Development and Future Outlook of Steering Systems

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This report first describes the history of steering systems, as well as the predicted future trends of ADAS (Advanced Driving Assist System) and the role of the steering system within ADAS as a steering function, including mechanical and electronic controls. It also describes the steer-by-wire system recognized as the means for achieving ADAS. Furthermore, this report illustrates the development of electric power steering and the achievement of equipment safety for safety requirements such as in ISO26262, which have accompanied its development. It also explains the application of the technologies achieving the required safety (achieving product safety conforming to the requirements of standards such as ISO26262) on ADAS.

Key Words: *EPS, ADAS, SBW, ISO26262*

1. Introduction

Modern day vehicles became able to detect the surrounding area and driving conditions with high accuracy, advancements have been made in the realization of active safety technologies such as automatic emergency braking systems. At the same time, the Electric Power Steering (EPS) system, which was first mass-produced by JTEKT in 1988, has spread widely, to the point where, currently, over half of all passenger vehicles are equipped with EPS systems. Furthermore, advanced driver assistance systems which use the degree of control freedom offered by EPS such as automatic parking systems and Lane Departure Warning (LDW) systems/ Lane Keeping Assist (LKA) systems are also gaining popularity. The further advancement of these technologies foreshadows the rise of the Advanced Driver Assistance Systems (ADAS) and the automated driving systems, therefore the function and performance of steering systems must be improved in order to facilitate ADAS systems. This paper reviews the history of steering system development, as well as describes the predicted future advancement of ADAS, the steering functions required for such advancement, and the concepts behind the system and safety design which enable the ADAS to be created.

2. History of steering systems

The realization of Hydraulic Power Steering (HPS) in the 1960's decreased the necessary steering force to turn the steering wheel (SW), thus reducing the burden on the driver. Moreover, the reduction of steering force required to turn the steering wheel while parking, stability in high-speed driving and good steering feeling have been achieved by controlling the assist power corresponding to vehicle speed. Furthermore, the first practical application of EPS, developed by JTEKT, contributed greatly to the reduction of fuel consumption.

Figure 1 shows production volume and forecast for vehicles on a global scale, according to the steering type. In 2001, HPS accounted for the majority of vehicles which adopted power steering, however the recent expansion of EPS to use in large size vehicles has led to a rapid increase of EPS production volume since 2010. At the same time, the installation ratios of each EPS type have changed. In addition to C-EPS, which has an assist mechanism incorporated in columns suitable for small vehicles, which were mainstream up until now, gear type EPS (DP-EPS, RP-EPS) which has an assist mechanism incorporated in rack shafts suitable for large vehicles have been increasing (**Fig. 2**). The transition to EPS in vehicles is predicted to continue increasing in line with stricter fuel economy regulations, popularization of advanced driving assist technology, and realization of various ADAS functions. The transition of JTEKT steering products is shown in **Fig. 3**. In order to respond to the various steering requirements of OEMs, JTEKT offers product series containing each product lineup and is constantly developing new technologies. We consider the development of steering systems which respond to the evolution of vehicles as well as the related technologies for such systems to be our mission.

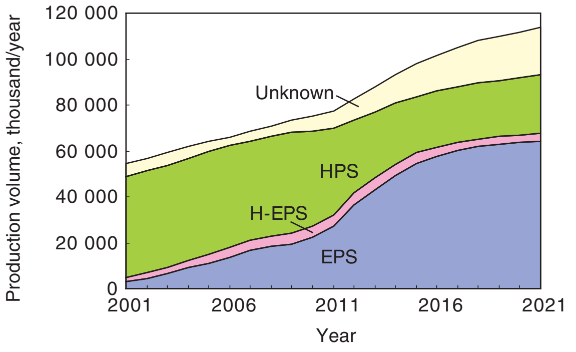


Fig. 1 Results and forecast (global) of automobile production volume by steering type

