ("Autobahn") was not inaugurated by the Nazi Regime, but in 1932 by the then mayor of Cologne, Konrad Adenauer (who became the first German Chancellor in 1949). After the Nazis came to power in 1933, they put a propaganda focus on automobiles and continued extension of the Autobahn construction. Contrary to their propaganda, however, automobiles continued to be a status symbol of elites, while the train remained the dominant mode of transport for the general population [47].

After World War II (1939–45) the growth of car ownership and use in Germany increased such that total automobile travel surpassed total travel by public transport (1955) and cars outnumbered motorcycles (1957) [19]. This development went along with strong economic growth, auto-oriented post-war reconstruction of German cities according to the principle of separating land uses, and a surge in suburbanization. Specifically, in the 1960s, transport policy and planning were strongly car-oriented [106]. Many cities replaced the tramways with bus systems and underground urban rail to make space for urban roads [46]. In the 1960s, there were a few years with hypothecation of fuel tax income to, initially, road construction, and then transport infrastructure construction in general. This provided generous funding and caused today's German cities to be partly characterized by over-dimensioned road and transport infrastructure.

From the 1970s onward, transport policy and planning paradigms began to change, as there was increasing awareness of topics such as energy dependence (specifically oil), environmental damage, or quality of life in cities. The foundation of the German Green Party in 1980 epitomizes this change in perspective. Specifically, in urban transport this paradigm shift manifested itself in an increased focus on public transport, a partial push-back of the car in central urban areas (traffic calming, reduction of public parking spaces etc.) and—from the 1990s—more focus on cycling infrastructure planning [106]. Nevertheless, the regulatory heritage (e.g., urban parking statutes, road transport law) or established planning conventions (e.g., for highway infrastructure) leads to an underlying structure for transport policy and planning that remains relatively car-oriented.

2.2 Japan

The main transportation routes in Japan are influenced by the ancient road network "Shichidou Ekiro", developed in the 7th century [89]. The Shichidou Ekiro was made up of seven wide, straight arterial roads, constructed by the Imperial Court to connect the central government and local counties. There was also a post-horse transportation system called "Ekiden-sei", similar to the Cursus Publicus developed by the Roman Empire [118]. However, pedestrian, horse, and boat traffic persisted until the Meiji Restoration in 1868, because wheel traffic did not develop in Japan.

After the Meiji Restoration, Japan's first railway was constructed in 1872 between Shinbashi and Yokohama. From this point, railway development progressed rapidly. For road traffic, horse-drawn stagecoaches commenced operating in 1868 between Yokohama and Odawara, followed by carriage operation between Tokyo and Takasaki in 1872 [105]. However, railroad construction was prioritized, and road construction did not progress. After the Sino-Japanese War (1894–1895), the railway network expanded rapidly, and in the 1910s, a comprehensive domestic transportation network was formed by the railway and coastal shipping networks.

Automobile importation began in 1901 in Japan; however, in 1913, the number of cars in use was only approximately 500, whereas more than 170,000 horse-drawn wagons were responsible for freight transportation. With modernization of the economic structure, the demand for road infrastructure development has increased. The Road Law was enacted in 1918, which included rules regarding road types, grades, management responsibilities, and cost burden. Japan's first long-term plan for road development was established in 1919; this comprised a 30-year planning period starting from 1920 [72]. However, owing to the economic recession after World War I (1914–18), and the Great Kanto Earthquake in 1923, the budget was reduced, and road development did not proceed. During WW II, resources were used for the war effort, and the level of road infrastructure remained low.

The Road Law was amended in 1952, and the National Expressway Law was enacted in 1957, resulting in the addition of the National Expressway to the road types. In terms of financial resources and planning, the first five-year road development plan was formulated in 1954, and road construction and improvement using the fuel tax as a specific financial resource began in earnest. In 1956, the Road Development Special Measures Law was enacted, and the Japan Highway Public Corporation was established to launch the existing toll road system.

In March 1947, the number of registered automobiles was more than 140,000 which increased significantly to approximately 77 million by March 2015. In addition, the length of national highways has increased approximately six times during the 66 years from 1949 to 2015 [56]. In 2005, the Japan Highway Public Corporation was privatized, and in 2006, the construction and operation of the expressway based on this privatization scheme commenced.

In recent years, road development and management has been pursued not only for automobile traffic but from other viewpoints. In 2016, the Bicycle Utilization

Promotion Law was enacted, and the basic measures promoting the utilization of bicycles were comprehensively clarified. In 2020, “The 2040 Vision for Roads in Japan [88]” was published by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). It states that road policy sets human wellbeing at the center, and addresses issues and needs such as climate change, aging infrastructure, declining population, digital transformation, and new post-COVID-19 lifestyles, by using digital technology and restoring the function of roads as a livable communication space.

2.3 Comparative Conclusions

The early historic evolution of the transport systems in Germany and Japan was formed by different political conditions and was specifically shaped by fundamentally different physical preconditions: Large parts of Germany are landlocked, and as a result the country’s transport infrastructure is characterized by intensive land transport interaction with its neighboring countries. Japan consists of islands which—in addition—are largely characterized by a challenging mountainous topography. In both countries, the transport systems underwent fundamental changes in the last 150 years, specifically with the advent of railways and automobiles. Hence, disruptions and revolutions in the transport sector are not new to Germany or Japan. However, in the case of both railways and automobiles it took decades until the new technologies unfolded their potential and reached their peak. This is partly due to the fact that there is always a multidimensional transport system heritage, ranging from physical infrastructures, through the legal framework, to societal, cultural and psychological settings. Vehicle automation may represent a similar revolution in the transport sector in the long-term. However, the speed with which this transition takes place likely depends on the number of required changes in the existing transport system heritage. While road vehicle automation may not require much adaptation in the physical infrastructure (which is still unclear), there are obviously fundamental changes as regards other dimensions of the transport system (e.g., the regulatory framework or digital infrastructure). The historic review of technological transitions in transport in Germany and Japan suggests that it may well take many decades to overcome the inertia of the transport system.

Table 1 Key figures on demography and settlement patters [36, 37, 71, 114]

	Germany	Japan
Total population	83 million (2020)	126 million (2020)
Proportion of population under 20	18% (2020)	16% (2020)
Proportion of population 20 to under 60	53% (2020)	49% (2020)
Proportion of population 60 and over	29% (2020)	35% (2020)
Proportion of population in cities under 100.000 population	68% (2020)	29% (2020)
Proportion of population in cities with 100.000 to under 1.000.000 population	22% (2020)	47% (2020)
Proportion of population in cities with 1.000.000 population and more	10% (2020)	24% (2020)
Population density (persons/hectare) in urbanized areas	54 (2013)	67* (2020)
Number of municipalities	10,787 (2021)	1,741 (2021)

* Population density of Japan is that of the densely inhabited districts

3 Demography and Settlement Patterns

3.1 Comparative Statistics

3.2 Germany

After centuries of high birth and death rates, as in other European countries, death rates in Germany declined substantially from the second half of the 19th century, while birth rates continued to be high [13]. Hence, this period was characterized by strong population growth superimposed with urbanization due to industrialization in urban areas. As a consequence, most German cities grew unprecedentedly during this era, for example Berlin by factor 10 [49], Aachen by factor 5 [110], and Essen grew by a factor of 100, partly due to incorporation of neighboring villages [127]. Despite such discrepancies in urbanization, growth was not concentrated in a few metropolises but spread across many cities, and the polycentric spatial structure that characterizes Germany today emerged. Many German cities took on more or less their current population size between 1850 and 1950. Thereafter they have mostly expanded in terms of space rather than population.

After WWII and following an influx of about 12 million post-war refugees, in 1950 the German population (west plus east) was about 70 million and continued to grow for another two decades [10]. This was mostly due to an annual birth surplus of about 400,000 more births than deaths. Germany reached a population of about 80 million around 1970—approximately the population it still has in 2022. However, birth rates started to drop drastically in the 1960s, and since around 1970 the relation of births and deaths has reversed, with a continued surplus of deaths over births of up to 200.000 in Germany per year. Since then, shrinkage of the German population was offset by immigration, which took place in several waves. The first waves (1960 and 1970s) mostly included migrants from southern Europe and the Mediterranean. Later waves were fueled by migrants from Eastern Europe and the former Soviet Union (1990s) and other EU countries, as well as the Middle East and Africa (after 2010). Today, about a quarter of the German population has a family background of international migration [10].

As immigration was mostly concentrated in urban and economically well-off rural areas, some rural areas—mostly, but not only, in eastern Germany—are severely affected by aging and shrinking of the population. For Germany as a whole this is not apparent yet, but this is likely to change as the 'baby boomer' generation (born between 1955 and 1969)—which currently still makes up a large part of the workforce—will retire in the next decade.

The aging of the population and an increasing proportion of senior single- or two-person households also contributes to increased consumption of living space per capita in Germany, which has grown from 33 m^2 per person to over 45 m^2 per person between 1990 and 2020 [38]. But declining household sizes and growth of living space per capita is not only a phenomenon caused by aging; it prevails in all age groups. This has contributed to declining population densities in built-up urban areas in Germany in recent decades, despite urban planning efforts to increase urban densities in order to curb land consumption for settlement. Overall, today Germany has average European population densities which continue to decline, even as metropolitan areas grow in population because of continued sprawl and suburbanization [71].

3.3 Japan

Japan had a population of 34.8 million in 1872, at the beginning of the Meiji era, but this began to grow rapidly, reaching 51.3 million in 1913, at the beginning of the Taisho era, 72.1 million by the end of WWII in 1945, and peaking at 128.1 million in 2008 [116]. Since then, Japan's population has been plummeting, and—using medium variant projections—is predicted to decrease to 83.2 million by 2070 and to 50.56 million by 2115 [95]. Japan is thus poised to experience a phenomenon without precedent in the history of human civilization: a population that, after a century of growth, undergoes a century of decline and then returns to where it began [80].

Transformative changes are apparent not only in Japan's total population, but also in the age distribution of its citizens. In 1970, at the heart of Japan's rapid-growth era, the proportions of the population represented by young people (below 15), working-age people (15–64), and older people (65 and above) were 23.9%, 69.0%, and 7.1% respectively, but by 2020 these numbers had shifted to 11.9, 59.5, and 23.6% [114]. The prediction for 2050 is 10.6, 51.8, and 37.7% [95]. This rapid depopulation and aging, unprecedented in world history, is a natural consequence of two trends: the rapid demographic transition Japan experienced as a late-emerging developed nation, and a total fertility rate that, for many years, has fallen well below the population-replacement level. Looking at households, as of 2020 Japan had 54.1 million households, of which 35.7% were one-person households and 55.9% were nuclear families; by 2050, the number of households is expected to fall to 50.8 million, of which some 40% will be one-person households—with senior citizens accounting for more than half [96]. Thus "parents-and-children" households, traditionally the most common variety, are becoming a minority, and will soon be outnumbered by senior citizens living alone.

