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Subject: The Latest Development Trends of Advanced Autonomous Driving Technologies

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Development Course of Advanced Autonomous Driving

■ The advanced autonomous driving industry shifts to the stage of verifying products and business models from the stage of validating key technologies

Stage of validating key technologies

At the stage of validating key technologies, a range of measures are taken to address 99 percent of long-tail problems

- Large-scale road testing + cloud-based simulation → acquire massive data and perform closed-loop management of data to enable continuous and rapid iteration of autonomous driving algorithms
- Move from simple to complex testing scenarios:
  - ✓ Enclosed sites → semi-closed environments → open roads

✓ **Goals:** ① make breakthroughs in the key and core technologies for AD algorithms → address 99 percent of the technological problems; ② build a more adequate testing management system → provide a system of standards for the industry and accelerate technology testing and validation

Stage of verifying products and business models

Since the last 1 percent of long-tail problems will always exist, various approaches should be taken to lower the possibility of accidents, so as to realize the productization and commercialization of AD technologies

The development of the industry entails upgrading the supportive factors in China, including policies, supervision, demonstration scale, infrastructure, use cases, products, and business models

Policies	• Autonomous driving may encounter accidents, thus requiring security during the productization and commercialization of AD technologies. It is not wise to give up the application or even ban autonomous vehicles on roads just because of accidents
Supervision	• Perform supervision over the standards for launching products to the market, data collection, information of vehicles and drivers → standardize the development of the autonomous driving industry from multiple dimensions
Demonstration scale	• Too small scale (not effective) or too large scale (accident-prone) → promote the demonstration in a gradual and orderly manner
Infrastructure	• Collaborative perception + cooperative control → make driving safer and lower the threshold of running on roads
Use cases	• Give priority to the use cases where AD technologies can be applied more easily (user demand and technology availability) → enable the rapid application of AD technologies
Products	• Lower the probability of long-tail problems from the perspective of product design (e.g., improving the human driver's take-over process during human-machine interactions)
Business models	• Boost the productization and commercialization of AD technologies to allow every player to access what they need and share resources → map out business models suitable for the industry development

Existing Challenges Facing Advanced Autonomous Driving

■ To address the last 1 percent of problems, relevant players face the following challenges during the stage of verifying products and business models

Technological problems (core challenge): hard to address the last 1% of problems

Intelligent vehicles:

- Disputes over perception solutions: camera-based and LiDAR-based solutions have their own merits
- Insufficient perception: traditional perception systems are hard to realize the BVR / omni-bearing / all-weather perception → piling up sensors for the sake of security will lead to high costs
- Hard sensor fusion: when there are differences between multiple sensors, the results of perception may go against each other
- Limitation of AD algorithms: manual work accounts for a high proportion of algorithm development → high cost + low efficiency of processing data → hard to address long-tail problems and ensure safety

The pathway of developing intelligent vehicles has limitations → addressing the last 1% requires V2X technology

Policies & regulations

Compliance of people/vehicles + road planning and construction + division of responsibilities and duties

Infrastructure

Long-period infrastructure construction: impossible to be accomplished in an action, requiring time

The commercialization of advanced autonomous driving technologies is advancing slowly

Test	Productization	Business model	Commercialization
• The test evaluation system for advanced autonomous driving requires further improvement	• The product verification system needs to be improved • Improve safety during the productization and provide safe user experience	• Cooperation, division of duties, and allocation of profits → require multi-lateral coordination / discussion	• Most cities have not allowed players to charge users for their AD-based mobility services / removed safety drivers → with heavy investment, relevant players still find it hard to scale up business and secure sustainable profits

□ **Commercialization is the ultimate goal of the autonomous driving industry, to which the key is to improve algorithm development methods, refine product verification systems, and faster integrate smart vehicles, smart transportation, smart cities, and smart energy (the so-called “4S”)**

Digest of the Challenges: Autonomous Driving Technology

■ Technology is always the core problem of autonomous driving, so selecting appropriate technology pathways is vital for relevant players to advance the progress of autonomous driving

Two technology pathways for autonomous driving at present: intelligent vehicles / V2X

- V2X: require heavy investment + large difficulties in cross-sector coordination + existing intelligent infrastructure hard to enable large-scale V2X application → most AD companies opt for the pathway of intelligent vehicles

Technology paths for all links of intelligent vehicles

- Perception: camera-only solutions or LiDAR-based solutions (cameras + maps → poor perception; LiDAR + HD maps → high cost)
- Decision: man-made rules or machine learning (man-made rules → long iteration cycle, high cost, and poor scalability; machine learning → need to collect massive data sets, beyond the capabilities of many players)

Sensor

- Perception: most players choose solutions that combine cameras and LiDAR
  - ✓ Cameras: insufficient depth perception + low ranging accuracy + more sensitive to inclement weather
  - ✓ LiDAR: both the range and the resolution of point cloud are far smaller than image sensors + high cost → difficult to realize large-scale commercialization

→

- Decision/execution: if the result of the cameras goes against that of the LiDAR system during sensor fusion, it will be hard to determine which will "have the final say"

□ **Autonomous driving will be always vexed by long-tail problems → relevant players need to opt for suitable technology pathways to address such problems as many as possible and accelerate breakthroughs in relevant technologies**

Digest of the Challenges: Policy System / Infrastructure

- Policy system: mainly the challenges mainly from people, vehicles, and roads; Infrastructure: mainly the challenges from construction investment

