# Outlook for Steering Technology in a Period of Major Changes in Mobility

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*The automotive industry is undergoing a major transformation. While technological change is progressing, new social issues are also emerging. To respond to these changes, many companies are working on various technological developments. JTEKT is developed technologies with an emphasis on interaction with the driver through the steering wheel. This paper introduces SBW technology, Pairdriver a collaborative steering control system for ADAS, vehicle dynamics control technology and the development of a column coaxial steering actuator for commercial vehicles.*

***Key Words****: CASE, Pairdriver, SDV (software defined vehicle), SBW (steer-by-wire), J-EPICS, JFOPS, BS-EPS*

## 1. Introduction

It is said that the automobile industry is entering a once-a-century period of great change. One catalyst was the concept of CASE (Connected, Autonomous/Automated, Shared & Services, Electric) that was announced by Daimler at the Paris Motor Show in 2016.

Now nearly 10 years later in 2024, differences in the state of progress have started to appear between different areas. One factor continually bringing large changes to the automobile industry may be emerging automobile manufacturers, who are being boosted by CASE. In 2008, top ranking electric vehicle manufacturers Tesla released the Roadster and BYD introduced the F3DM. Emerging automobile manufacturers see automobile production from a new perspective, have simplified hardware and completely changed component configurations. At the same time, realizing a large number of functions in software on limited hardware has resulted in more complex control logic, and the software volume continues to grow without end.

In recent years, in addition to market changes in the logistics industry caused by the COVID-19 pandemic, issues facing society now include changes in the transport industry environment including personnel shortages caused by the aging of professional drivers and stricter overtime regulations (known as the "2024 problem")[1]. Efforts to help solve these kinds of social issues, and adapting to changing times and markets, have accelerated technical innovations.

## 2. Technical Trends Surrounding Automobiles

In particular, improvement of driving assistance technologies to reduce accidents is a pressing issue for drivers of automobiles including commercial vehicles. Support technologies which recognize the lane a vehicle is travelling in using cameras or other means, and which control the travelling position, are becoming commonplace. Progress is also being made in steering angle control technologies which indirectly control the angle of the road wheel with respect to the direction of vehicle forward travel in order to keep the vehicle in the target driving position (on course). Electric actuators have a higher control response than hydraulic systems, and electric power steering (EPS) makes it easy to achieve fine-tuned control.

JTEKT has been working since an early stage to create a full lineup of steering systems. In addition to EPS, JTEKT has also been working on control technologies for hydraulic assist systems, and are mass producing steering actuators that provide driving assistance. One of the strengths of JTEKT is the range of hardware and control technologies that efficiently and accurately transmit steering torque. Element technologies such as gears, bearings, and ball screws, as well as reduction gear technologies used in EPS systems, are fundamental technologies that are required in order to correctly control a system through the vehicle. In recent years, in order to add functions for detecting the steering wheel angle and pinion angle to EPS systems, there has been demand for torque and angle sensors, and JTEKT is also working to improve its technical capabilities and develop products for this purpose (**Fig. 1**).

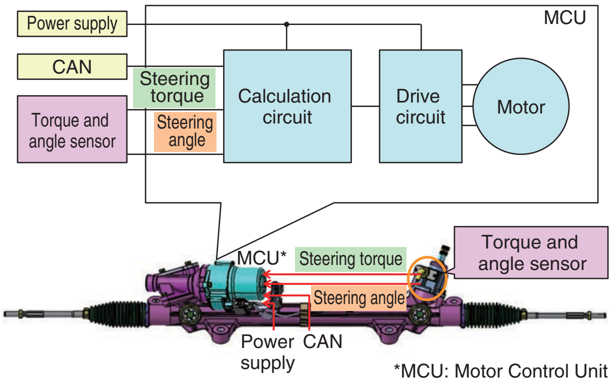


**Fig. 1** EPS system with torque and angle sensor[2)]

Correctly transmitting the torque applied from the steering wheel to the vehicle by the driver, and correctly communicating information from the road surface to the driver, are the functions of the steering system, and this will not change as long as there is a driver holding the steering wheel. Therefore, an important issue is collaboration with the driver using the steering angle and steering torque for the aforementioned vehicle position (course) as the interface. JTEKT is continually engaged in technical development, and in 2023 JTEKT announced Pairdriver as a solution for collaborative control. Contributions to driver-centered autonomous driving (AD) or advanced driver assistance systems (ADAS) are a foundation of JTEKT technologies.

The following sections describe the development of the JTEKT Steer-by-Wire (SBW) technology, Pairdriver control technology, vehicle control technologies using the steering and the driveline system, and column coaxial steering actuator for commercial vehicles.