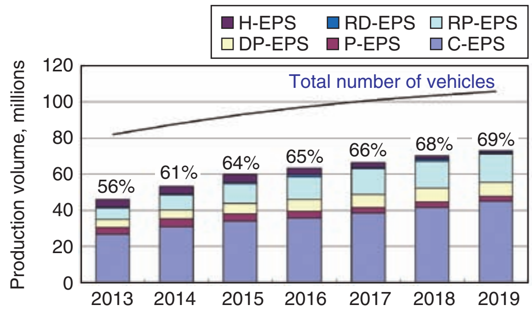


Fig. 2 Production volume percentage (global) by EPS type

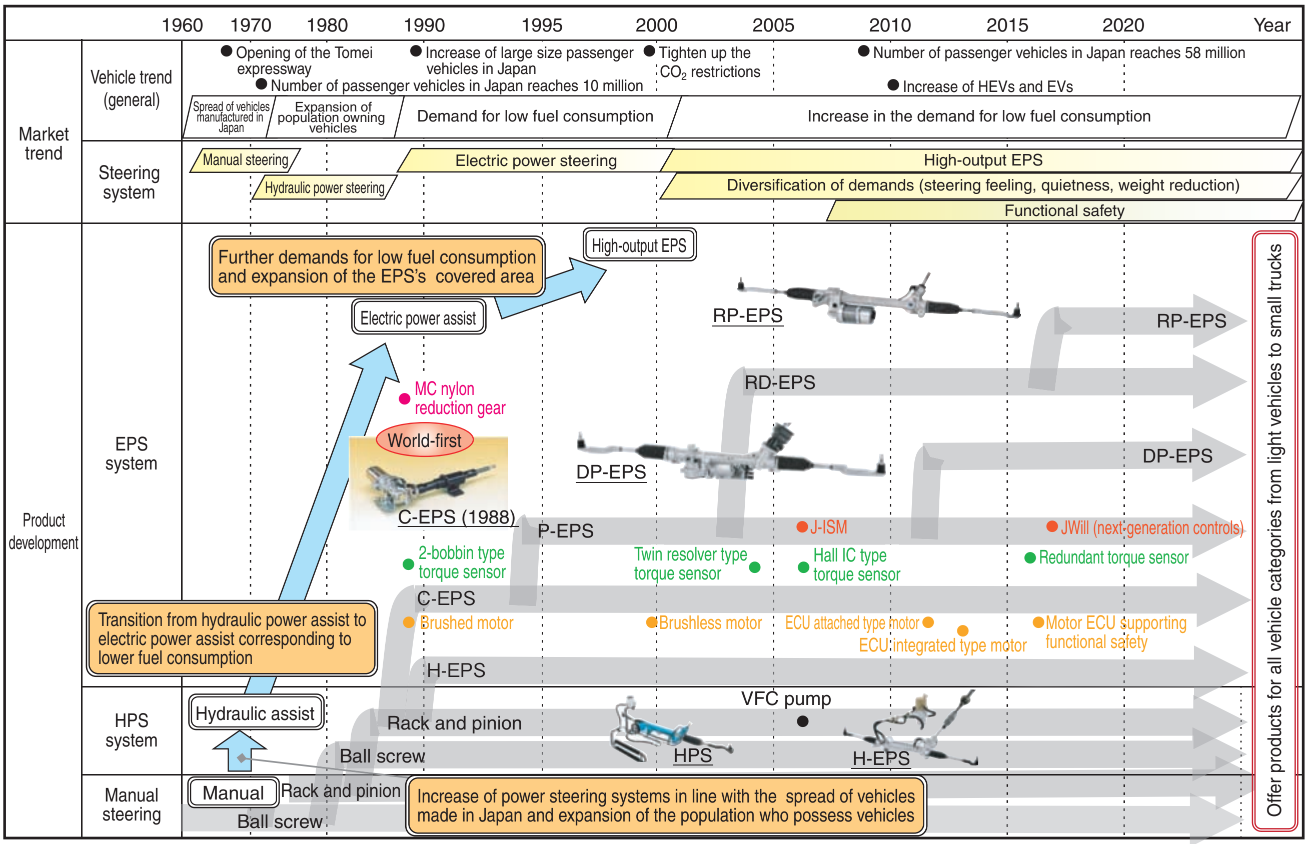


Fig. 3 History of JTEKT steering products

3. Advancement of ADAS and evolution of steering systems

3. 1 Market trends of ADAS

The type and number of driving assistance systems able to enhance the safety performance of vehicles such as automatic emergency braking system and LDW/LKA system have increased dramatically in line with the recent rapid evolution of computer processing ability, the dramatic improvement of sensing ability and the cost reduction of environmental recognition sensors such as cameras and radars. The penetration rate of these systems is expected to increase significantly in line with their gradual legal enforcement and as they become an item for NCAP rating, because the systems largely contribute to a decrease in the number of traffic accidents and the number of victims. The possibility of the practical application of automatic driving systems which fully replace the operation of the system by the driver has been growing due to the advancement of ADAS. The advancement of functions and the expansion of applicable roads for the automated driving system will be expected to increase in stages at almost the same time in Japan, the United States and Europe (**Fig. 4**). These have the potential to drastically change the vehicle society as well as people's lifestyles, through a change of vehicle themselves, the acceptance level of the system by society and the revision of laws and regulations.