Policy system	People	• Compliance of drivers: ✓ Allowing the hands-off driving requires the formulation of laws and regulations to restrain and judge the availability of hands-off driving ✓ Providing standardized and systematic training of safety drivers needs to think about the necessity of referring to the driving license examination • Driving license management system: ✓ Pose a challenge to the incumbent traffic laws and regulations → Does it mean driving "without driving licenses" is available?
	Vehicle	• Compliance of vehicles: ✓ There are numerous autonomous vehicle models (passenger vehicles, commercial vehicles, etc.) → require detailing the procedures of releasing the licenses for autonomous vehicles to run on roads ✓ Need to find solutions for **mixed traffic** composed of both ordinary vehicles and autonomous vehicles
	Road	• Road planning and construction: ✓ There are disputes over the setting of dedicated roads for autonomous vehicles → there have been some roads for autonomous delivery vehicles, but how to further open the right of way in the future
	Other	• Division and determination of liability: ✓ When AI-enabled systems take the responsibility for safety accidents instead of human drivers → how to determine the liability and ensuing ethical and moral issues
Infrastructure		• Existing infrastructure is hard to meet the requirements of autonomous driving: heavy investment in the construction of intelligent infrastructure → long construction period + time-consuming implementation + impossible to realize the construction goal in a short term

□ Most of the problems and challenges in the policy system and infrastructure origin from the to-be-solved issues related to the industry development → require joint efforts of government and business

Digest of the Challenges: Commercialization

- The key problem of commercialization is whether the last 1% of problems can be successfully addressed → realize commercialization. The application of advanced autonomous driving in different use cases will encounter roadblocks in productization, testing, and business model, so players need to pinpoint suitable use cases

Robo-taxi

- Hard to ensure the safety → regulatory restrictions
  - ✓ Most cities have not allowed players to charge users for their rides (except Beijing, Shenzhen, and Shanghai)
  - ✓ Most cities have not allowed players to remove safety drivers out of vehicles (except Beijing, Shanghai, Guangzhou, and Shenzhen)
- High cost:
  - ✓ Safety driver: 250,000 CNY per vehicle per year; sensor suite: 400,000 per vehicle
  - ✓ Data collection and labeling → manual cost and time cost
  - ✓ Cost of continuous iteration and development of software

Not allowed to charge users + high cost → hard to turn business into a reality → continuous investment ("burning money")

Robo-truck (main-line logistics)

- Vehicles:
  - ✓ Need to redesign hardware supply chains (like chassis and control system) for heavy-duty truck platforms, resulting in high cost of customization → no vehicle platforms suitable for large-scale commercialization at present
  - ✓ Most players choose retrofitted vehicles → encounter the problem of poor stability
- Cost: the cost of retrofitted self-driving heavy-duty trucks is higher than that of passenger vehicles
  - ✓ Enterprises have vehicles (fleets) → high costs of vehicle purchase and repair & maintenance

High cost of autonomous heavy-duty trucks → large difficulties in business operation

Robo-van (intra-city freight)

- No proven business models + few players in the game → have not entered the stage of verifying business models at scale
- Uncertain product service models (fixed route or non-fixed route) (warehouse-to-station/warehouse-to-store/C2C, etc.)

Robo-delivery vehicle

- Hard to provide satisfactory user experience → during the "last mile", users have increasing requirements on the efficiency and experience. Human-machine interactions require improvement
- During the scale-up, players need to control the cost of every link to further cut costs and realize volume production at scale → enhance the profitability

- **Operation in different use cases will face cost pressure. Since it is impossible for single participants to hold all necessary technologies, resources, and capabilities in their hands → cost reduction requires the stakeholders to explore ways of cooperation, dividing duties, and allocating profits**

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Concept and Limitation of AD Algorithms Development Methods (Stage 1.0)

- The assumed premise for the autonomous driving algorithms development methods (1.0): with accurate enough perception, the rule-based planning method can reach the level of human drivers

Link	Perception	Prediction	Planning	Testing
Algorithm generation (1.0)	Machine learning		Man-made rules → program the rules into the software that defines the driving system	

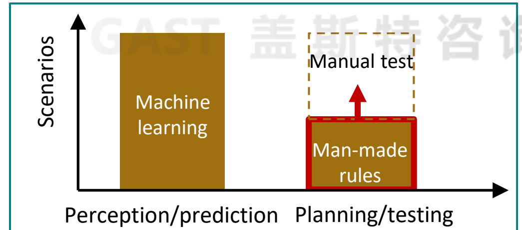
Require a large-scale extension of commercial applications to discover and properly handle the long-tail effect of incidents with small probabilities, then the limitations of the development method (1.0) will emerge as follows

Man-made rules are not able to cover all scenarios of machine learning

- Planning/testing (based on man-made rules) cannot cover the complexity and diversity of perception/prediction (based on machine learning):
  - ✓ Hard to timely discover and well handle small-probability incidents
  - ✓ Require manual adjustment of rules based on different road conditions
- Obtain no benefits from the progress of deep machine learning technology

Limited effectiveness

- The efficiency and functions of simulation tests based on man-made rules are all watered down:
  - ✓ Complete evaluations mainly via road tests → long development cycle + high cost of road tests + poor scalability



Manual tests can increase the upper limit of rule-based development methods, but the long-tail effect will always exist → unable to cover all scenarios of machine learning

□ Due to the planning and simulation testing that rely on unscalable and rule-based systems in the AD algorithm development method (1.0), there is still a way to go before large-scale deployment

Concept and Merits of AD Algorithms Development Methods (Stage 2.0)

- The autonomous driving algorithms development methods (2.0) are based on machine learning and data priority