## 3. Steer-by-Wire (SBW) Systems

Development of JTEKT SBW systems began in 1995, and in 2000 JTEKT developed the SBW system utilizing E-VGR and the EPS system, a proprietary JTEKT technology (**Fig. 2**). Subsequently JTEKT began applying for many basic technology patents related to SBW systems and vehicle dynamics control (**Fig. 3**).

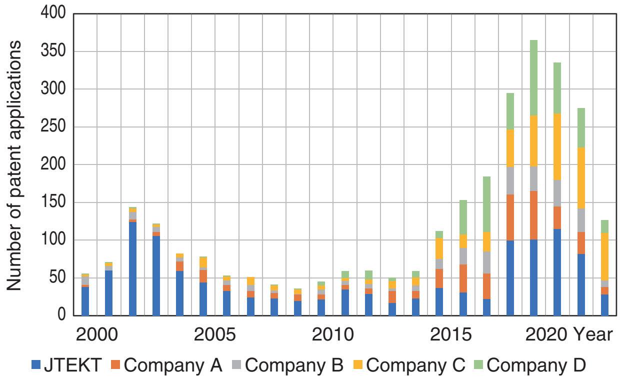


**Fig. 3** Number of patent applications related to SBW

**Figure 4** shows the system configuration of J-EPICS (JTEKT Electronics Performed Intelligent Control Steering), which is the SBW system currently in development by JTEKT. J-EPICS is composed of a road wheel unit that turns the road wheel and a hand wheel unit that detects the hand wheel angle and provides feedback torque to the driver, and EPS systems are applied for the mechanical structures of both. With this system, the devices for driver input are not limited to the steering wheel, and they include an electrical linkage that sends the driver's intentions to the road wheel devices.

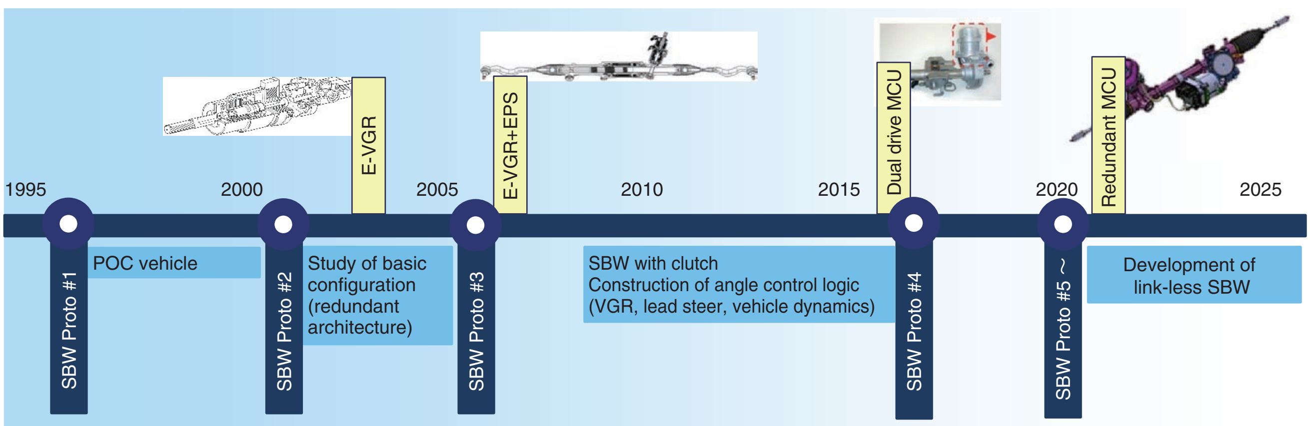


**Fig. 2** History of JTEKT SBW development

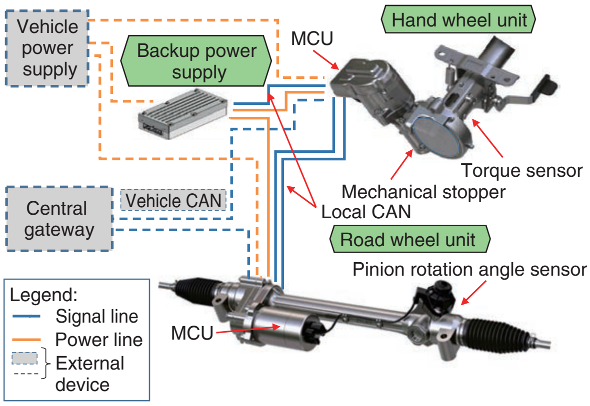


**Fig. 4** J-EPICS system architecture[4)]

In a SBW system that does not have a mechanical link between the steering wheel and the road wheel, the most important development concept is ensuring safety in the event of a functional failure. In order to continue driving and stop the vehicle safely, in the unlikely event of a system malfunction, JTEKT uses a redundant architecture for the element components that make up the SBW system. This enables the other side to maintain function even when a malfunction occurs in one side (**Fig. 5**). In the event that multiple failures cause a loss of road wheel steering function, measures for safely moving the vehicle to the shoulder of road by linking the brakes, rear wheel steering, and other vehicle systems other than the SBW system are also possible.