An aging society with declining birth rates will soon find itself short of workers, and around the time of the bubble economy in the late 1980s, Japan attempted to compensate for this shortage by accepting foreign laborers. At present, the number of foreign nationals in Japan is estimated to be 2.7 million; 2.2% of the population in 2020 [114]. In Japan, "immigrants" are distinguished from "foreign workers". Foreign nationals working in Japan are accepted only for limited periods of time; unlike the U.S., Canada, and Australia, Japan has no system for admitting foreign nationals or their families as permanent residents (that is, immigrants) in a systematic way each year.

As for the geographical distribution of the Japanese population, after WWII, residents of rural Japan flocked to cities to study and work; the rural populations of Eastern and Western Japan were absorbed primarily into the Tokyo, Nagoya and Osaka areas, respectively. In Europe, foreign workers supported post-war growth, but in Japan it was this internal population migration that supported the growth of cities.

A characteristic feature of Japan's geographical population distribution is the prominent concentration of the population in cities. Of Japan's 47 prefectures, Tokyo is the most densely populated, with 6,402.6 persons per km^2 in 2020—some 19 times the national average of 338.2 persons/km^2. Tokyo is followed by Osaka and 5 other prefectures with populations exceeding 1,000 persons/km^2. At the other extreme, there are four prefectures with fewer than 100 persons/km^2: Kochi, Akita, Iwate, and Hokkaido, whose population densities are 1/66, 1/78, 1/81, and 1/96 that of Tokyo [114]. Incidentally, we note that the 23 wards of Tokyo, which had received a net annual influx of residents for many years, crossed-over to a net outflux in 2021 [115]. This, however, did not reverse the overall trend of increasing concentration of population in the Tokyo metropolitan area and is just one indication of a trend—driven by the COVID-19 pandemic and the rise of remote working—that may shape the distribution of Japan's population in coming years.

When comparing municipal populations and population densities in Japan and Germany, the substantially different total number of municipalities (*Shi-Chō-Son* in Japan; *Gemeinde* in Germany) must be taken into account (Table 1). Both countries have undergone a long history of reducing the number of municipalities, with the objective of providing basic services such as education, police, administration etc. effectively and efficiently [78, 108]. This, however, has led to far fewer municipalities in Japan relative to Germany, which are also about ten times larger than their German counterparts [60]. As a result, Japanese municipalities are often much more heterogeneous with regard to land use, population densities and transportation network characteristics.

3.4 Comparative Conclusions

Current and future demographic trends in both countries seem to align well with vehicle automation. Firstly, there is the aging and long-term shrinkage of the population in Japan, which is a global forerunner when it comes to such demographic change, and in Germany, which is among the most rapidly aging countries in Europe. As a consequence of aging, an imminent lack of workforce is inevitable, and replacing human drivers through automation technologies is an obvious approach to address this challenge. Secondly, aging populations are characterized by an increasing proportion of travelers with mobility impairments, even if these may occur at a later age in the future. Travelers with mobility impairments may be among those who benefit the most from automation technologies if they are relieved from the task of operating vehicles. Thirdly, despite high overall urbanization rates, there is a trend towards smaller household sizes and declining urban population densities due to sprawling suburbs. This is very likely associated with more individualization of travel demand, i.e., mobility patterns are likely to be spread out more in space and time in the future. This favors low-capacity vehicles over high-capacity vehicles and may thus go hand-in-hand with vehicle automation. This is because replacing drivers makes more economic sense for low-capacity vehicles where driver costs represent a larger share of the total costs relative to large vehicles. Overall, against the background of these demographic trends, Japan and Germany appear to be predestined to move forward on the path of vehicle automation, as their aging societies are likely to benefit from its potential in many respects.

4 Road Transport—Policy, Governance and Regulation

4.1 Germany

Responsibilities for planning, building and maintaining the public road network in Germany closely follow the political structure of the Federal Republic. According to the Federal Trunk Road Act (FStrG)—officially enacted in 1953—federal trunk roads are public roads that form a coherent transport network and are intended to serve long-distance transport [15]. A distinction is made between federal motorways (usually grade-separated) and federal roads. Infrastructure expansion planning for federal trunk roads is partly embedded in European infrastructure development planning. The core strategic document is the Federal Transport Infrastructure Plan (Bundesverkehrswegeplan, BVWP), which covers all investments by the Federal

Government in its transport infrastructure, not only construction and expansion, but also maintenance and renewal [21]. Since 2005, federal highways are subject to road tolls for heavy goods vehicles. Since then, the toll system has been gradually expanded to cover substantial parts of the remaining federal roads network. Beyond this, the initially introduced restriction of road tolls to motor vehicles or vehicle combinations with a total permissible weight of 12 tons or more has been lowered to 7.5 tons since October 2015. A toll for passenger cars in Germany was discussed since the 1990s and formally introduced on January 1, 2016. But the respective law did not come into force because the European Court of Justice (ECJ) held that it is incompatible with European Union (EU) law.

Responsibilities for the remaining road network are regulated by state road laws. As a general rule, the responsibility for road construction and maintenance for state roads lies with the respective federal state, for county roads with the respective county, and for local roads with the respective municipality. Private road infrastructures and public private partnerships (PPP) in road infrastructure construction and operation are a matter of ongoing political debate. So far, only a very small number of projects have been realized.

The legal framework for traffic regulations, liability, penalties and fines, driving suitability, vehicle register and driver's license register is provided by a federal law, the Road Traffic Law (StVG). This was first introduced in 1909, and more than 100 years later the current law still contains much of the original version, exemplifying the longevity of regulatory frameworks despite fundamental technology transitions in road transport [18]. The most important specific provisions for the use of public roads as well as the 'rules of the road' are contained in the Road Traffic Regulations (StVO) [17]. The StVG thus delegates the creation of concrete regulations to ensure the safety and ease of road traffic to the level of legal ordinances. In addition to the StVO, the Federal Government has issued a General Administrative Regulation on the German Road Traffic Regulations (VwV-StVO) [23]. These contain explanations for the competent authorities on the practical interpretation of the StVO. The VwV-StVO do not themselves have the quality of a legal norm, but they do bind the authorities. This is particularly important when it comes to the application of discretionary regulations, which is the case with a number of the central regulations of the StVO. This construction—and specifically the overall stated objective of Road Traffic Regulations to ensure safety and ease of road traffic—has triggered a broader debate on whether it favors motorized road vehicle use compared to other modes of transport, and creates legal obstacles to a transportation policy aiming at more sustainable and safer mobility options [93]. StVG and StVO are regularly amended. Two amendments of the StVG in 2017 and 2021 were specifically dedicated to address topics that emerged in the context of connected and automated driving (CAD)—to enable the integration of automated driving as a new principle into the regulatory framework for road traffic (2017), and to support the deployment of fully automated vehicles on German roads (2021).

4.2 Japan

In Japan, the Road Law stipulates the road significance and type, management entities, procedures of route designation, certification and abolition, and allocation of cost burden required for road management. The Road Law specifies four types of roads for public traffic: National Expressways, National Highways, Prefectural Roads, and Municipal Roads. Generally, the Minister of Land, Infrastructure, Transport and Tourism (MLIT) is the road administrator for National Expressways and National Highways within designated sections. For National Highways outside the designated sections and Prefectural Roads, the prefecture or designated city is the road administrator. The respective municipalities are the road administrators of Municipal Roads. An expressway company may, with the permission of the MLIT, construct or improve toll roads and act on behalf of the road administrator for certain authority. In 1987, an arterial high-standard highway network plan was approved to develop National Expressways and National Highways with access control of approximately 14,000 km, and the progress rate at the end of fiscal year 2021 reached approximately 87%. The approximately 1,100 km expressway between Tokyo and Fukuoka constitutes the Asian Highway Route (AH1) that was adopted by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) [90].

In the 2013 revision of the Road Law, a road inspection cycle was established from the viewpoint of preventive maintenance, based on the current situation of aging road infrastructure that was constructed predominantly during the post-war high economic growth period of the 1960 and 1970s. The enforcement and guidance for appropriate routing of heavy vehicles that cause road deterioration are being strengthened.

The Road Traffic Act stipulates measures to prevent danger on roads, and ensure the safety and smoothness of other traffic. Specifically, it stipulates the driver's license system, traffic rules, penalties, and fines. The Road Transport Vehicle Law stipulates automobile ownership, safety regulation, and a periodical vehicle inspection system. The Road Transportation Law and Freight Car Transportation Business Law regulate the automobile transportation business.

In recent years, the Road Traffic Act, under the jurisdiction of the National Police Agency, and the Road Transport Vehicle Act, under the jurisdiction of Road Transport Bureau of MLIT, have been amended to enable automated vehicles to travel on public roads (for a more detailed discussion concerning this legal reform, see chapter "Governance, Policy and Regulation in the Field of Automated Driving: A focus on Japan and Germany"). In addition, the embedded facilities that support automated driving have been added to road accessories in the revised Road Law.

4.3 Comparative Conclusions

Despite many differences in detail, the regulatory frameworks of the road infrastructure in both countries share many similarities. There is a hierarchical road network

Table 2 Key figures on the physical extent of the federal highway infrastructure [19, 89]

	Germany	Japan
Federal/National highway network length (km)	51,027 (2017)	52,243* (2020)
Federal/National highway network km per capita	0.0006 (2017)	0.0004* (2020)
Federal/National highway network km per km^2	0.143 (2017)	0.138* (2020)

* Roads less than 5.5 m in width have been excluded from the statistics

system ranging from federal highways to municipal roads, with responsibilities for the respective administrative levels. At least for the federal road network, there is high-level and long-term planning looking several decades ahead. In combination with the enormous financial investment and sunk costs of building the infrastructure, this is one important component of the inertia of the transport system when it comes to all aspects associated with the infrastructure hardware. This emphasizes potential barriers to vehicle automation if alterations or upgrades of the physical infrastructure are required in order to enable vehicle automation. As for the organization of road traffic through road traffic regulations, it should be noted that some parts of the regulations are even older than large sections of today's road network. Hence, there is also substantial inertia in the regulations. Nevertheless, both countries have taken the first regulatory steps to enable automated driving, illustrating the ambition to at least overcome the regulatory barriers to automation as soon as possible.

5 Road Transport—Infrastructure Supply

5.1 Comparative Statistics

See (Table 2).

5.2 Germany

The modern German road network—urban and interurban—was predominantly shaped in the 20th century. While in some cases modern roads were built on or extended street layouts from ancient or medieval periods, the majority of today's roads are a result of 20th century planning. This applies to urban roads as a result of the spatial extension of settlement areas in the last century, as well as to interurban roads, as the planning of the modern interurban road network was ignited by the advent of the automobile. The layout and design of the vast majority of streets in Germany today reflects post-WWII planning [106].