Dimension		Development method 1.0	Development method 2.0
Concept	Perception	• Collect data via high-cost sensors • Manually collect data via testing vehicles	• Collect data via low-cost sensors for commercial use • Collect data at a large scale by ordinary human drivers
	Prediction	Based on machine learning	Machine learning (based on the collected driving data)
	Planning	Based on man-made rules	
	Testing		
Merits	Scalability	Low	High
	Route planning & decision	Manually improve (based on man-made rules) algorithms	Imitate human driver behaviors via machine learning
	Verification method	Manual road tests	Offline simulation
	Hardware cost	High	Affordable

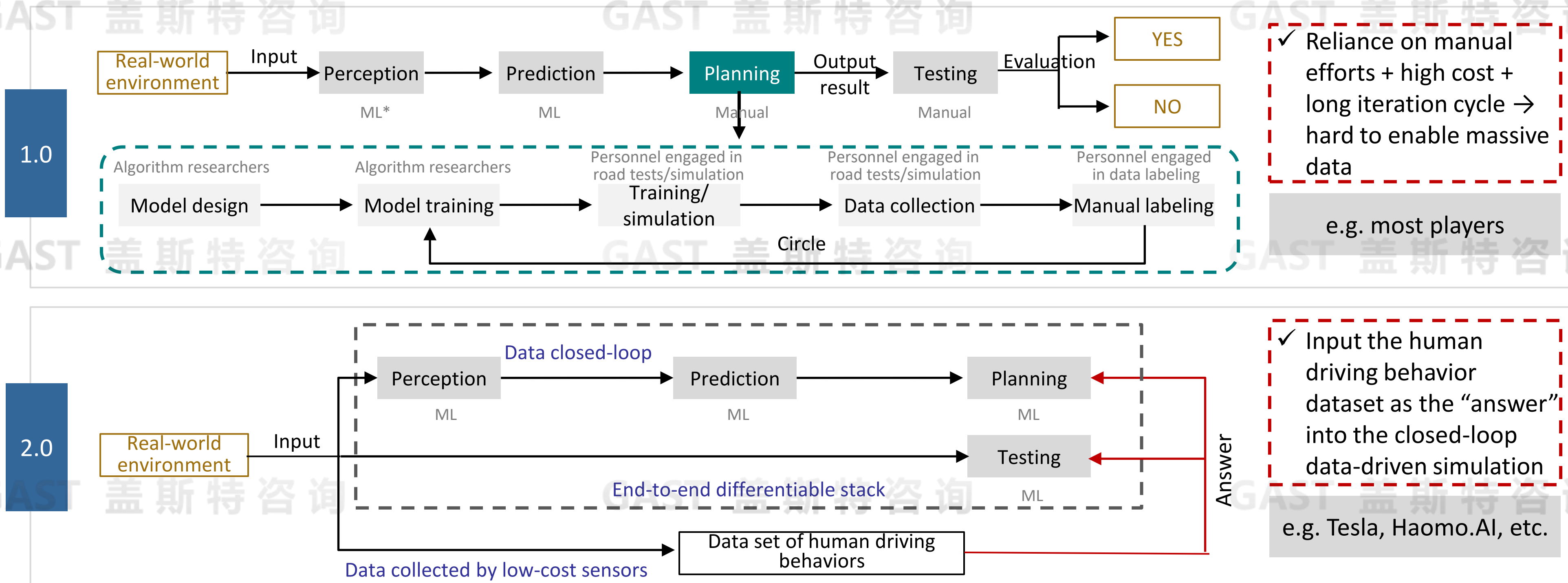
Two differences

- ✓ Complete large-scale collection of human driving data in diversified and real-world scenarios via perception systems with low-cost sensors → replace costly road tests
- ✓ Conduct training/offline simulation via machine learning based on the collected massive data sets → replace manual upgrades of software that is designed based on rules

- **Give priority to machine learning + reduce the proportion of manual efforts during development → with higher extensibility, the development methods (2.0) can address the long-tail effect of small-probability events and accommodate more new road conditions → turn high-performance autonomous vehicles into a reality at a faster pace**

Comparison of AD Algorithm Development Processes (1.0 vs. 2.0)

■ Translating the full stack of development methods into data issues, the development method 2.0, based on closed-loop simulation and fully differentiable neural networks, use the data collected by low-cost sensors to improve performance



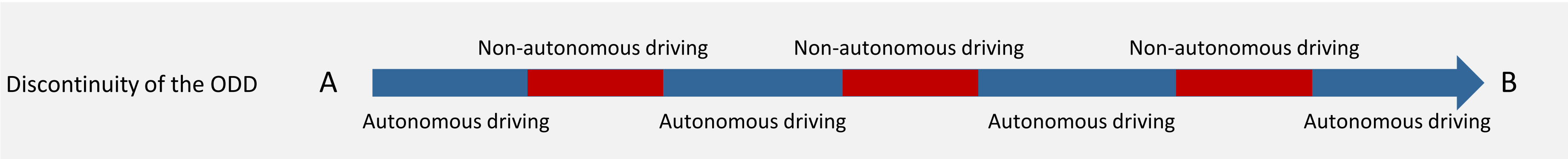
*ML: machine learning-based algorithm generation; manual: algorithm generation based on man-made rules

☐ Essentially, the AD algorithm development method 2.0 is a "Shadow Mode" → favorable for the large-scale commercial application of AD technologies

Discontinuity of the Operational Design Domain (ODD)

■ Discontinuity of the ODD is one of the challenges facing the advanced autonomous driving

Insufficient infrastructure construction | Long-tail effect of SOTIF | Incomplete architecture of ICV standards



① Continuity in finite domains

- Restrictions of the ODD → select the areas with small SOTIF risks for autonomous driving
- Low-level autonomous driving → match with lower-level infrastructure

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Lower the requirements to create continuous ODDs → only a palliative

② Strive to create continuous ODDs

- Build "data lakes" → collet massive and trainable data to enhance the performance of AD systems (as the development method 2.0)
- Develop an architecture of standards for ICVs → redefine the standards for scenarios, maps, etc.