*The levels in **Fig. 4** reference the NHTSA levels[1)] in **Table 1**

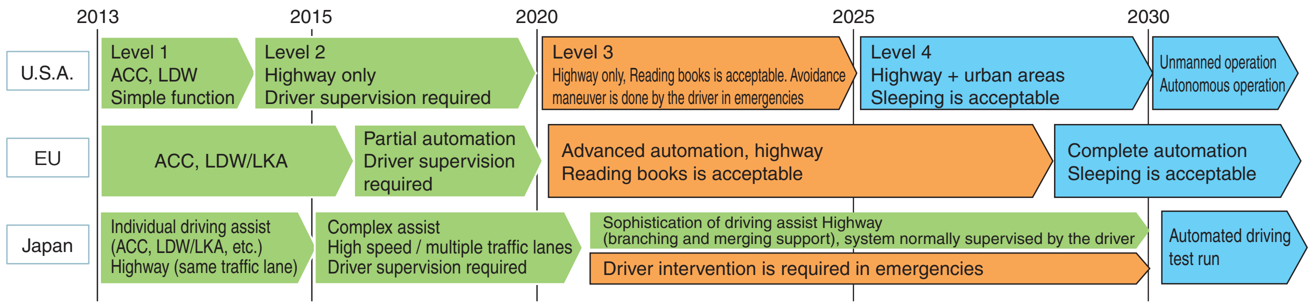


Fig. 4 Roadmap of automated driving system introduction by country

Table 1 Levels of automation (Draft)[1)]

NHTSA level	SAE level	SAE name	SAE definition	Responsible for steering wheel operation and acceleration / deceleration of the vehicle	Monitoring of traveling environment	Responsible for the backup of driving operation	System capability (driving mode)
	Driver themself monitors driving environment						
0	0	Manual	The driver always performs all driving operations.	Driver (human)	Driver (human)	Driver (human)	–
1	1	Assistance	The driving assist system performs either steering wheel operation or acceleration/deceleration depending on the driving environment while the driver operates parts that are not assisted by the system.	Driver (human) + system	Driver (human)	Driver (human)	Some driving modes
2	2	Partial automation	The driving assist system performs steering wheel operation and acceleration/deceleration depending on the driving environment while the driver operates parts that are not assisted by the system.	System	Driver (human)	Driver (human)	Some driving modes
	Automated driving system monitors driving environment						
3	3	Automation with conditions	The automated driving system performs all driving operations of the vehicle in the specified driving mode, under the condition that the driver responds appropriately to system requests for transfer of driving responsibility.	System	System	Driver (human)	Some driving modes
4	4	Advanced automation	The automated driving system performs all driving operations of the vehicle in the specified driving mode, even if the driver does not respond appropriately to the system requests for the transfer of driving responsibility.	System	System	System	Some driving modes
	5	Complete automation	The automated driving system always performs driving operations of the vehicle, on the road and with the driving conditions in which even the driver is able to operate as well.	System	System	System	All driving modes

3. 2 Requirements for steering systems

The functions which are required of steering system are predicted to change in line with the advancement of ADAS and automated driving systems.

Figure 5 shows the relationships between the functions of each type of driving assist system, the level of automation of the automated driving and the requirements of steering systems. LDW/LKA and TJA systems, which are conventional systems, are either in mass production or planned for mass production in the next few years at many OEMs. Since they are driver responsibility systems, an override function which prioritizes the driver's intention in emergencies is mandatory for the steering system. Maintaining of the steering function until the driver takes over the responsibility of driving in cases where emergency steering is required is mandatory for the system responsibility automatic driving systems which will be in mass produced around the year 2020. Furthermore, if a system reaches the level where the judgments made by the system are safer than the judgments made by the driver, the steer-by-wire (SBW) system, in which coordination and interference with the driver can be controlled freely, would be an extremely effective system and highly likely to become mainstream.