In transport planning in Germany from the 1950s through to the 1970s, the car was clearly center stage, and the paradigm of the "car-oriented" city dominated urban infrastructure planning. In the central cities, parking on historic market places or other public spaces was commonplace. There were widespread plans for high-capacity urban roads, in many cases freeways and even freeway intersections in central neighborhoods of major cities such as Munich or Berlin [120]. Likewise, plans for suburban neighborhoods aimed to facilitate vehicular travel. Specifically, during the 1960s, when these paradigms dominated and funding for road construction was abundant, and during the 1970s, when the earlier plans were carried out, such plans were implemented. Much of the heritage of the era of auto-oriented planning such as inner-city parking structures and urban freeways, which still largely shape automobile infrastructure in German cities today, originate from that era. Examples that epitomize both the philosophy of auto-oriented planning in the 1960s and the paradigm shift that has taken place since then, are elevated freeways in the city of Ludwigshafen (built in the 1970s and torn down from 2020 onward [2]), and a city-center parking garage in Aachen (built in the 1960s and torn down in 2021 [111]). Since the 1980s, planning paradigms gradually changed. Examples are pedestrian areas in city centers which became commonplace in the 1980s, and a reinforced focus on cycling infrastructure from the 1990s. Since 2007, official German urban street design guidelines place a higher value on the quality of the urban space than on vehicular flow [42].

Today, German cities are characterized by a street infrastructure that includes a mix of design elements ranging from the era of auto-oriented planning to today's planning paradigms. Despite German expert self-assessment of road infrastructure which ranks Germany only on position 20 globally with regard to road quality [119], it is fair to say that the automobile infrastructure is relatively good in Germany. Drivers find favorable conditions, which are exemplified by many interurban roads which provide for high driving speeds, a lack of a general speed limit on the "Autobahn", and an ample supply of parking except in dense urban neighborhoods. Parking policies (as well as parking costs) also represent a good example for the continued policy paradigm of accommodating cars in cities rather than banning them: While public parking spaces are gradually removed in numerous urban areas, parking requirements provide for a growing inventory of private parking at the same time [112]. Travel mode-specific accessibilities are another indicator for good conditions for driving relative to using other modes: With regard to the number of inhabitants one can reach within a given travel time budget from almost any location in Germany, including central cities, the car outperforms other modes of travel by far. In simpler terms: The car is mostly the fastest and most convenient mode of passenger travel in Germany.

5.3 Japan

The intercity road network and major urban roads in Japan were formed after WW II. For topographical reasons, some intercity roads follow the same routes as ancient trunk roads. From 1940, inspections of the existing roads were carried out as well as assessments of the needs for road infrastructure. These formed the basis for road development planning, and most of the road infrastructure currently in use was constructed after WW II.

In 1957, the number of registered automobiles exceeded 2 million, although this number was only approximately 130,000 just after WW II. Thus, the era of motorization had arrived in Japan. However, the road infrastructure at that time was so poor that only 23% of the first-class national roads were paved [89]. Ralph J. Watkins, who was invited by the Japanese government to investigate and plan the Meishin Expressway in 1956, stated in his report, "The roads of Japan are incredibly bad. No other industrial nation has so completely neglected its highway system."

In 1953, the "Act on the State's Tentative Financial Measures for Road Construction Projects" was enforced, and fuel and other automobile-related taxes were consequently used for road development. As a result, stable financial resources were secured and five-year road development plans, from the 1st to the 11th, were created and executed. Thus, significant nationwide road development was achieved for more than 50 years. During this period, major roads have been paved and over 10,000 km of expressways have been developed nationwide.

As of April 2021, 12,082 km of the Arterial High-standard Highway, which is 86% of the planned approximately 14,000 km extension, has been developed in Japan. However, when compared internationally, Japan's road infrastructure is inferior [57], especially high-standard highways. First, the network is discontinuous, and many sections have been provisionally constructed with two lanes. In other countries, expressways have 4 and 6 or more lanes for approximately 75% and 25% of their length, respectively. However, in Japan, 38% of the length is 2 lanes, and the extension of 6 lanes or more accounts for only 6%. Second, the travel speed is low. A comparison between the average speed on roads connecting major cities reveals speeds of 80 km/h or more in European countries, 95 km/h in Germany, and 60 km/h in Japan. This is partly due to speed limits; the general speed limit on interurban roads in Japan is 100 km/h; however, this varies between 80 and 120 km/h, according to local conditions. An additional reason for low travel speeds in Japan is presumably the discontinuous sections of expressways, provisional two-lane expressways, and sections with steep gradients and topographical restrictions that have low speed limits. Third, there are many tunnels and bridges, resulting in high construction and maintenance costs. Approximately 12.9% and 15.8% of the length of expressways in Japan consist of tunnels and bridges, respectively, which are expensive to construct and maintain. Approximately 50 years have passed since the construction of this infrastructure, and large-scale renewal is expected to be required in the near future.

Conversely, from a global perspective, the advantages of Japan's expressway infrastructure are as follows. First, a nationwide unified Electronic Toll Collection (ETC) system has been introduced and expanded, and one on-board unit can be used even when different expressway company routes are used. In addition, travel demand management (TDM) through toll rate measures has become easier. Second, rest facilities provide a high standard of service. Since the privatization of the Japan Highway Public Corporation in 2005, expressway companies have endeavored to improve the service level of rest facilities. In addition, as a disaster prevention base, the number of expressway rest facilities that also support activities such as rescue and medical care in the event of a large-scale wide-area disaster is increasing.

5.4 Comparative Conclusions

As for the quantity and quality of the road network there are noteworthy differences between the two countries. This particularly applies to the federal interurban highway network, where use of vehicle automation is likely to become widespread first. Relative to the population, the German federal highway network is denser, allows for higher driving speeds and there is no tolling system implemented so far. These are factors which may contribute to a stronger motivation to move towards automated vehicular flow in Japan: The infrastructure, which—due to the country's topography—is characterized by tunnels and bridges and is therefore much more expensive to construct and maintain, is more constrained when it comes to capacity and cannot easily be extended. Vehicle automation—if implemented as connected and cooperative automation—comes with the promise of making better use of existing infrastructure capacity. Due to the restrictions described above, the Japanese expressway infrastructure may thus benefit more from automation than Germany's. Moreover, with lower travel speeds due to speed limits and an electronic tolling system in place, there is already stronger traffic control in place in Japan relative to Germany. However, the small number of lanes and narrow shoulders on expressways may hinder the spread of automated driving in Japan. Hence, Germany may not only benefit less with regard to traffic flow from automation, it may also have a longer journey to transition from today's human driving habits to automated homogeneous vehicular flow.

6 Public Transport and Transport Services—Policy, Governance and Regulation

6.1 Germany

Planning, operation and financing of public passenger transport in Germany are organized in a comparatively complex manner. For a better understanding, it is necessary to differentiate with regard to the mode of transport and the responsible governance level within the context of a federal republic integrated into the structures of the EU.

Long-distance rail transport is dominated by Deutsche Bahn AG (DBAG), a company fully-owned by the Federal Republic of Germany and organized under private law. It is provided on an economically self-sufficient basis [41]. Other domestic and foreign railroads are in principle free to offer long-distance passenger services. However, this has so far been practiced only to a modest extent. Potential competitors regularly complain about high barriers to market entry. As an infrastructure company, DBAG also operates around 87% of the German rail network [19]. The federal states are responsible for organizing regional rail transport. In their local transport laws, they have assigned this function either to themselves or to municipal special-purpose associations. These in turn contract and finance the local transport services in cooperation with the respective state planning authorities [24]. A whole range of companies, which may be privately- or publicly-owned, act as providers of these ordered services.

The legal basis for local road passenger transport in Germany is the Passenger Transport Act (PBefG), which applies to the paid or commercial transport of passengers by streetcar, trolleybus and motor vehicle [16]. According to this law, for-profit services and specifically scheduled public transport supply are subject to approval. The responsible authorities are the counties or cities. As a rule, these services are operated by county- or city-owned public transport companies, sometimes also by private transport companies. In practice, they use a wide range of means of transport, such as streetcars and local, city and regional buses, and in large cities often also subways or light rail systems. In addition, special forms such as dial-a-ride buses or dial-a-ride shared cabs, and "exotics" such as suspension railways or people movers are also included in public transport. The PBefG was amended in 2021 in order to accommodate new forms of mobility services like private- or shared vehicles for hire if they replace, supplement or consolidate conventional public transport services [129].

Most local public transport authorities are also organized in transit districts (Verkehrsverbünde) or tariff associations, in which all means of transport can be used with one ticket. These are special-purpose associations to which the public transport authorities have delegated certain management tasks, for example, the preparation of local transport plans, in addition to the coordination of fares [65]. The legal basis is provided by the relevant local transport laws of the federal states. Some of them have made these districts or associations mandatory by law, while others leave their formation to voluntary decisions of public transport authorities [103]. Services and payments in passenger transport are often regulated in a transport contract.

The distribution of responsibilities among different actors in a multilevel governance system [104] such as that which has emerged in Germany does not always lead to satisfying results, especially when origin–destination patterns cross jurisdictional boundaries. Cost- and revenue allocation, different interests, and different political power structures (including different transport policy priorities) create tensions and coordination challenges between organizations working at the same level of governance within different jurisdictions (horizontal coordination). The same holds true for vertical coordination, since scale differences may drive different perspectives, objectives and priorities.

6.2 Japan

In order to understand the characteristics of public transport in Japan, the underlying paradigm of private management and fare revenue as the economic basis for the services is important. In Japan, there is a strong belief that transport is a private business that can make a profit and loss, apart from the state-owned railways and the state-owned airlines, which were privatized in the 1980s.

Japan National Railway (JNR) was established as a public corporation in 1949, but was unable to keep up with changes in the industrial structure associated with rapid economic growth from the late 1950s, and fell into a deficit from 1964; in 1986, a bill related to JNR reform was submitted to parliament, and in 1987, division and privatization were implemented [83]. Excluding the impact of COVID-19, the listed Japan Railway (JR) companies are profitable. In addition, the private railway companies have generated revenues through diversified management, including real estate and lifestyle service businesses.

Against this background, the idea that it is better for transport to make a profit as a private-sector business is strongly entrenched in Japan. This is known as the "independent profit-making system" and is the basic concept of public transport in Japan. Laws were amended in the early 2000s to bring more market principles into transport. From the perspective of enabling operators to develop their business flexibly based on management decisions and to improve the efficiency and vitality of their business, the Railway Business Law was amended to ease the freight railway business exit from a permit system to a prior notification system (2000), and the Road Transport Law was amended to ease bus and taxi entry from a license system to a permit system, and exit from a permit system to a prior notification system (charter buses in 2000, passenger buses and taxis in 2002) [91].

Another characteristic of public transport in Japan is its vertically divided organization, which impacts on the coordination between municipalities. In recent years, local authorities have increasingly become the operating body for local transport. However, there are many problems, such as routes that do not cross the boundaries of municipalities. With privatization and an increased focus of the management on profitable services, there has also been a decline in the number of buses in rural areas, and a withdrawal of bus services. Increasingly, local authorities are taking the lead in operating community bus services after private operators have withdrawn [92].