↓

Address the discontinuity of ODD from the perspectives of algorithm development and regulations

□ Restricting the boundary of ODDs can seemingly realize the goal, but truly delivering continuous ODDs from a long-term perspective will require solutions to the long-tail effect of SOTIF and the improvement of relevant policies and standards

Business Cases: Haomo.ai's "Windmill Strategy"

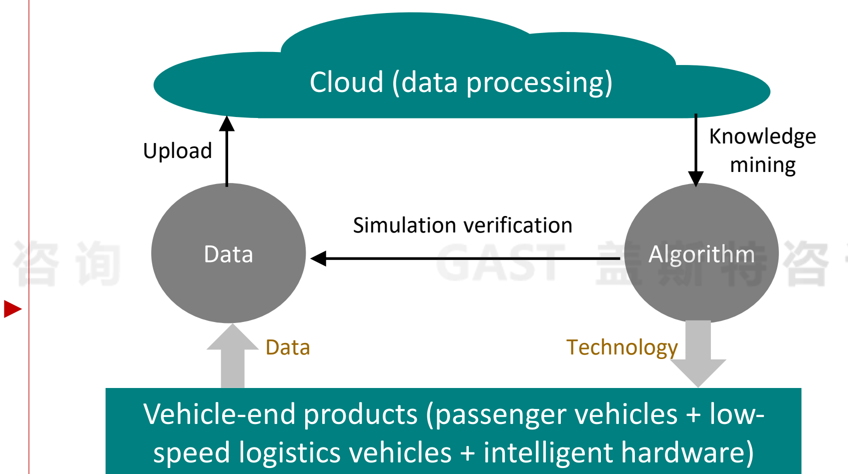
- Pursuant to the "Windmill Strategy" with data intelligence as the core, Haomo.ai lays out its autonomous driving business from three directions: passenger vehicles, low-speed logistics vehicles and intelligent hardware

- Intelligent hardware:
  - ✓ Little Magic Box 3.0 (Xiaomohe 3.0) → ICU domain controller
  - ✓ Small Magic Disk (Xiaomopan) → universal chassis-by-wire for driverless vehicles

- Driver assistance systems for passenger vehicles: L2+
  - ✓ Navigation on HPilot (NOH), a smart pilot driving system
  - ✓ Backed by Great Wall Motor → a stable enough source of orders

Data intelligence

- Low-speed logistics vehicles: L4 AD capability
  - ✓ Build delivery vehicles via cooperation with Qualcomm, Meituan, etc.



- Cost/iteration:
  - ✓ Fine control of data collection + data processing + AI training + system testing → lower cost and faster iteration

□ Haomo.ai can source good enough data from its ample production-ready offerings, while data intelligence drives continuous iteration of AD technologies, which bring benefits to the three business units in turn → expedite technology advances

Business Cases: Haomo.ai's Urban NOH

- Haomo.ai's autonomous driving system, though launched later, is upgraded faster and delivers better user experience than other players → mainly thanks to the MANA system and GWM

HPilot system: launched late, but upgraded fast

Player	Navigation on X	Urban NOH	Full-scenario NOH
Tesla	Jun. 2019	Tested abroad only	/
NIO	Oct. 2020	Sep.2022	/
XPeng	Jan. 2021	2022	2023
Li Auto	Dec. 2021	2022	/
Haomo.ai	Nov. 2021	H1 2022	H2 2022

Good user experience

Traffic light recognition	Recognize different forms of traffic lights on the road
Unprotected turns	Handle complex intersections with multi-lane interactions
Enter and leave a roundabout	Accurately perceive and identify roundabouts to select an appropriate route according to the navigation information
Lane marking recognition	Design the so-called BEV Transformer to increase the accuracy and continuity of recognition
Complex scenarios	When encountering a vehicle that breaks traffic rules, the system will make emergency avoidance and pass safely as soon as possible
Avoid other targets	Select an appropriate route according to the navigation system and dynamically avoid other vehicles and pedestrians

- MANA: allow automated processing of the collected data → fast

- Backed by Great Wall Motor – collect real-world data and iterate the system → good experience
  - ✓ Application to vehicles: HPilot has been applied to six vehicle models
  - ✓ Data collection → have logged over 7 million kilometers (as of March 2022)

Backed by GWM, Haomo.ai has in-house developed its data intelligence system MANA → realize large-scale acquisition and efficient utilization of data, thus promoting the continuous and rapid iteration of intelligent driving technologies

Business Cases: Haomo.ai Builds an AD Data Intelligence System MANA

- MANA is a set of data processing tools based on massive data, which is developed as a data intelligence system centric to perceptual intelligence, cognitive intelligence, labeling, simulation, and computation

MANA consists of four subsystems: TARS, LUCAS, VENUS, and BASE

VENUS: a data visualization system	LUCAS: application of algorithms in use cases	TARS: develop prototype algorithms on the vehicle end → more serve vehicle-end algorithms

BASE: data analytics and data services (e.g. data acquisition, transmission, storage, and computation)

- Over 70% of the data is automatically labeled and processed by the system
- Virtual driving experience = 20,000 years for human drivers