4. Ensuring safety

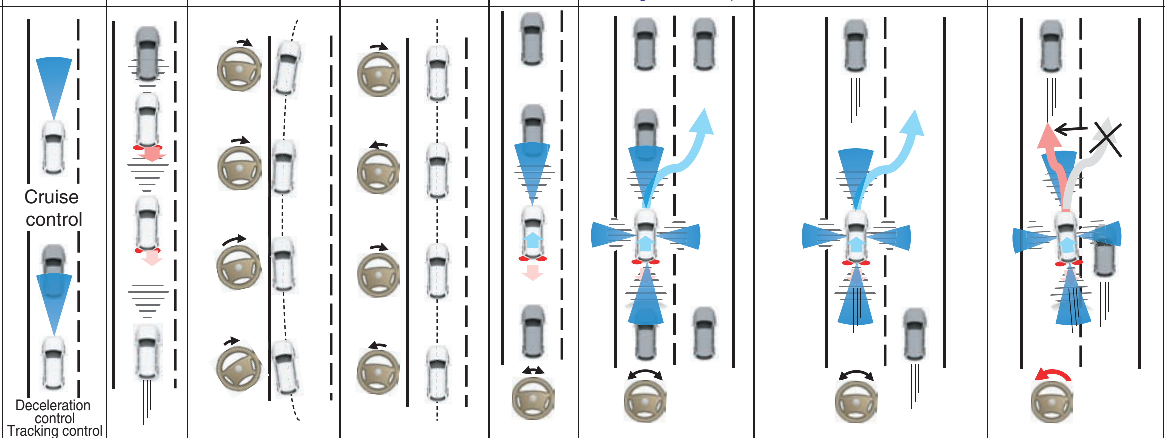
4. 1 Support for functional safety

Recently, EE systems which are equipped on vehicles have become more complex and significantly advanced in their performance and function, as seen in the example of the EPS system. Moreover, the number of EE systems has increased rapidly. As such, these systems are required to operate without failing or malfunctioning to enable the safe operation of vehicles. Therefore, the concept of functional safety, established as the international standard IEC61508, has been introduced to the automotive industry as the international standard ISO26262 for functional safety in vehicles. ISO26262 became effective from 2011. According to ISO26262 specifications, failures and bugs which occur within electronic control devices are ranked corresponding to risk, the rate of occurrence of failure and the ability to avoid collisions. (ASIL designation (**Fig. 6**), Failures and bugs are treated in a v-model for product development which integrates safety measures and traceability functions corresponding to their rank (**Fig. 7**).

4. 2 Concept of ADAS support and ensuring safety in EPS

The following failure modes are categorized as ASIL-D in ISO26262 and are the most critical failure modes of current EPS systems.

Function name	ACC	AEB	LDW	LKA	TJA	TJA (with lane change function)	Automated steering	Automated steering /collision avoidance
Control details	Cruise control Deceleration control Tracking control							
Mass production (predicted)	Mass production				2015–2018		Around 2020	Around 2025
Automation level	Driver responsibility				Driver responsibility		Driver responsibility → System responsibility	System responsibility
Steering requirements			Override by the driver				Maintaining of basic functions in case of failure	Avoid interference with driver input
Steering system			EPS		SBW		SBW EPS	SBW



ACC: Adaptive Cruise Control AEB: Automatic Emergency Braking LDW: Lane Departure Warning
LKA: Lane Keeping Assist TJA: Traffic Jam Assist SBW: Steer by Wire

Fig. 5 Outline of advanced driving assist system controls and steering system requirements

<Quantification of risk>
"Risk" = Quantification as Automotive Safety Integrity Levels (ASIL)

<Definitions of risk>

Grade of severity	S1 (Low) through S3 (High)
Driving conditions	E1 (Rarely occurs) through E4 (Occurs whenever driving)
Ease of troubleshooting	C1 (Easy) through C3 (Difficult)

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	E1	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	E1	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

Fig. 6 Definitions of ASIL[2)]

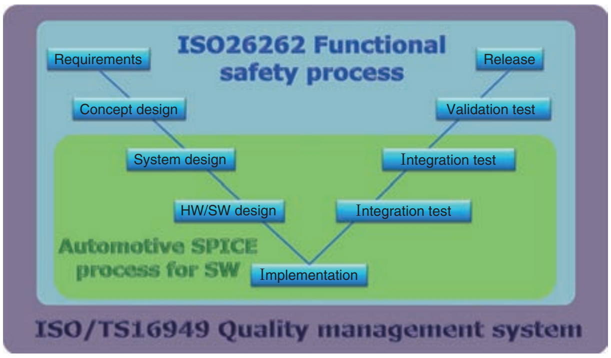


Fig. 7 V-model of functional safety

- Self Steering (SW rotates without steering input by the driver or without any steering instructions, such as automatic parking command, from the vehicle.)
- Steering lock (SW in not able to rotated.)