The background of more municipalities beginning to introduce community buses is the Law on the Revitalization and Regeneration of Regional Public Transport (2007), which sets out a system to promote the formulation of a "comprehensive regional public transport coordination plan" to be initiated by the municipalities. However, many local authorities have difficulties responding to the given responsibilities in local transportation planning, in terms of inadequate institutional structure, personnel, and budget [117]. Besides, regional associations such as the Transport Union (Verkehrsverbund) in Germany have not flourished in Japan. As a result, many community buses are set up with routes that do not straddle the boundaries of the municipalities, which does not always match the user flow-lines. It remains to be seen whether this law will function effectively.

6.3 Comparative Conclusions

Regarding the organization and regulation of public transport, the main difference between Germany and Japan refers to the role of private companies and the belief in market forces when it comes to the provision of public transport. In Germany—as in much of continental Europe—there is a historically-rooted and deeply ingrained belief in state intervention in transport, and specifically public transport. Despite deregulation and a simulation of competition through a complex system of tendering and procurement, public transport is essentially a state-run and heavily subsidized enterprise. One could say that in Germany the starting solution for public transport provision is that of a public enterprise with some market elements. In Japan, it is the opposite: public transport—as other domains of the transport sector—is a private business with some state intervention in those cases where it does not work without. As for vehicle automation, these different approaches in public transport provision raise different expectations regarding the introduction of automated public transport services: It seems likely that private stakeholders will be more dominant in initiating automated public transport services in Japan than in Germany, where the activities of the public sector are likely to play a bigger role.

7 Public Transport and Transport Services—Infrastructure and Supply

7.1 Comparative Statistics

See (Table 3).

Table 3 Key figures on the physical extent of the rail network in Germany and Japan [19, 29, 45, 113]

	Germany	Japan
Total rail network length (km)	38,394 (2019)	27,311 (2015)
Total rail network per capita (km/capita)	0.00046 (2019)	0.00021 (2015)
Total rail network km per km^2	0.11 (2019)	0.072 (2015)

7.2 Germany

Modern public transport in Germany originated in the 19th century when rail transport—urban and interurban—started to be widespread. Hence, in its early days, public transport was mostly rail-based and initiated by private investors. From the beginning of the 20th century, the state took over, and since the mid-20th century many tramway systems—which at their peak were also present in smaller cities—stopped operating and were replaced by buses or high-capacity urban rail such as subways and metro rail [47]. The latter, however, never reached the territorial coverage that tramways once offered, and are concentrated in high-density urban areas and corridors.

Today, rail-based public transport—commuter rail, subways and tramways—represents the backbone of public transport in large cities. All except four German cities over 200.000 population have rail public transport [46]. Smaller cities, rural areas or the low-density areas of large cities are usually catered for by buses. Since the 1990s there is also a tendency to re-introduce (e.g., Saarbrücken) urban tramways, or re-extend remaining tramway networks (e.g., Karlsruhe) in German cities. This, however, takes place at a much lower scale compared to other European countries such as France or Spain. There are also many examples where the re-introduction of urban tramways—often favored by planners and politicians—were declined in local referendums [46].

In large German cities, specifically those areas with rail public transport, the quantity and quality of public transport in terms of travel times and service frequency can generally be regarded as good. This is exemplified by the public transport modal split, which in large cities (population over 100.000) with urban rail is about twice as high as in cities without. Despite good coverage of public transport, even in large cities—and of course even more so in rural areas—travel speeds by public transport are in most cases well below those of the car [46].

As in other parts of the world, new flexible transport services based on street motor vehicles—mostly shuttle buses—have emerged in Germany. There are two strands to this development: First, conventional—often state-owned—public transport providers sought new options to provide public transport in low demand areas. In such areas, ridership has declined in recent years due to increased car ownership among seniors, and fewer school students due to demographic change. The cost of offering basic public transport services in such low-demand areas has increased. Flexible transport services which operate on request and often utilize smaller vehicles are believed to be a solution in such a situation [58].

Secondly, private entrepreneurs hoped for a business case by offering flexible transport services in high-demand urban areas in Germany. This was inspired by business models of Uber or Lyft in the US, where private individuals offer for-profit services. These business models are not allowed in Germany due to public transport regulation (even though Uber exists as a brand in Germany, it offers a different kind of service). Nevertheless, in recent years new flexible, on-demand shuttle-like services emerged in various German cities (e.g., Berlin, Hamburg, Hannover) as an addition to existing high-capacity urban transport [27, 94]. With regard to user cost, these services usually sit between conventional public transport and taxis. While there is now—after amendments to the public transport regulation—a long-term legal perspective for such services, it is unclear if they are economically sustainable and meet expectations with regard to profitability [59].

7.3 Japan

As for public transport in Japan, before WW II, passenger transport consisted mainly of railways and trams. With post-war reconstruction, trams and buses became the main modes of transport. With motorization beginning at the end of the 1950s, and the 1964 Tokyo Olympics, trams were closed to make space for cars. In large cities with populations of one million or more, many of the tram lines became subways. Around 2000, trams began to be re-evaluated, and in some cases, such as Toyama City, the old, disused freight railway line was revived as tram, but it has been difficult to revive trams once they have been closed due to opposition from car users and other factors.

The number of public transport passengers is divided between the three metropolitan areas of Tokyo, Osaka and Nagoya, and other regional cities: in 2010, 70% of commuters in the Tokyo metropolitan area used public transport (railways and buses), and 10% used private cars. In rural Tottori Prefecture, however, public transport accounted for 7%, and private cars 74%. The national average is 33% for public transport, and 48% for private cars [121].

Deregulation around 2000 caused transport operators to withdraw from unprofitable routes, forcing local authorities to invest taxpayers' money to maintain mobility for daily life. However, many local governments lack the skills to manage public transport, making it a difficult task to maintain travel services for vulnerable groups who cannot drive. In towns, villages and rural areas where fixed-schedule buses are not economical, on-demand buses have been introduced in some cases, operated by local authorities according to user-demand. However, as public transport in the rural region is not a profitable business to begin with, the more passengers the on-demand bus service attracts, the more it puts pressure on the local government's finances.

Private transport services for profit such as Uber have not yet been authorized due to concerns about competition with taxi services in Japan. In addition to lobbying by the taxi industry to MLIT and the Parliamentary Association for Taxis, this is due to the idea that public transport in Japan is regarded as a private profit-making business, but that its safety should be guaranteed by the Japanese government. The idea that the government guarantees the safety of passengers is different from, for example, the US idea that safety is the responsibility of the passenger because they choose to use convenient services.

One issue specific to Japan is the shortage of bus drivers. Bus driving has become an occupation avoided by young people because of the lower-than-average wages, irregular working hours and the need for a Class 2 driver's license. There is concern that the shortage of bus drivers will accelerate in the future due to the aging of the existing bus driver population. This major social problem could be alleviated if automated driving technology improves, and the regulations are relaxed so that a regular driver's license holder can become a bus driver.

As mentioned above, public transport in Japan is based on an independent profit-seeking system. Although this may lead to improved service levels through competition, the reality is that increasing car ownership makes it difficult to continue profitable business, especially in rural areas. The voluntary curfew due to COVID-19 and the generalization of telework and online conferencing have dealt a heavy blow to public transport services, raising the question of whether and how to maintain and expand public transport, as well as the pros and cons of an independent profit-making system.

7.4 Comparative Conclusions

Despite differences in the underlying philosophies—i.e., public and state-controlled vs. private for-profit provision of public transport services—there are many analogies between the status quo, trends and challenges as regards public transport supply in Japan and Germany. Rail-based services are the backbone of public transport in major metropolitan areas, but in many smaller cities rail-based services—specifically tramways—were dismantled in the mid-20th century. Despite a recent tendency to re-introduce and extend urban rail transport to address urban transport problems, there are substantial barriers to re-introduction. However, in rural areas, providing public transport represents a major challenge, and the emerging lack of bus drivers is an additional problem. Against this background, there are two important conclusions as regards vehicle automation: Firstly, public transport providers in rural areas would benefit substantially from automation as it may help to lower the cost of providing public transport while at the same time solving the staffing challenge. Secondly, the perspectives regarding the balance of rail-based and road-based public transport in metro-areas are unclear. The question is whether road-based public transport with automated vehicles will offer a suitable alternative to rail-based transport as regards comfort and capacity, without exacerbating environmental problems. If so, this may curb the recent trend to urban rail and reinforce the focus on road-based urban public transport, possibly even with smaller and more flexible vehicles.

8 Pricing, Taxation and the Cost of Transport

8.1 Comparative Statistics

See (Table 4).

Table 4 Key figures on the cost of and expenditures for transport by car and public transport, Germany and Japan [14, 19, 28, 33, 39, 40, 79, 84, 97, 123, 124]

	Germany	Japan
Average annual vehicle tax per passenger car (local currency unit, LCU)	158€* (2016)	39,500 JPY** (2019)
Average annual vehicle tax per passenger car as percent of GDP per person per day (%)	152%* (2016)	325% ** (2019)
Cost per liter of gasoline (LCU/liter)	1.42€ (2019)	147.40 JPY (2019)
Cost per liter of gasoline as percent of GDP per person per day (%)	1.24% (2019)	1.21% (2019)
Tax as proportion of total gasoline price (%)	60% (2020)	36.5% (2019)
Average user cost per passenger km of public transport (excl. Taxis) (LCU)	0.11€ (2017)	16.6 JPY*** (2018)
Average user cost per passenger km of urban public transport as percent of GDP per person per day (LCU)	0.1% (2017)	0.1% (2018)
Total expenditure for transport and communication as proportion private household expenditure (%)	16% (2019)	17% (2019)

* The annual vehicle tax for passenger cars in Germany depends on displacement and CO_2-emissions; the average annual vehicle tax as presented here is the average expenditure per vehicle based on an income and expenditure survey

** The annual vehicle tax for passenger cars in Japan depends on displacement and environmental performance; the average annual vehicle tax as presented here is the amount for the vehicle whose displacement is over 1,000 cc and not more than 1,500 cc. The amount is reduced depending on the environmental performance. The value does not include the amount of tonnage tax

*** Calculated using the values of passenger-km and operating income for private charter buses, scheduled buses, JR, and private railways

*** *Calculated using real income and expenditures for transport and automobile related cost in worker households

8.2 Germany

During recent decades, Germans have been spending a relatively stable proportion of about 15% of their disposable incomes on transport [33] with similar proportions of income spent on transport by households of different income classes [31]. In 2013, the average transport budget amounted to 350 Euro per household per month, 90% of which was spent on automobile travel. This illustrates that ownership and use of cars constitute the most important factor when it comes to the total cost of mobility.

In 2016, the average monthly total cost of ownership (TCO) of a passenger car in Germany (including used and new vehicles) was 310 Euro. Depreciation, other fixed costs (vehicle tax, insurance, repair and maintenance) and fuel each constituted about a third of this total cost [39]. In Germany, the costs of fuel and parking represent the only marginal cost of automobile use (road pricing is a rare exception). There is little knowledge about parking expenditure in Germany, but it is evident that relative to neighboring high-income countries, parking is relatively inexpensive in German cities. In rural and suburban areas drivers usually face no costs for on-street parking. Overall, parking does not add much to the average cost of driving in Germany, and the marginal cost of driving is mostly defined by fuel costs [66].