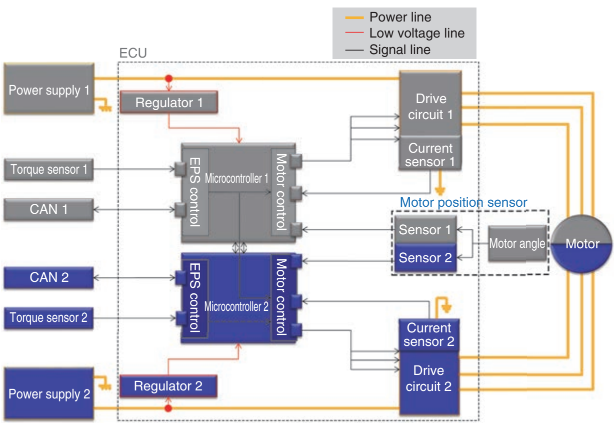


**Fig. 5** JFOPS4 HW architecture

At present, there are no international standards that prescribe safety guidelines for SBW systems, and the safety of vehicles where SBW systems are installed is decided based on the safety standards of each automobile manufacturer. While proposals from system suppliers are also important, collaboration with the automobile manufacturer is critical, and how extensive the measures to ensure safety must be a major subject of discussion.

In recent years, based on a proposal from VDA (Verband der Automobilindustrie), international discussions regarding the formulation of ISO 19725 standard for safety of SBW systems are being conducted. In China, a revision of GB 17675 for SBW systems is being discussed. It is expected that standards and other materials that can serve as global guidelines for safety will be established in the near future.

In the redundant architecture of the MCU, JTEKT has defined the original safety concept JFOPS (JTEKT Fail-Operational System) shown in **Table 1** in order to support a wide range of functional safety levels, and has proceeded with development of J-EPICS based on JFOPS4 as the highest-level concept[3)].

**Table 1** JFOPS design concept

| Level | Design concept | Corresponding autonomous driving level 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| JFOPS4 | Fully redundant HW design | | | ● | ● | ● |
| JFOPS3 | Redundant HW design (excepting power supply and microcontroller) | | ● | ● | | |
| JFOPS2 | Expanded backup area from JFOPS1 | ● | ● | | | |
| JFOPS1 | SW backup in case of failure (sensors, driver) | ● | ● | | | |

HW: Hardware SW: Software

For J-EPICS where there is no mechanical connection between the hand wheel actuator (HWA) and the road wheel actuator (RWA), an example of a configuration connecting the ECU, sensors, and actuators (EE architecture) as a configuration that ensures safety is shown in **Fig. 6**.

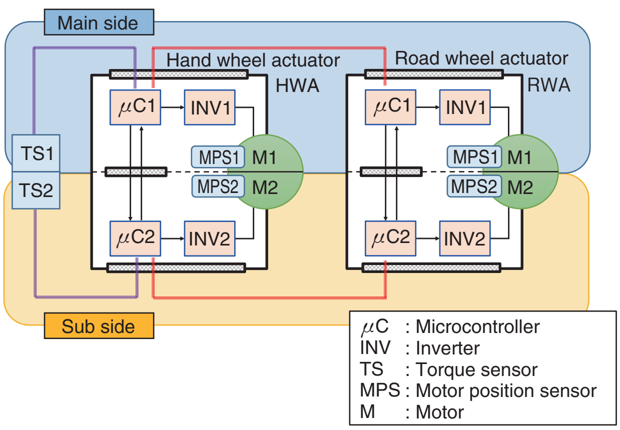


**Fig. 6** J-EPICS architecture

Each architecture is made as simple as possible in order to improve software reliability. Following is an explanation of the state machine of the HWA and RWA in this configuration. First, the system state machine indicates the state that is transitioned to when a malfunction or other event occurs, and the route leading to that transition destination is called the state machine path. As shown in **Fig. 7**, in a conventional redundant EPS system, there are two state machine paths between normal state, failure state of a single side, and failure state of both side, and they are both generally one-way paths. In contrast, with the J-EPICS configuration, the HWA and RWA each has its own state machine, and the design specifications produce state machine paths that support vehicle system safety standards in the event of a failure.