These failures are managed by improvement of quality corresponding to the function safety requirement in each development, design and production phase and by making the failure occurrence rate consistent with the function safety requirement by selecting electronic parts with low failure rates. EPS systems are also designed to prevent a situation from becoming more dangerous in the case of system failure, including those described above, by shutting down the system using a dual-core microcontroller monitoring function and failsafe function. Recently however, EPS assist power has been increased in order to equip EPS to large vehicles (weight increase), hence the approach of shutting down systems in case of failure became unacceptable because drivers can no longer steer in a large vehicle without EPS assist power. Moreover, in the case of ADAS and automated driving systems, the system suspension of ADAS/automated driving functions and/or EPS/SBW, which realize these functions will be categorized as ASIL-D. There is a high possibility that maintaining of the steering system function will become mandatory in the case of system failure. JTEKT will supply fail-operational EPS systems which either have minimal possibility of system shutdown (**Table 2**) or never stop system operation (refer to **Fig. 8**).

Step 1: Application of backup control (mass production)
Continuing of EPS operation by launching a specific software in case of failure if it is possible.

Step 2: Hardware redundancy design. (Partially applied in mass production in 2015)
Continuation of partial EPS operations during failures by duplicate circuits and EPS sensing functions.

Step 3: Hardware and power supply redundancy design. (Mass production scheduled in 2020: details currently under discussion)
Continuation of full steering operation by duplicate circuits and EPS sensing functions combined with duplication of vehicle power supply in case of system failure.

Table 2 Fail-operational EPS system

Step	Concept	Method of achievement	ASIL relating to system suspension (including suspension by fail-safe)	System output during fail operation	Target ADAS system	ASIL for self-rotation and rotation lock
3	Complete fail-operational function	Complete redundancy of EPS system electronic hardware including vehicle power supply	ASIL-D	50%～100%	Automated driving	ASIL-D (Incident rate less than 10FIT)
2	Fail-operational	Redundancy EPS system electronic hardware	(ASIL-C)	50%	TJA/ LKA collision avoidance	
1	Partial fail-operational	Backup using steering wheel	(ASIL-B)	20%		
0	System suspended in case of failure	Conventional EPS	QM	0% (Stopped)	LKA/ LDW	

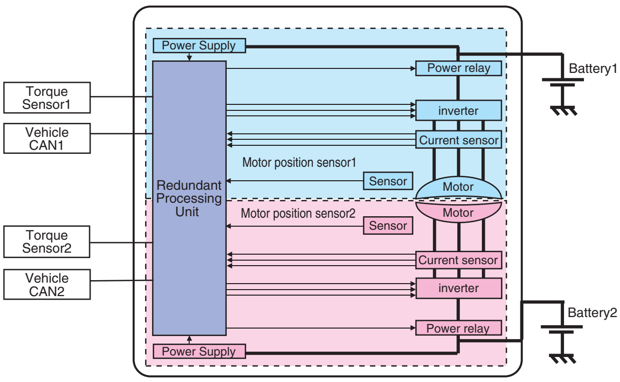


Fig. 8 Fail-operational system block diagram (Example)

5. Conclusion

The realization of automated driving systems, which would have been labeled science fiction only a decade ago, is rapidly becoming a conceivable reality. We stand on the eve of a massive revolution in both vehicles and motorized society. Despite many technical issues and difficult legal issues such as where responsibility lies in the case of traffic accidents, industry, government and academia in countries across the world are actively engaging in the research and development of this technology and the prospect of realizing this dream is rapidly progressing thanks to the achievement of automated driving which dramatically increases the convenience and safety of vehicles. As the company with the top global share in steering systems, we at JTEKT believe it is our duty to contribute by developing new technologies to support the realization of ADAS and automated driving system that will continue to develop.

*1 J-ISM is a registered trademark of JTEKT Corporation.

References

1) 5th Study meeting about the automatic pilot system Document 2, p. 6 (Ministry of Land, Infrastructure, Transport and Tourism)
http://www.mlit.go.jp/road/ir/ir-council/autopilot/doc05.html
2) ISO26262-3 Road vehicles-Functional safety-Part 3: Concept phase 7.4.4 Determination of ASIL and safety goals Table.4

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