In 2016, given a monthly mileage of about 1100 km, 310 Euro per passenger car per month resulted in total costs per passenger car vehicle km of about 30 Euro Cents per km, or marginal (fuel) costs of about 10 Euro Cents per km [39]. Considering a passenger car occupancy rate of about 1.4 this leads to car usage costs per passenger km of about 21 Euro Cents TCO, or about 7 Euro Cents with regard to marginal costs. These marginal costs are below the average cost for public transport use in Germany of about 10 Euro Cents per km (after factoring in all discounts, season tickets and single fare tickets). The costs for all other motorized modes of transport (taxis, emerging mobility services, rental scooters etc.) are substantially above that price level (50 Euro Cents per km and more) [66].

Depending on current fuel costs, taxes constituted about 50–60% of the fuel price in the last decade [1]. The largest tax component of fuel price (energy tax plus CO_2-emission levies) is a fixed amount per liter (Gasoline: 73 Euro Cents/liter; Diesel: 55 Euro Cents/liter) and only the absolute amount of the value added tax (19%) fluctuates with the total fuel price. This also means that—after accounting for inflation and increased vehicle efficiency—real tax income from fuel taxes actually declines over time. This problem is aggravated by the emergence of electric vehicles which currently pay substantially less use-related taxes and levies (only electricity tax). Hence, the introduction of road pricing in Germany in the next few years appears a likely option to compensate for the fuel tax income foregone.

While fuel taxes constitute an important source of state revenue (and are about twice as high as the annual state budget spent on the road network in Germany) [19], public transport is heavily subsidized: About 30% of the operational costs and about 50% of the total costs of public transport are covered by subsidies [11]. Hence, the total cost of public transport of about 10 Euro Cents per km is a result of strong subsidization.

According to the German consumer price index development over the last 30 years, overall transport costs increased somewhat more strongly than the average consumer price index [34]. This is mainly due to the fact that the cost of public transport usage and fuel increased above average consumer price trends. In contrast, the growth of the costs of passenger car purchases was below average price increases. Hence, overall public transport consumer prices increased more than passenger car use, with a shift in the cost of passenger car use from fixed costs to marginal costs.

8.3 Japan

In Japan, automobile taxes are imposed at multiple stages in the lifetime of vehicles: acquisition, ownership, and actual travel. At vehicle acquisition, a consumption tax and an automobile tax or a light automobile tax (environmental performance discount) are levied; during ownership, class-based automobile taxes/light automobile taxes for mini cars, and tonnage taxes apply; and, when vehicles are driven, there are multiple fuel taxes: gasoline tax and local gasoline tax for gasoline, diesel oil delivery tax for diesel, and oil and gas tax for liquefied petroleum gas. Of these, the environmental performance discount was introduced in 2019 to replace the older automobile acquisition tax; the old tax was assessed on acquisition price at the time of vehicle purchase, but the new tax, which applies to used as well as to new vehicles, is based on acquisition price but also takes fuel efficiency and other factors into account. The tonnage tax is based on gross vehicle weight at time of vehicle purchase and subsequent inspections. The class-based automobile taxes/light automobile taxes are assessed yearly based on vehicle emissions. For many years, the tonnage tax, together with fuel taxes and the now-abolished acquisition tax, were earmarked for use by the national and municipal governments primarily to maintain and construct general-purpose (non-highway) roads, but this system was discarded in 2009, and today the proceeds of these taxes are treated as general-purpose funds. Usage fees for highways are collected separately from these taxes. In general, roads in Japan are open to the public and free of charge; however, for a brief period in the mid-20th century, stretching from Japan's post-war recovery through its high-growth period, an exception was made in the form of a toll-road system to raise funds for building and maintaining a trunk network of roads connecting major cities at high speeds (see Ministry of Land Infrastructure Transport and Tourism (MLIT) [85]).

According to the Japan Automobile Manufacturers Association, initial budgeting for fiscal year 2021 shows that total tax revenue collected from automobile users in Japan—including consumption taxes on vehicle acquisitions and fuel purchases—amounted to 8.6 trillion JPY, or 8.7% of the nation's overall tax revenue of 99.3 trillion JPY [54]. As an example, to illustrate the scale of these taxes, the acquisition of one standard-sized car and its 13-year ownership would entail an automobile tax (environmental performance discount) of 21,700 JPY, a consumption tax of 410,400 JPY, class-based automobile taxes of 504,000 JPY, and a tonnage tax of 196,800 JPY [55].[1]

Let us compare the costs borne by Japanese automobile users against the cost of public transportation: According to the Annual Report on the Family Income and Expenditure Survey from the Statistics Bureau of Japan, the average monthly automobile-related cost (including purchase cost) in a household was 19 thousand JPY in 2019. Average monthly distance traveled per privately owned passenger car is calculated to be 729 km in the fiscal year 2019 [87]. Considering the passenger car occupancy rate of 1.41 in 2015, and the number of passenger cars owned by a family

[1] Conditions for calculation are as follows: Displacement: 2 L; vehicle weight: less than 1.5 t; fuel economy under JC08: 20.4 km/l (CO_2 emission: 114 g/km); vehicle body price: 2.42million JPY.

of 1.04 (Automobile Inspection & Registration Information Association [6] at the end of FY2019 the average cost per person-kilometer of privately-owned passenger cars is roughly estimated to be some 17.4 JPY. In comparison, the average user-cost per passenger km of public transport, including buses and railways, costs 16.6 JPY, and thus from a cash-burden perspective vehicle travel costs slightly more than public transport travel. Note that public-transit facilities in Japan, even if operated by public institutions, are intended in principle to be independent and self-supporting based on fare revenue; however, the reality is that many public-transit networks in rural areas of Japan are unsustainable without national or local government support. Indeed, according to 2019 data, 69% of Japanese transit-bus operators are unprofitable, and some 3.5% of all transit-bus routes (measured by distance) have been eliminated since 2007 [86].

8.4 Comparative Conclusions

Despite many differences between Germany and Japan as regards pricing private vehicular travel and setting prices for public transport (e.g., through subsidization) there are relevant analogies: Firstly, depreciation—or the cost vehicle purchase respectively—represents only one component of the costs of private motoring, which comprise a wide range of different fixed and variable cost components. Hence, an increase in vehicle purchase costs due to automation technology is not linearly an increase in the cost of driving. Many other factors come into play and—depending on other framework conditions—operating automated vehicles may not be much more costly than conventional vehicles. Secondly, the car, i.e., the mode that today often offers the most individual comfort and higher overall travel speeds in most everyday travel situations except in high density urban environments, costs as much or more on a per-km basis than public transport. The population of travelers is very heterogeneous and some are capable of opting for high-cost high-speed modes, while others rely on low-cost modes with lower travel speed and comfort. Today's mode use patterns emerge as a result of the interplay between these properties of the transport system and the population's needs and economic capabilities. It remains to be seen how automated vehicles will be positioned in this spectrum of cost, speed and comfort in a future transport system, and which socio-economic groups in the population will benefit the most from vehicle automation.

9 Automotive Industry as an Economic Factor

9.1 Comparative Statistics

See (Table 5).

Table 5 Key figures on the economic relevance of the machinery and transport equipment industry [26, 128]

	Germany	Japan
Machinery and transport equipment (value added, % of GDP)	9% (2018)	9% (2018)
Number of passenger cars produced per capita 1961	25 (1961)	3 (1961)
Number of passenger cars produced per capita 1991	58 (1991)	79 (1991)
Number of passenger cars produced per capita 2019	56 (2019)	66 (2019)

9.2 Germany

In Germany, the contemporary automotive industry is a key industrial sector and a major economic factor. The companies Daimler and Benz, both located in today's southern German state of Baden-Württemberg and combined in the 1920s to Daimler-Benz, were among the first companies to start industrial production of automobiles at the end of the 19th century. Volkswagen, today the second largest automobile manufacturer worldwide after Toyota, was founded in 1937 by the German Nazi regime. Volkswagen production started shortly thereafter in the rural municipality of Fallersleben, which today is part of Wolfsburg, a city that developed around the Volkswagen production plant in what today is the northern German state of Lower Saxony. Today, the two regions, southern Germany and parts of Lower Saxony, are still epicenters of the German automotive industry. However, the automotive industry—including automobile manufacturers and suppliers—is a key player for the regional economy almost everywhere in Germany. For example, in 2016 there were a total of 41 final assembly plants distributed throughout Germany [12].

Before the COVID-19 pandemic, in 2019, the total turnover of the German automotive industry was about 440 billion Euros, equivalent to about 13% of the German GDP or almost 25% of the total industry turnover in Germany [35]. Vehicle manufacturers account for about three quarters of this automotive industry turnover. Consequently, the automotive industry is of paramount importance for the German job market. In 2016 the automotive industry employed about 800.000 individuals directly; about 2% of the German workforce [12]. About the same number of employees depend indirectly on the automotive industry, e.g., in the chemical or textile industries. With this relevance of the automotive industry for the job market, Germany clearly stands out in Europe: almost half of the European jobs that directly or indirectly depend on the automotive sector are to be found in Germany.

Germany's automotive industry is strongly and increasingly international in both production and sales, and its growth is driven by the global market: While in 2008 about half of the 11 million cars produced by German manufacturers were produced in Germany, this figure reduced to about a third in 2016, when German manufacturers produced about 16 million vehicles. Likewise, the proportion of German vehicles sold abroad increased from 80 to 85% in the same period. Thereby, German car makers—specifically the brands Mercedes-Benz, Audi and BMW—specialize in high-margin luxury vehicles. As for sales in this vehicle segment, German manufacturers have a large lead in the global car market, and much of the recent increase of the automotive industry turnover was driven by the growth of SUV sales [12].

As a consequence of this strong position of the German automotive industry and its key role for the national economy, it is no surprise that automotive industry lobbying is a major influential factor in German transport and industrial politics [9]. For example, there is a long history of lobby intervention at the national and European levels opposing stricter CO_2 emission standards, which supposedly specifically affect German car makers due to their focus on large high-margin vehicles [100]. Germany's aspiration to be the first country to pave the legal way to enable operation of automated vehicles on public roads is also linked to the relevance of the automotive sector.

9.3 Japan

Japan's automotive industry ranks among the nation's most significant industrial sectors. In 2019, the industry shipped 62.3 trillion JPY worth of product and accounted for some 18.8% of all Japanese manufacturing. In 1985, the corresponding figures were 27.7 trillion JPY and 10.4%, showing that, over the past 30 years, the automotive industry has increased in stature in Japan [52]. Large automobile manufacturers have developed together with the region where they are located—a so-called business castle town—and constitute an important part of the local economy. For example, Toyota Motor's headquarters is located in Toyota City, Aichi Prefecture, and its group companies, including parts suppliers, such as Toyota Industries Corp., Denso Corp., AISIN Corp., and Toyota Auto Body Co., Ltd., are dispersed throughout the neighboring cities.