Applications of MANA

Data labelling	• Coarse setting of targets + fine estimation of attributes → increase the automation level → reduce labeling costs
Data storage	• Build a data mining system LUCAS: filter out valuable data from the massive data transmitted back by users and manage it at different levels according to its value → reduce storage costs
Data fusion	• Introduce the Transformer* algorithm: fuse data from cameras and LiDAR sensors to achieve deep perception that integrates the data of space, time, and sensors → ① solve the problem of fusion and association between multiple cameras; ② effectively improve the visual detection effect through LiDAR

*Transformer: centric to the attention mechanism, it has redundancy in processing massive data

- **MANA system can add the understanding of scenarios to global tasks (e.g. detection of drivable roads) and can also provide global information for better understanding specific scenarios**

Business Cases: Haomo.ai Weaves DL Algorithms into Path Planning

■ Haomo.ai introduces scenario digitalization and large-scale reinforcement learning technologies for the decision-making link and performs learning by constantly iterating perception

Haomo.ai's AD algorithm development approach – planning phase

TarsGo → provide vehicle-end models

Model learning + three-dimensional learning → learn the behavior of human drivers

New models → replace rule-based scenario determination and parameter setting

LUCAS Go → provide high-value data of vehicles driven by human drivers for TarsGo

- Introduce scenario digitalization and large-scale reinforcement learning in the decision-making phase:
  - ✓ Scenario digitalization: use parameters to represent different scenarios → classify and differentiate scenarios + use AI algorithms for learning
  - ✓ Reinforcement learning: simulate behaviors of human drivers to evaluate each driving behavior objectively → refine the reinforcement learning algorithm in the decision-making system

Driving environment entropy

- Set "driving environment entropy" as an indicator of the passing ability of the assisted driving mode during tests → evaluate the performance of its products
  - ✓ A function related to the number of traffic participants in the surroundings, relative distance, relative position, and direction of motion
  - ✓ Classify the traffic environment into 7 levels based on the function → compare test results and capabilities of products from Haomo.ai and other players in the industry

□ **Haomo.ai taps massive data to develop its algorithm development approach during the planning phase, which is important for the development and commercialization of AD technologies**

Business Cases: QCraft's Dual-Engine Strategy

■ Based on the "Gigafactory for Autonomous Vehicles" methodology and the past R&D efforts, QCraft has proposed a dual-engine strategy (power engine + innovation engine) → accelerate the large-scale application of AD technologies to vehicles

Power engine – L4 AD technologies

- The Power Engine is developed based on software and hardware solutions for L4 autonomous driving on public roads
- Make deeper dive into AD technology from the vertical dimension → bring autonomous driving to more use cases

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Continuously improve the efficiency of transportation in cities

Data generation and sharing

Innovation engine – L2 AD technologies

- The Innovation Engine is developed based on the solutions for production-oriented autonomous vehicles
- Expand use cases in a horizontal way → achieve the large-scale application of AD technologies

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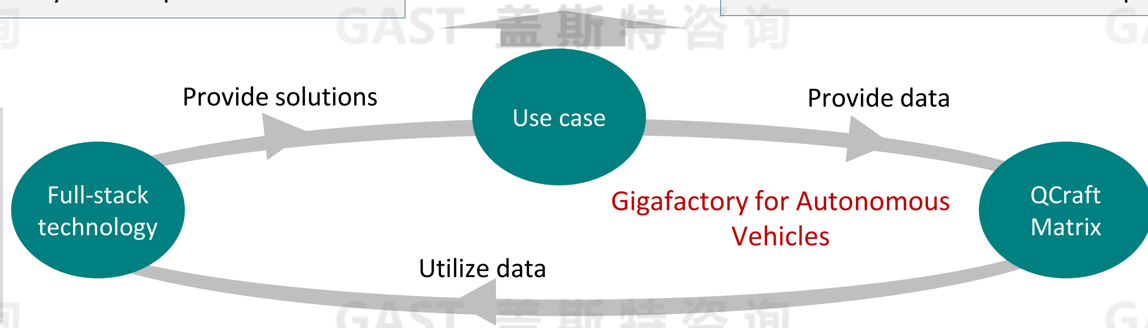
More cost-effective + safer + help customers explore new ground

- Full-stack technologies:
  - ✓ Hardware → sensors + x-by-wire + computing platforms
  - ✓ Software → perception algorithms + map-based positioning + cloud-based control



- Closed-loop approach of QCraft Matrix → data platform + labeling platform + training platform + simulation modules

Use cases → public urban roads + highways + enclosed industrial parks/scenic spots + fixed bus stations

□ Develop the "Gigafactory for Autonomous Vehicles" methodology at the underlying layer to achieve data closed-loop management and efficient data-driven iteration. Harness the two engines to enable data sharing → serve as an effective way to balance technology advance and commercialization

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Two Different Technology Pathways for Enabling Intelligent Vehicles with Autonomous Driving Capabilities

- There are mainly two technology pathways for enabling intelligent vehicles with autonomous driving capabilities: ① base on LiDAR and heavily rely on HD maps; ② base on cameras and moderately depend on HD maps

First technology pathway

- Laser radar*4 (sitting on every side of the vehicle)
- Top radar*1
- Camera*1
- Front and rear 77G millimeter wave radar*4
- Sound sensor*1

✓ **Evaluation:** adopt laser radars and highly rely on HD maps → better perception but high cost, which is not conducive to mass production

&

Second technology pathway

- Front camera*3 (normal / long-focus / wide-angle)
- Rear camera*3
- Side camera*2 (resting on each side of the vehicle)
- Ultrasonic radar*12
- Front MMW radar*1

✓ **Evaluation:** using automotive cameras to obtain data for the generation of HD maps → low cost + large-scale application, but with relatively insufficient perception

High cost

- To improve the vehicle safety → continuously increase perception, decision, and control redundancy
- Costly sensors and computing platforms → hard to realize commercialization

Hard to ensure safety

- Cameras are prone to accidents under extreme conditions, leaving smaller space for improving the intelligence level of vehicles and making it harder to ensure reliability → safety issues increasingly loom large

The two technology pathways have their own merits. To be specific, the LiDAR-based pathway is suitable for the testing and demonstration of advanced autonomous driving technologies, while the camera-based pathway is applicable to production vehicles to collect data at large scale

"Camera-Based Solutions" and "LiDAR-Based Solutions" for AD

- Camera-based solutions: similar perception principles, low cost, suitable for production, etc.
- LiDAR-based solutions: high coverage, better safety, lower technological requirements, etc.