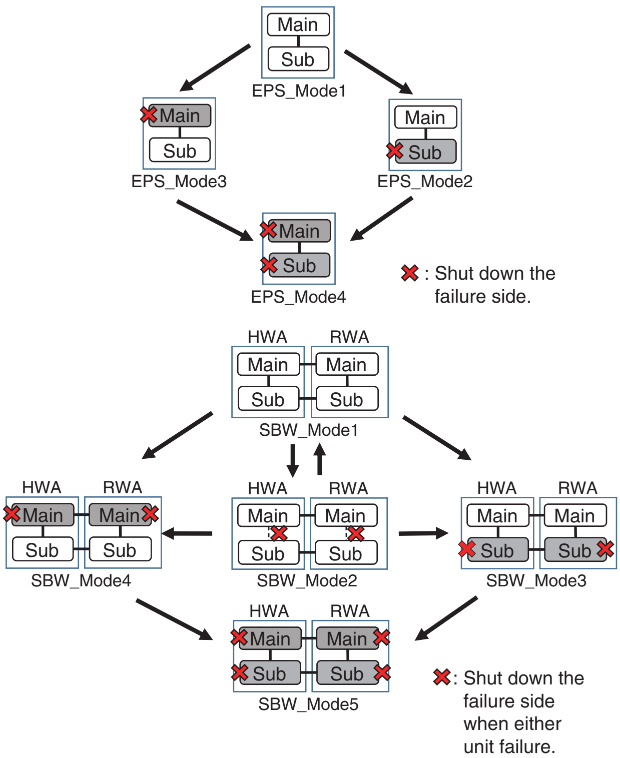


**Fig. 7** EPS system and SBW system state machine

Furthermore, since J-EPICS requires synchronizing the states of the HWA and RWA when transitioning, compared to a conventional EPS system, the scale of system evaluations is enormous and difficulty is higher. The SBW system EE architecture is still under development, and international discussions for standardization of configurations based on safety standards are in progress.

Considerations related to the power supply system are also extremely important. As described before, SBW systems have no mechanical link unlike conventional EPS systems. For this reason, if a failure occurs that stops the power supply to both systems, a conventional EPS system changes to manual steering and the driver can still steer the vehicle, however this is not possible with a SBW system. Therefore, power supply failure mode in a SBW system must be considered more carefully than ever before. One solution produced by JTEKT from this consideration is the backup power supply (BPS) system shown in **Fig. 4**.

## 4. Collaborative Steering Control for AD or ADAS (Pairdriver)

With the growing use of AD or ADAS in recent years and the advancing automation level, vehicle lane tracing based on automatic steering has improved. On the other hand, when the driver intervenes in steering operation, the steering by AD or ADAS interferes with the steering by the driver, and therefore the vehicle may not behave in the way the driver intends. To address this problem, JTEKT is developing Pairdriver as collaborative steering control that adapts to the conditions of steering by the driver and steering by AD or ADAS (**Fig. 8**).


**Fig. 8** Pairdriver concept

When Pairdriver detects driver steering intention during AD or ADAS enabled, the system smoothly applies this steering intention, harmonizing the intentions of the driver and system and achieving both smooth steering intervention and good lane tracing performance, leading to safe driving (**Fig. 9**). Because the feedback torque when the driver intervenes in steering during AD or ADAS enabled can be freely designed with Pairdriver, an appropriate feedback torque can be generated for each AD or ADAS function, enabling AD or ADAS that are safer and more comfortable[6)].

In the future, JTEKT will update the Pairdriver software functions in order to install and tune AD or ADAS functions at an early stage, customize the feedback torque characteristics for each driver, and in other ways provide new value as software solutions that rapidly meet customer demands.