The automotive industry forms part of a wide-reaching family of interrelated industrial sectors, together with associated industries such as manufacturing and procurement, sales, service, and shipping. At present, workers in automobile-related industries in Japan number 5.42 million, or 8.1% of Japan's total workforce [52]. The impressive breadth of the automotive industry's reach is also reflected in the high values of *power of dispersion* computed from input–output tables. Power of dispersion are economic indices used to quantify the relative importance of specific industrial sectors; the influence coefficient for a given sector is defined as the overall production impact—on the economy as a whole—induced by 1 unit of final demand in that sector, normalized such that the average industrial coefficient of all sectors takes the value 1. Based on data contained in the Updated *Input–Output Tables 2014* released by Japan's Ministry of Economy, Trade and Industry (METI), the three most influential subsectors of Japan's automotive industry are passenger vehicle, other vehicles and automobile components and accessories.

Although this analysis provides solid quantitative evidence for the centrality of the automotive industry in Japan, perhaps even more crucial is the industry's *symbolic* importance as the modern-day representative of Japan's industries, which manufactured sophisticated products requiring extensive teamwork—or, in the parlance of modern economics, products with *integral product architectures.* The term *product* *architecture*, as discussed by Takahiro Fujimoto at the Manufacturing Management Research Center (MMRC) (See e.g., Fujimoto [43]), refers to the design and optimization of the various interfaces through which the many components of complex modern products interact. In general, product architectures may be broadly classified into two categories: *modular* and *integral*. Products with *modular* architectures consist of individual components that are largely independent of each other; a good example of a modular-architecture product is a modern desktop computer. *Integral* architectures, by contrast, describe products with highly interdependent components that must all work together in complex ways for the product to perform its function—with automobiles furnishing a prime example. In products with integral architectures, changes to any single component require changes to surrounding components; thus, bringing products to completion requires extensive and intricate teamwork. Japan's talent for just this sort of teamwork is widely regarded as one of the key drivers of the nation's international competitiveness, and the automotive industry serves as a powerful symbol of Japan's unique strengths in this area.

9.4 Comparative Conclusions

Looking at the automotive industry's relevance for the national economy, Germany and Japan stand out from other industrial countries. For both countries, global leadership in the automotive sector is highly relevant for the prosperity of the respective national economy and its national innovation system, and hence of high priority for policymakers and parts of the general public. Hence, it is clear that for Germany and Japan vehicle automation is not only—and very likely not even primarily—a transport sector issue, but more a pursuit driven by industrial sector interests: maintaining the technological lead in this regard appears to be a question of national industrial reputation and prestige, as well as of one of economic importance in order to maintain the current advantage in the global competition in the automotive sector. This may apply even more to Germany with its focus on luxury cars and a sentiment that other countries' automotive industries managed to outperform the German car industry when it comes to vehicle electrification. In Japan, however, the state tends to directly intervene in scientific and technological innovation activities, because historically, scientific independence, or technological superiority, has been an important concept in national (economic) security. In short: given the relevance of the automotive industry in both countries, political support for paving the way for vehicle automation can be expected, ranging from laying the legal foundations, to financial support for research and development (R&D) in this area.

Table 6 Key figures on travel demand and mode use in Germany and Japan [82, 98]

	Germany	Japan
Key figures on travel behavior (per person per day)		
Trip makers per day on weekdays (%)	86 (2017)	81 (2015)*
Trip makers per day on weekends (%)	77 (2017)	60 (2015)*
Trips per day, all persons (#)	3.1 (2017)	2.0 (2015)*
Daily distance, all persons (km)	39 (2017)	23 (2015)*
Daily travel time, all persons (min)	85 (2017)	56 (2015)*
Countrywide trip-based modal split on commuting trips		
On foot (%)	22 (2017)	8 (2010)
Bicycle (%)	11 (2017)	16 (2010)**
Personal Motorized Transport (PMT) driver (%)	57 (2017)	52 (2010)
Public transport (%)	10 (2017)	22 (2015)

* The values for Japan are averages for urban areas which in total account for more than 90% of Japan's population
** Includes motorcycles in addition to bicycles

10 Multimodal Transport Indicators

10.1 Comparative Statistics

See (Fig. 1).

10.2 Germany

The first German national household travel survey was conducted in 1976. For the first time, this dataset provided a systematic overview of travel behavior of German residents. In the four decades that followed, per capita travel grew considerably: While travel time per person per day increased by 25% from 68 to 85 min, daily travel distance increased by 44% from 27 to 39 km (excluding travel outside Germany). Much of this growth, and specifically the increase in travel speed which caused distances to grow more than travel times, can be attributed to increasing car ownership and use [126]. More and more people were able to afford a car, and consequently to travel longer distances. Currently, personal motor transport is used for about 57% of trips and about 75% of the daily mileage [99].

Overall, about a third of the German population uses a bicycle during the course of one week. Those who cycle use their bicycle on about a third of their trips, which translates to a national bicycle mode share of about 11%. The bicycle mode share is similar across the adult age groups and days of the week. Children and teenagers between 13–18 years show higher shares, with 21% of trips on weekdays and 14%

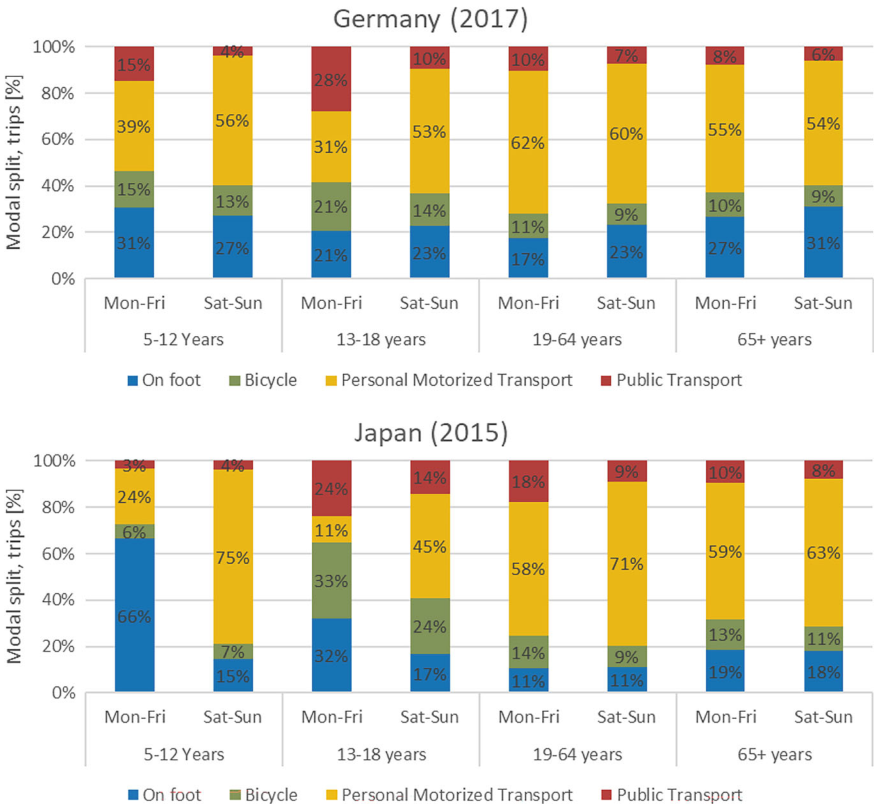

Fig. 1 Modal split (trips) in Germany (year 2017) and Japan (year 2015), distinguished by age and time of week (workday, weekend) (authors' analysis based on data from the National Travel Surveys)

of trips on weekends. The same applies to public transport, i.e., about a third of the population uses public transport during an average week, and if so, on about a third of their trips. This translates to a national public transport mode share of about 10%. Children and teenagers aged 13–18 years show the highest public transport modal split shares, using public transport for 28% of their trips on weekdays, i.e., mainly for commuting. Also, two-thirds of the population drive their cars during an average week, and drivers use their car on about two-thirds of their trips, yielding the national car driver mode share of about 43%, and car passenger mode shares of 14%. Adults between 19–64 years show the highest car usage mode shares (i.e., car driver and car passenger) of 62% on weekdays and 60% on weekends. Moreover, around 37% of Germany's inhabitants travel multimodally (as of 2017), meaning they use more than one mode of transport to meet their mobility needs in everyday travel. More than half of them combine the car and the bicycle in the course of the week [98].

Since the 1990s, the bicycle—which had lost mode share to motorized modes in the previous decades—has experienced a slight renaissance in Germany. Many

German cities have actively promoted this development by expanding cycling infrastructure and increasing cycling safety. Some cities, for example Münster, Karlsruhe or Freiburg, reach cycling shares of more than 25% of all trips. In addition, electric bicycles (also dubbed “pedelecs”) are becoming increasingly popular in Germany. In 2021, 13% of households owned at least one pedelec. Pedelecs enable greater distances to be covered due to the ride-assistance provided by the electric engine. The average distances traveled by bicycle and pedelec therefore also differ. In 2017, the average trip distance traveled by bicycle was 3.7 km, while the average trip distance traveled by pedelec was 6.1 km [98].

10.3 Japan

The Japanese National Census is a survey of the entire population conducted every five years, with the travel modes to and from work being surveyed every ten years since 1970. The motorization of Japan is said to have started around 1960, and the data shows an increase in car trips (from 15% in 1970 to 47% in 2010) and a decrease in the use of walking (from 23% in 1970 to 7% in 2010), railways (from 29% in 1970 to 25% in 2010) and buses (from 15% in 1970 to 7% in 2010). This data is limited to commuting to and from work for people aged 15 and over, and the actual situation of travel for personal purposes and on weekdays and weekends is discussed below.

Table 6 shows the travel modes share by age group, based on data from the National Person Trip Survey (NPTS) of Japan in 2015. The NPTS, which was conducted in 1987 for the first time, is a data set of one-day person trips during the autumn season for specific cities, selected in consideration of their size and relationship with surrounding cities, and obtained through a questionnaire survey. The target population was aged 5 years and over; 70 cities were covered by the NPTS survey in 2015.

The high weekday walking share of 66% for children aged 5–12 is due to the fact that walking to and from school is the designated mode of transport in many elementary schools in Japan. Many public elementary schools do not allow parents to drive their children to and from school. However, the private car trip share of 5–7-year-olds on weekends in 2015 was 75%; larger than the values for adults aged 19–64 (71%), and older people aged 65+ (63%). Japanese children tend to be transported in their parents’ cars on weekends. The number of children killed in road traffic accidents in Japan has fallen sharply from 2115 in 1987 to 270 in 2015. This is thought to be due partly to the increase in children travelling by private car and a decrease in the number of children walking, rather than to safer towns. Among junior- and senior high school students aged 13–18, the share of public transport on weekdays is 24%, while cycling is as high as 33%. In Japan, many junior high school students are required to walk or cycle to school. However, the share of private cars is 45% on weekends.