Camera-based solutions	LiDAR-based solutions
• Like human eyes in terms of perception ✓ Data captured by cameras resembles the real world perceived by human eyes to the highest level ✓ Obtain data of the surroundings with a high frame rate and a high resolution Disagreement: ① camera-only solutions are prone to accidents in the case of backlighting and darkness; ② constrained by the limitations of technology, cameras cannot really change the focal length and the depth of field like human eyes	• High coverage: ✓ Cover more working conditions with the support of multiple sensors → enable more accurate description of the environment and obtain data from more dimensions Cons: ① the data rate of cameras is higher than that of radars by several orders of magnitude → better recognize the environment and make a response; ② outperform existing radars by adding cameras
• Low cost / suitable for mass production: ✓ When collecting data, autonomous vehicles with camera-only solutions can drastically reduce costs Disagreement: LiDAR manufacturers focus on lower-cost hybrid solid-state or semi-solid-state products	• Better safety: ✓ Safety is the top priority of vehicles → multi-sensor fusion solutions can better accommodate the conditions in China Cons: some players turn L4 autonomous driving into a reality merely via camera-only solutions
• Camera technologies are more sophisticated: ✓ Realize large-scale data acquisition without the need of vehicles with advanced AD capabilities Cons: the multi-sensor fusion technology is advancing g (for example, Huawei can integrate the data from multiple sensors about the distribution of obstacles)	• Lower technological requirements: ✓ With lower cost and simpler technical principles, cameras have high requirements on software algorithms ✓ As a fan of the camera-based solution, Tesla has accumulated massive algorithms, data and computing power → competitive edge
Typical players: Tesla, Mobileye, Toyota Woven Planet, etc.	Typical players: Nio, SAIC, BMW,BENZ, Volvo, XPeng, etc.

□ Limited performance of cameras is the pain point of camera-based solutions → it is uncertain whether they can reach the performance of LiDAR in the future. Cost is the pain point of LiDAR-based solutions, which will be reduced → LiDAR-based solutions are a notch above camera-based solutions

Case Analysis: Tesla's Camera-Based Solution

■ As a typical player in the "pure-vision" game, Tesla is not a fan of LiDAR

Tesla FSD relies entirely on the "vision" → phase down radar sensors

Evolution	• In 2021, Tesla released the FSD Beta V9.0, which was completely based on visual perception and dependent on cameras and AI algorithms • In May 2021, Tesla removed the millimeter-wave radars from its vehicles sold in the United States and Canada → adopt a vision system composed of eight 1.2-megapixel cameras • From February 2022, Tesla will not equip vehicles built for the North American market with millimeter-wave radars
Cost	• Camera-based solutions have a good cost advantage: a monocular camera costs 150~600 CNY + a complex trinocular camera costs less than 1,000 CNY ✓ The 8 cameras adopted by Tesla cost less than 1,400 CNY + the self-developed AD chip→ the total cost ≤ 10,000 CNY

Tesla's pure-vision approach has a marked cost advantage → favorable for large-scale application. However, it is still vexed by the problems of technologies, supervision, and the environment

Technology	• Translate 2D images into 3D images → ① the problem of delay; ② higher requirements on image processing algorithms, the quantity and quality of scenarios, and hardware computing power • Since "pure-vision" solutions cannot directly measure speed and acceleration → "ghost braking" will be a long-standing problem
Supervision	• According to the data security requirements in China, the cross-border transfer of data is not allowed, while "pure-vision" solutions require massive data, which means Tesla needs to "rebuild" its local organization to adapt to the unique scenarios in China → require a team composed of thousands of employees
Environment	• The traffic environment in China is far more complex than that in the United States, which requires massive auxiliary information beyond the vision → relying on real-time data, the "camera-based" perception system is difficult to be widely applied

□ Relevant players can try to find ways for camera-based solutions and LiDAR-based solutions to coexist: as the most appropriate approach at present adopted by most players → build safety redundancy based on camera-enabled solutions and other sensors like LiDAR

Case Analysis: Haomo.ai's Technology Pathway

■ Haomo.ai makes up for the loss caused by the lack of HD map by training algorithms. Meanwhile, it maps out technology pathways according to application scenarios

Haomo.ai adopts a "perception-focused" technology pathway to optimize the perception algorithm via training	
Reasons	① No city-level HD maps approved at present; ② Even if approved, HD maps will take quite a long time to be generated → hard to be applied to production vehicles in a short term
Traffic lights (an example)	• Create traffic lights under different lighting and weather conditions via a 3D simulation engine, which are then used for model training → increase the number of training samples • Without HD maps, the autonomous vehicles can process and recognize traffic lights merely by perception and figure out the relationship between the traffic light and the road
Technological barriers	• Accuracy of the perception algorithm: with poor accuracy, the vehicle will not run well on the road even with accurate topology information, let alone its own accuracy difference
Haomo.ai selects sensor technology pathways by scenario → production vehicles (camera-based approach) + AV test (LiDAR-based solution)	
Production vehicles	• A range of GWM's production vehicle models have been equipped with Haomo.ai's intelligent driving system, with a certain mileage logged in the autonomous driving mode → without LiDAR, it is hard to empower vehicles with autonomous driving capability by 2D data. Only by translating 2D data into 3D information, the value of such data can be fully tapped
AV tests	• Allow free data flow between testing scenario, but the sensors for logistics vehicles and passenger vehicles vary greatly in terms of the version and location. There are some differences in the ODD for logistics vehicles and passenger vehicles, albeit some similarities → making good use of these data entails the improvement of technologies