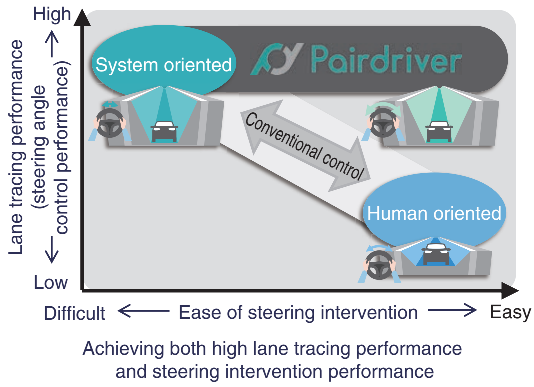


**Fig. 9** Pairdriver target

## 5. Vehicle Dynamics Control Technologies Using Steering, Braking, and Driving

Vehicle stability and other vehicle dynamics control primarily involves control by steering and control by braking and driving. With the electrification of vehicles, including battery electric vehicles (BEV), further improvement in vehicle dynamics control using braking and driving is expected. Improvement in vehicle dynamics control using steering is also expected, and a SBW system is one useful device. For control technologies, JTEKT has collected technologies through E-VGR, including stabilization control during μ split braking, and these control technologies can be applied to SBW systems. Rear wheel steering is another useful device for vehicle dynamics control. While rear wheel steering was commercialized decades ago, it was used in only a fraction of vehicles. However, its use in vehicles has been growing in recent years. This is thought to be because, due to the increase in vehicle sizes, it is not possible to maintain the vehicle minimum turning radius with the current maximum front wheel steering angle. Furthermore, in BEV, the wheelbase may be expanded in order to secure battery space, and there are expectations for rear wheel steering as a means of improving the minimum turning radius. Rear wheel steering is also a SBW system, and in combination with a SBW system for front wheel steering, it will be possible to actively control all four wheels. Integrated control of steering, braking, and driving has the potential to deliver greater value than ever before with software.

## 6. Column Coaxial Steering Actuator for Commercial Vehicles

Faced with the social issue of a shortage of professional drivers in the logistics industry mentioned above, in order to reduce driving burdens on commercial vehicle drivers and ensure safe driving, there have been demands for commercializing AD of buses and trucks from an early stage. JTEKT is participating in national projects and other verification testing, and has cooperated with a variety of start-up companies developing AD. Because the required steering power is large, hydraulic power steering is used in many commercial vehicles. Although there has been growing use of driving assistance technologies such as lane-keep and automated parking with EPS systems in passenger cars, advanced support technologies for hydraulic power steering are currently an important issue that needs to be addressed.

In recent years, the use of AD or ADAS in large-size commercial vehicles has become possible with combinations of electric steering actuators upstream of existing hydraulic power steering, and operating the steering actuators based on AD or ADAS steering demands. To support commercial vehicle drivers and alleviate their workload, JTEKT has begun mass production of column coaxial type steering actuators as well as steering actuators utilizing column type electric power steering (C-EPS) (**Fig. 10**). The JTEKT systems add steering actuators to the column, and producing no interference with the floor in low-floor commercial vehicles, allowing installation on existing commercial vehicles with only minor modification of the column. Even with normal steering, it helps improve steering performance including reducing steering torque at ultra-low speeds and improving steering wheel return. JTEKT will continue to develop control systems aiming to make further contributions to safety and comfort in the future.

**Fig. 10** Column coaxial steering actuator

In 2023, such a system was adopted for the commercial vehicles of a domestic OEM, and JTEKT is expanding the scope of AD or ADAS use in large-size commercial vehicles in cooperation with a variety of venture companies in addition to existing automobile manufacturers. As a result of progress in technical development for higher outputs and improved steering performance, in addition to lane keep assist, a range of contributions to safe driving are expected, including emergency avoidance and moving out of the driving lane in the event of hydraulic power steering failures or when the driver suffers a health event[5].

Aiming for the installation of EPS systems in future commercial vehicles, JTEKT is also developing the EPS for commercial vehicles (BS-EPS) utilizing recirculating ball-type steering (RBS) (**Fig. 11**).

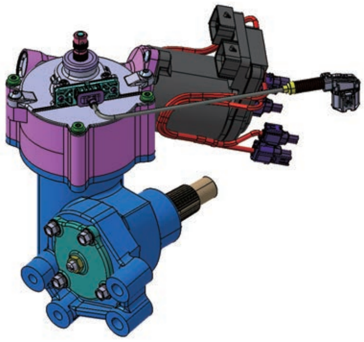

**Fig. 11** Commercial vehicle EPS (BS-EPS)

## 7. Conclusion

It has long been said that the automobile industry is experiencing a once-a-century period of great change, and the global situation and technical trends are still in flux. The contents of technical development continue to become ever more complex. At the same time, it will become possible to identify the value of a product not from its main functions alone, but by understanding its relationships of mutual benefit with other systems. For this purpose, it is necessary to direct our attention broadly to surrounding parts and surrounding environments. In order to propose further new value, it is also necessary to directly face and actively learn about social issues and customer orientation. Various proposals that are consistent with solutions to social issues and customer orientation are proposals that directly link the customer, ourselves, and those around us. The road to creating a better society is a difficult one but also enjoyable. Learning, thinking, and proposing is the only way for JTEKT to continue to be a company that is needed into the future, and JTEKT will strive to do so.

*J-EPICS, BS-EPS and Pairdriver are trademarks of JTEKT Corporation.

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