The use of bicycles by children under 18 years in Japan for weekends and private purposes was 38% in 1987, but this figure had fallen sharply to 19% in 2015. Bicycling is recognized as a healthy and environmentally-friendly mode of transport, but this reduction may be partly due to the slow development of bicycle lanes in Japan. Although bicycles are categorized as vehicles in Japan, they are generally allowed on the sidewalk, and accidents between pedestrians and bicycles have occurred. Although the police authorities and the government have made it mandatory for new roads to have bicycle lanes and have emphasized that bicycles should be ridden on the road, not the sidewalk, it is not easy to break the Japanese custom, which has continued since the 1960s, of legally allowing bicycles on the sidewalk.

Among adults aged 19–64, the share of public transport on weekdays was 18%, and 9% on weekends, while the share of private cars was 58% on weekdays, and 71% on weekends, indicating a trend towards greater use of public transport for commuting on weekdays, and private cars for personal purposes on weekends. For the elderly aged 65 and over, the private car share was around 60% on both weekdays and weekends, indicating that there was little difference between weekdays and weekends. This would be because they are retired and not commuting. Looking at changes over time, the private car share of the elderly was 19% in 1987, but increased dramatically to 59% in 2015. On the other hand, the share of walking was 45% in 1987, but had fallen dramatically to 19% in 2015. This is thought to be due to motorization, which has created cities where it is difficult to live without a private car, and an increase in the number of healthy elderly people who own a driving license.

10.4 Comparative Conclusions

Current travel and mode use in Japan and Germany are a result of a long evolution driven by extending activity radiuses, i.e., longer trip distances, and a tendency to move towards faster and more convenient modes, mostly the private car, which today shows the highest mode share for both countries. It seems likely that the underlying trend towards more individualized destination choice—causing trip distances to grow and epitomized by the example of school choice—will continue as long as it is affordable for individuals. Throughout history, changes in the transport system, from increased travel mode choices to extensions of the infrastructure, have fueled this seemingly latent demand for longer trip distance at affordable generalized costs of travel. We do not see any reasons why vehicle automation may not follow this same path. The model-based analyses in chapters "Social Acceptance of CAD in Japan and Germany: Conceptual Issues and Empirical Insights and Transportation Effects of Connected and Automated Driving in Germany" illustrate on a quantitative basis that growth of overall travel demand is very likely a consequence of vehicle automation. The concrete incarnation of vehicle automation, however, will be key for the question which mode of travel—in essence individualized motorized modes or collective motorized modes—benefits the most from this development.

Table 7 Key figures on car ownership and use [4, 5, 7, 19, 51, 62, 63, 76, 77, 81, 87]

	Germany	Japan
Number of passenger cars on register per 1.000 population 1960	80 (1960)	5 (1960)
Number of passenger cars on register per 1.000 population 1990	420 (1990)	266 (1990)
Number of passenger cars on register per 1.000 population 2020	574 (2020)	490 (2020)
Passenger car average age (years)	9.8 (2020)	8.7 (2020)
Km per passenger car per year 1960 (km)	16,300 (1960)	19,080 (1960)
Km per passenger car per year 1990 (km)	15,300 (1990)	11,488 (1990)
Km per passenger car per year 2019 (km)	13,700 (2019)	8,860 (2019)
Passenger car occupancy rate (trip based)	1.3 (2019)	1.4 (2015)*

* Weighted average of the value for weekends and for holiday

11 Vehicle Ownership and Use

11.1 Comparative Statistics

See (Table 7).

11.2 Germany

Between 1952 and 2019, the number of cars per capita in Germany increased more than 30-fold, and the number of kilometers per capita traveled by car about 12-fold. Until the 1970s, annual growth rates of car ownership and use were about 10%, and strong growth continued until about 1990 [19]. This was a period when economic growth (in West Germany) was strong, and the baby boomer generation entered adulthood and took up driving. However, also after 1990 both car ownership and car use continued to grow steadily, albeit on a somewhat lower level of about 1% annually.

In the past twenty years, there were about 3.5 million new passenger cars registered annually in Germany, while 3 million cars were deregistered and either scrapped or sold abroad [64]. This resulted in an annual net increase of the German passenger car stock of about half a million vehicles. Given the total number of cars on the register (about 40–50 million during that period), these figures translate to an annual growth rate of about 1%, and about one out of 15 vehicles being replaced every year. In other words, with this renewal rate it would take about 15–20 years to replace the entire existing car stock in Germany, exemplifying the inertia of the vehicle fleet.

The early growth of car ownership in Germany up until the 1990s was mainly driven by the economically active age groups acquiring their first vehicle. Step-by-step, this trend was replaced by two other developments which sustained the continued growth of car ownership from the 1990s: Firstly, a generation of seniors—specifically women—who were born before WWII and had lived without a driver's license and car were succeeded by a new generation of seniors who sustained driving habits which they had acquired during their younger years. This replacement of a senior generation without cars by auto-oriented seniors accounts for about a third of aggregate car-ownership growth since the turn of the millennium. Secondly, there is a trend to second and third cars in multi-driver households of all ages, i.e., there is a trend towards a personal car for each driver. This trend accounts for about two-thirds of the recent growth in car ownership in Germany [32].

There was a strong increase in car-sharing membership in Germany after the turn of the millennium, and especially after 2010 when automobile manufacturers such as Mercedes and BMW rolled out free-flow car-sharing schemes in various German cities [25]. This coincided with a decline of car-ownership rates among young adults in the 2000s. In the public and media debate, these indicators were interpreted as a sign for a new paradigm among the next generation of travelers, who were expected to turn to car usage instead of car ownership [67]. This trend may still materialize in the future, but long-term empirical evidence so far suggests different: Over the last decades, car ownership has grown more strongly than car use, leading to declining mileages per vehicle; there are more vehicles per licensed driver and also occupancy rates continue to decline (1950s: 2.5; 2000s: 1.5; 2019: 1.4, km-based occupancy rate) [19]. All of these are long-term indicators showing that the Germans in total continue to trend towards more individualized ownership and use of vehicles, which also conforms to other societal trends of continued individualization.

11.3 Japan

The number of automobiles owned in Japan, which in 1960 was just 1.4 million, grew to 58 million by 1990 and to 82 million by 2020, an increase of more than 60-fold in just over 60 years. These years also witnessed a dramatic evolution in the composition of Japan's automobile fleet: in 1966, passenger vehicles, freight vehicles, buses, and other vehicles (including two-wheeled vehicles) respectively accounted for 28.2%, 57.7%, 1.3%, and 12.8% of all Japanese vehicles, but by 1990 these shares had evolved to 56.8%, 36.1%, 0.4%, and 6.7%, and in 2020 they were 75.5%, 17.6%, 0.3%, and 6.7% [4]. Thus, we see that as the number of automobiles increased, their main use shifted from transporting goods to transporting people. Indeed, the number of passenger vehicles (including commercial vehicles) per 1,000 people exploded from 5 in 1960 to 266 in 1990, and then to 490 in 2020—demonstrating that notwithstanding the much-publicized aversion of young people to cars in recent years, the growth trend in the popularity of automobiles in Japan has remained undiminished.

Let us consider automobile ownership and usage in Japan on a household-by-household basis. According to "Passenger Car Market Trends in Japan" [53], an annual survey of households—including single-person households—conducted by the Japan Automobile Manufacturers Association (JAMA), 77.9% of all households in 2021 owned one or more passenger vehicles, with 34.5% of which owning two or more. According to the Automobile Inspection & Registration Information Association (AIRIA), the average number of private-use passenger vehicles owned per household was 1.04 in 2020, with lower numbers in major cities with extensive transit networks (such as Tokyo, with 0.42 vehicles per household, or Osaka, with 0.64), and higher numbers in rural areas (such as Toyama, Yamagata, and Gunma prefectures, each of which had more than 1.6 vehicles per household) [6].

"Passenger Car Market Trends in Japan" also inquires how respondents use their most-recently purchased vehicles. Respondents were asked to identify the primary purpose of their vehicle use. The two most common selections in 2021 were "Shopping, running errands, and other tasks" (41% of respondents), and "Commuting to work or school" (30%). Regarding the frequency of vehicle use, just under 45% of respondents reported using their cars seven days per week, while the average response was approximately five days per week.

In recent years, "Passenger Car Market Trends in Japan" has begun asking households owning 4-wheeled vehicles about the availability of car-rental or car-sharing services in their neighborhood, and how willing they might be to use such services. The fraction of respondents reporting the presence of a car-rental station within 10 min' walking distance of their homes was just over 30% in the Tokyo area, averaged around 30% in the 5 major cities (Tokyo's 23 wards, Yokohama, Kawasaki, Osaka, and Kyoto), and lower elsewhere in 2021. Similarly, the fraction of respondents within a 10-minute walk of a car-sharing station was 45% in the Tokyo's 23 wards, averaged 31% in the 5 major cities, and was lower elsewhere. However, when asked "Are you currently using, or have you used in the past, these services?" the share of households answering "Yes" was over 50% for car-rental services, but just 3% for car-sharing services. Similarly, in response to the question "In the future, do you hope to use car-sharing services, or would you use car-sharing services if the opportunity arose?" only 16% of respondents answered in the affirmative for car sharing services.

While these statistics paint a quantitative picture of automobile ownership and use in Japan, we glean some cultural insight from the colloquial evolution of the Japanese-language phrase "three sacred treasures" (*sanshu no jingi*). Historically a reference to three priceless artifacts handed down through generations of Japanese imperial rulers as symbols of power, the phrase was adapted in the 1950s to describe three possessions then epitomizing the typical Japanese household's aspiration to a life of abundance: a black-and-white television, a washing machine, and a refrigerator. By the 1960s, economic progress had expanded expectations, and now the new three sacred treasures were a color television, an air conditioner—and a car. Indeed, until quite recently, ownership of a home and a private passenger vehicle were widely seen as the central material goals of Japanese families. The act of owning an asset entitles the owner to both residual profits from the asset and residual control rights over use of the asset, thus enhancing the asset's usefulness to the owner and creating powerful incentives to increase its value. At the same time, private asset ownership leads to increased energy usage and greater environmental impact due to production and disposal of assets, and creates inefficiency when assets lie idle and unused. Car sharing, enabled by autonomous vehicles and internet-of-things-based monitoring, may prove a powerful tool for alleviating these shortcomings while retaining the advantages of private ownership. Nonetheless, international comparative surveys conducted in 2017 show that Japanese consumers are far less willing than consumers in other nations to consider using ride-sharing services and other innovations of modern sharing economies—an attitude that seems as prevalent among younger Japanese consumers in their 20 s as among their older compatriots [75]. The growing popularity of car sharing in Europe and the US is far from guaranteed to be replicated in Japan.