* Topology information: refers to the number, type, and relationship of topological elements (vertices, edges, and surfaces) of an object

□ **Important thresholds for Haomo.ai to move towards advanced autonomous driving: ① translate the data collected by cameras on production vehicles to 3D information; ② allow free data flow between AD testing scenarios**

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Digest of the Concept of Safety for Smart Vehicles

- The safety for smart vehicles includes basic safety, functional safety, Safety Of The Intended Functionality (SOTIF), and information security

Safety for smart vehicles

Classification	Regulations/standards	Specific content	Solutions
Basic safety	Traffic regulations	Collision safety & non-collision safety	Road traffic regulations
Functional safety	ISO 26262	Caused by the failure of automotive electric and electronic devices	Relevant standards, specifications, and regulations
SOTIF	ISO 21448	Caused by random unknown scenarios, limited algorithm performance, and random HMI behaviors	Hard to define "unknown" issues with the incumbent laws
Information security	SAE J3061	Information security	Resolved by government laws

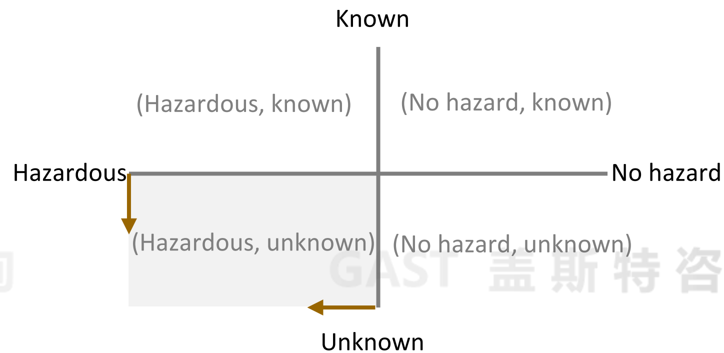
- **Different from the other three kinds of safety problems, it is hard to define the "unknown" issues of SOTIF under the incumbent legal framework, which means "we don't know what we don't know" (unknown unknowns) → it is one of the biggest problems for the commercialization of AD technology**

Digest of Long-Tail Problems of SOTIF

- The main purpose of SOTIF is to control the risks caused by insufficient design and performance limitations within an acceptable range

Causes	Specific phenomenon
Random unknown scenarios	• Scenarios not included in the scenario library: ✓ Unconventional perception targets such as traffic accidents ✓ Unknown environmental factors such as extreme weather ✓ Even the tests in which vehicles log hundreds of millions of kilometers are not enough to cover all low-probability events
Limited algorithm performance	• There are limitations in perception performance: unable to recognize irregularly-shaped vehicles ✓ A white truck knocked over on the road ✓ Involve in a rear-end collision with a sanitation truck on the highway ✓ Encounter a rear-end collision with an irregularly-shaped truck
Random HMI behaviors	• Behaviors of unexpected traffic participants: ✓ An autonomous delivery vehicle collided with a private car ✓ An autonomous vehicle killed a pedestrian crossing the road • Human drivers' misuse of the autonomous driving technology

Diagram of SOTIF states



Ways to reduce "the hazardous unknowns":

- Introduce empowering outside vehicles → develop V2X
- Enhance automotive enabling → improve algorithms
- Improve HMI:
  - ✓ Intelligent driving that can alert the human driver ≠ autonomous driving
  - ✓ Regulate the behaviors of pedestrians as traffic participants

☐ **Nearly 80% of the safety problems can be quickly solved during the R&D of intelligent vehicles, while addressing the rest 20% of the SOTIF problems will require enormous (80%) efforts**