11.4 Comparative Conclusions

As regards car ownership and use, there are substantial differences between the two countries: Germany has a higher level of car ownership and higher mileage per passenger car, leading to an overall higher level of driving per capita. However, the overall trends in the recent decades are similar: There has been an increasing trend towards individualized ownership and use of cars as exemplified by the increasing number of cars per household and declining occupancy rates. Both countries have also seen a public debate about a possible trend towards replacing private car-ownership by shared or rented vehicles. Even though transitioning to shared cars seems more logical in Japan given the low mileage of private cars there, car-sharing schemes appear to be more successful in Germany. However, neither in Germany nor in Japan have the car-rental or car-sharing schemes that have emerged in recent years substantially impacted the overall trend towards more individual ownership and use of cars. Automation of private vehicles is rather likely to reinforce prevailing trends toward higher car ownership because it increases the utility of private vehicles. Nevertheless, vehicle automation is being discussed as a possible game-changer because it could enable automated individual mobility services which would diminish the utility advantage that private vehicles have over the use of other modes. Chapter "Transportation Effects of Connected and Automated Driving in Germany" in this book analyzes likely impacts of automated service on car ownership in a model-based quantitative manner.

12 Road Transport Automation—Evolution and Policy Approach

12.1 Germany

Technological and social developments in information and communication technologies (ICT), transportation technologies and mobility are closely intertwined. Between the 1920 and 1950s, the motor car was adopted by the masses and became the dominant means of personal transport in Germany. This development created substantial pressure on governments to expand existing and create new road infrastructure, but also new challenges for public safety, transport efficiency and (later) environmental protection. The rise of semiconductor electronics, microprocessors and computers in the 1950 and 1960s apparently already offered options for technological fixes. Certain ICT components, such as loop detectors and ramp metering, bus automatic vehicle location or dynamic message signs, were added to the road transport system. However, the grand vision of centralized road traffic management using computers as a central planning and steering device had to be abandoned, and electronics systems were still too bulky, too expensive and not sufficiently reliable to become part of the average passenger car [130].

This situation had changed by the mid-1980s to early 1990s. After two energy price crises, with a growing environmental protection movement, increasing growth in vehicle miles traveled and approaching limits to further infrastructure expansion, safety and environmental concerns again became a focus of transportation policy. At the same time, ICT had become smaller, more powerful and cheaper, which led both industry and governments to rediscover and revisit their earlier ambitions. At this time, R&D on "artificial intelligence" enjoyed a new upswing, and ICT increasingly became subject to industrial policy disputes between the major national economies. As a consequence, specific application programs for ICT in important sectors were initiated. One of the central projects in this field in Germany in the 1980s was the EUREKA research program "PROMETHEUS" (1987–1994) [101, 102]. It was understood as an integrated transport concept in which the unwanted social and ecological consequences of individual transport were to be reduced, and at the same time its advantages further utilized by exploiting the problem-solving potential of new technologies, in particular by combining transport technology with ICT. The work carried out at that time, especially on system analysis and problem definition for the application of ICT in road traffic, had a significant influence on further R&D activities in Germany (and beyond), and probably still does today. This also applies to approaches for the development and implementation of automated driving within PROMETHEUS, which resulted in a number of demonstration vehicles being introduced in this period.

Around the middle of the 2000s—starting with the DARPA Grand Challenge and the private-sector activities it triggered—another "renaissance" of automated driving began [73]. This was due, among other things, to the fact that much more powerful and specifically more cost-effective components for automation hardware and software (especially machine learning methods) became available. In countries where globally important players of the vehicle and electronics industry or the so-called platform economy are based, these industries are considered to be key assets for the national economy, and enjoy direct and indirect political support. This was also the case in Germany. After initial activities like founding a working group on legal implications of automated driving at the Federal Highway Research Institute [44], an inter-ministerial working group on automated driving, and a large technology assessment scoping study (Ladenburg study, financed by Daimler and Benz Foundation [74]), the German government adopted its "Strategy for Automated and Connected Driving" in 2015 [20], and collaborated with the Automotive Industrial Association (VDA) in making the IAA 2015 a major showcase for its ambitions. Since then, a number of additional policy initiatives have been started. Federal and state research funding has been increased and partially redirected toward various—mainly technical and organizational—aspects of automated driving. In 2016, the Federal Minister of Transport and Digital Infrastructure had set up an "Ethics Commission on Automated and Connected Driving" with the task to reflect on a number of ethical and social aspects of automated driving [50]. The German road traffic law has been amended twice within the last five years—in 2017 in order to enable the integration of automated driving as a new principle into the regulatory framework for road traffic, and in 2021 in order to support the deployment of fully automated vehicles on German roads. This was accompanied by German activities on the international level, especially within the World Forum for Harmonization of Vehicle Regulations (UNECE WP.29). An Action Plan, "Research for autonomous driving", which further intensifies and coordinates the activities of three federal ministries in the field of connected and automated driving, was published in 2019 [22]. Beyond governmental actors and public research organizations, also industrial players like car manufacturers and Tier 1s have substantially increased their R&D activities and collaborated in a number of verification, validation and demonstration projects.

12.2 Japan

Automatic train operation (ATO) on railways has a long history and comprises two types: with or without a driver. The type in which a driver has boarded and completed safety checks has been tested since the 1960s. The first ATO test in Japan took place on the Nagoya Municipal Subway Higashiyama Line from 1960 to 1962. The first operational ATO with a driver was employed in the monorail providing transportation to the Japan World Exposition venue in 1970. Subsequently, ATO has been widely used mainly for railways such as subways and monorails, which do not intersect with other traffic horizontally, in Sapporo, Sendai, Tokyo metropolitan area, Kyoto, Osaka, Kobe, Fukuoka, and other cities. ATO without drivers is widely used in Automatic Guide Weight Transit (AGT), which is a medium-weight trucking system that automatically drives small, lightweight vehicles with rubber tires along the guideways of dedicated lanes. The Port Island Line of Kobe New Transit Co., Ltd., which opened in 1981, was the first practical AGT in Japan, and the world's first automatic unmanned operation system. Subsequently, AGT became commonplace throughout Japan.

The history of actual automated driving implementation on roads is not as extensive as that of railroads, although automated driving research on roads had already been initiated by the government in the early 1960s [122]. In addition to the difficulties associated with technological realization related to the complexity of the road environment, this lag resulted from different government agencies administering various laws governing automated driving on roads. The Road Transport Vehicle Act, which defines vehicle standards, and the Road Transport Act, which defines business requirements for buses, taxis, rental cars, and car-sharing, fall under the jurisdiction of the MLIT. The Road Traffic Act, which sets traffic rules, is under the jurisdiction of the National Police Agency (NPA). The Ministry of Internal Affairs and Communications (MIC) and Ministry of Economy, Trade and Industry (METI) are also involved in automated driving operations. To achieve the operation of automated driving on public roads, coordination among these ministries was required, which was challenging.

However, in the 2010s, the trend toward interagency collaboration accelerated. Since 2014, the Public–Private ITS Initiative Roadmap has been updated and published annually on the initiative of the Cabinet Secretariat and collaborations between ministries and agencies. The 2014 roadmap included an expected timeframe for Level 3 automated driving marketability (see the introduction for more information on Level 3). In the same year, the Strategic Innovation Promotion Program (SIP), a cross-ministry technology development project led by the Cabinet Office, was launched. These developments gradually laid the groundwork for cross-ministry discussions and instigated the cooperation between ministries and agencies necessary for the social implementation of automated driving. Under the SIP, a test was conducted in 2017 consisting of platooning trucks, as well as a test demonstration of an unmanned cart service centered on local roadside stations.

For the implementation of unmanned operation on public roads, operators must meet the requirements of the Road Traffic Act, under the jurisdiction of the NPA, and the Road Transport Vehicle Act, under the jurisdiction of the MLIT. Based on the Public–Private ITS Initiative Roadmap, two laws were amended in April 2020 to allow Level 3 automated driving operation on public roads under certain conditions. Thereafter, on March 4, 2021, Honda launched the world's first mass-market vehicle equipped with Level 3 functions. In addition, an amendment to the Road Traffic Act, which was passed in April 2022 and is expected to go into effect by the end of the same year, will allow Level 4 operation on public roads under certain conditions. The amendment defines automated driving without a driver in the vehicle as "specified automated driving" and requires permission from the Prefectural Public Safety Commission. The "Chief Supervisor of Specified Automatic Operation," who remotely monitors the vehicle, will have the same duties as the driver, such as providing first aid in the event of an accident.

12.3 Comparative Conclusions

Above all, this analysis on the evolution of road transport automation in Germany and Japan clarifies the long history of research and technology development dedicated to vehicle automation. This history goes back much further than the automation technology hype which has dominated the discussion since around 2010. While in Germany there was an early focus on road transport automation dedicated to the idea to render the use of road capacity more efficiently, transport automation technology in Japan was first mostly concentrated on rail transport and slowly spilled over to road transport. It is clear that in both countries, transportation automation technology development was fostered by the government and closely linked to the dominance of the transport and automotive industry. Laying the legal foundations quickly to enable real world operation of automated vehicles has obviously been an ambition in both countries: working towards this objective, both governments—in close interaction with the automotive industry—have amended relevant laws within the last five years. Given this temporal analogy, it appears that both governments intend to maintain, or even strengthen, the current competitive positions of the national automotive industries by permitting their national industrial players to test and deploy autonomous driving technologies on public roads before global processes of harmonization of vehicle regulations (like UNECE WP.29) have been concluded.

13 Conclusions and Outlook

This chapter has provided a broad overview of the framework conditions that characterize the transport systems in Germany and Japan today. It presented the respective historical evolution as well as selected key factors that shape contemporary passenger transport and are likely to be influential in the future. It is clear that vehicle automation will be embedded in such existing systems that are characterized by path dependencies and considerable degrees of inertia. With respect to the factors presented in this chapter, Germany and Japan partly differ substantially (e.g., with regards to car use) but partly share important similarities (e.g., with regard to the relevance of the automotive industry). Germany and Japan make suitable case studies because they represent prototypical paths of mobility development: Germany represents a typical European path which is relatively car-oriented but not as extreme as the North American transport development trajectory. Japan follows a mobility pathway which—relative to other large high-income countries—is somewhat less auto-oriented. Hence, the two countries possibly represent transport systems pathways that many emerging countries may be following.

At the same time, Germany and Japan stand out from other countries with regard to factors which may be influential in making them forerunners with regard to the implementation of vehicle automation technologies. Both may be motivated more than others to introduce automation technologies because their densely-populated and rapidly-aging countries may benefit more than others from vehicle automation. Addressing an emerging lack of drivers, sustaining the mobility of an aging population and harnessing the potential for increased space-efficiency of automated traffic are just examples. However, likely even more important—vehicle automation may be key to sustaining the technological advantage that Germany's and Japan's automotive industries have over automobile manufacturers from much of the rest of the world. Hence, there are strong economic and political motivations to lay the legal, infrastructural and technological groundwork for the introduction of vehicle automation.

This chapter conceptually discussed how the presented factors influence, firstly, the motivation to introduce vehicle automation; secondly, the speed with which vehicle automation is likely to diffuse in the coming decades; and thirdly, how autonomous vehicles may alter transport systems and mobility behavior in the coming decades. This chapter has therefore laid the groundwork for understanding the context for introducing vehicle automation, and provides a framework for interpreting the findings of the subsequent chapters in the overall context of the national transport systems. The subsequent chapters of this book focus on selected key issues in this context, using a range of methodological approaches.

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