Traditional Vehicles versus Smart Vehicles: Product Certification

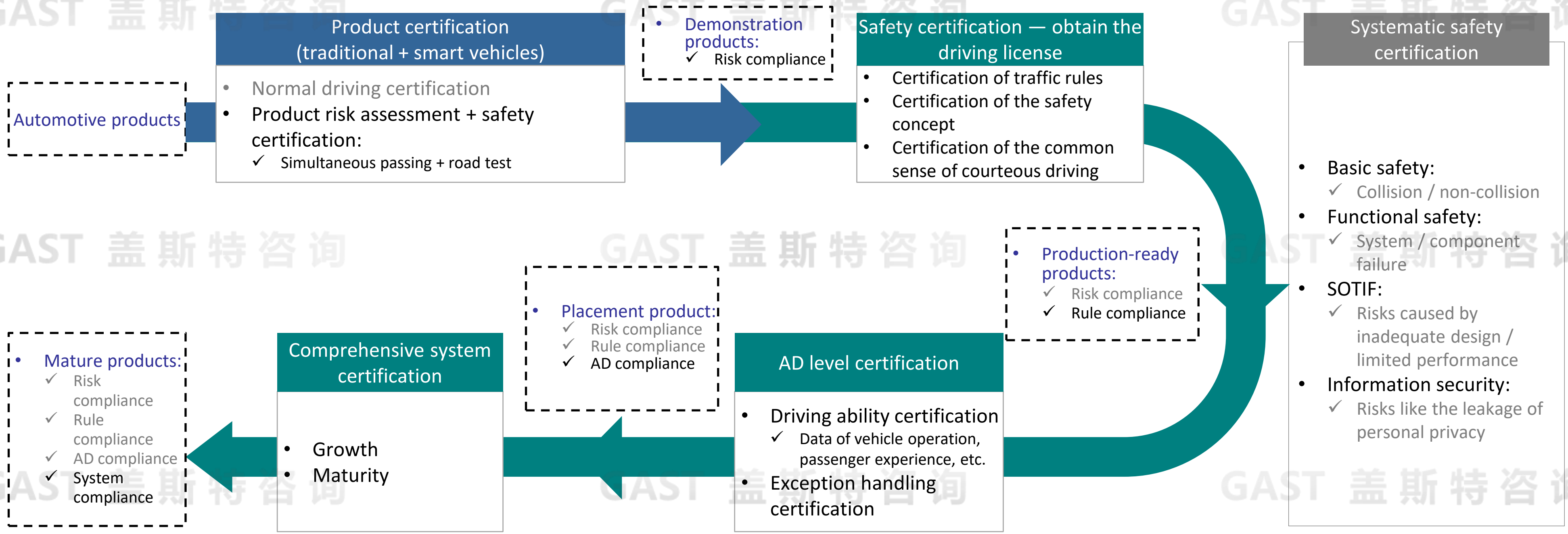
- Based on traditional vehicle architectures, smart vehicles are equipped with sensors and functional modules to achieve intelligent driving and other functions. Smart vehicles and traditional vehicles vary greatly in terms of the test object and test content

Product certification for traditional vehicles	Product certification for smart vehicles	There are long-tail problems of the product certification for smart vehicles
• Most of the test objects are the electromechanical systems of the vehicle: ✓ Reliability ✓ Noise Vibration and Harshness (NVH) ✓ Heating, Ventilation and Air Conditioning (HVAC) ✓ Electro-Magnetic Compatibility (EMC) ✓ Chemical analysis ✓ Vehicle performance on the road • Test environment: ✓ Various kinds of indoor laboratories ✓ Enclosed site for testing the comprehensive performance of the vehicle ✓ Public roads with different geographical conditions ↓ ✓ Test subject: no specific driving behaviors/processes ✓ Test environment: required environment/mileage	• Test object → electromechanical and intelligent systems • Electromechanical systems: ✓ Similar to the product certification for traditional vehicles • Intelligent systems: ✓ Driving performance ✓ SOTIF ✓ Functional safety ✓ Information security ✓ System maturity ↓ ✓ Electromechanical systems: the certification standards are relatively sound ✓ Intelligent systems: there are basically no certification standards	The scope of certification is extended to machine driving capabilities → put the test of driving capabilities in traffic scenarios → complex and random traffic scenarios ↓ ① Scenarios: infinite ② Probability of scenarios: approximately under a normal distribution → hard to obtain low-probability scenarios ③ Existing testing verification methods: low efficiency → unable to complete large-scale testing ④ Algorithms: no reasoning/self-learning capabilities → unable to guarantee the adaptability/reliability of verification results

- **The scope of intelligent vehicle certification is extended to intelligent driving systems and algorithms, which is a new problem for the automotive industry. The absence of the certification standards will greatly affect the commercialization of smart vehicles**

Digest of Smart Vehicle Product Certification: New System & Key Content

■ Based on the product certification system for traditional vehicles, the new product certification system for smart vehicles combines the certification of testing technologies and traffic regulations to address the long-tail problem



□ The new product certification system for smart vehicles enables the full life cycle (R&D → after-sales service) from such four aspects as product certification, safety certification, AD level certification, and comprehensive system certification

Contents

Forecast of Advanced Autonomous Driving Development Trends

■ The development of advanced autonomous driving requires continuous innovation, which is mainly reflected in the following aspects

First trend

advance technology development and commercialization together

AD: validate technologies → verify business models

- Four available scenarios by 2025: highways + restricted areas + mixed traffic on urban roads + suburban/rural roads
- Promote the development of technologies, business models, and the industrial pattern
  - ✓ Aggregate players + promote diversified services + create new business models

Future development directions of ICV products and application scenarios

- ICV products: develop autonomous passenger vehicles, shared cars in cities, and platooning commercial vehicles
- Scenario: limited areas → limitation-free areas

Second trend

more extensive benefits / play a role at a higher dimension

Realize future goals via AD based on the "vehicle-road-cloud synergy"

- Infrastructure enables autonomous driving + mobility service + additional application under the V2X concept → increase the travel efficiency
- Upgrade the communication technology → 4/5G-V2X

Boost the integration of "4S"

- Developing smart vehicles, smart transportation, smart cities, and smart energy (4S) in an integrated manner has become an industrywide consensus
- ICVs with autonomous driving capabilities will play a role at a higher dimension

Third trend

faster create new product development models

AD will push vehicles to become "software-based and chip-enabled"

- Value of vehicles: hardware + software → hardware + software + service + content
- AD algorithms have high requirements on the speed of computing and the timeliness of processing → software code will surge, requiring high-performance automotive-grade computing chips/platforms

New data-driven AD SW development mode

- New mode: road data → AI training → OTA updates
- Improve the data collection capability → generate large data sets
  - ✓ Characteristics: large scale + non-repetitive + AI-trained data
  - ✓ Significance: expand the ODD and address the long-tail effect

Summary

The Latest Development Trends of Advanced Autonomous Driving Technologies

- **Autonomous driving algorithm development methods**
  - ✓ At Stage 1.0: there are man-made rules, with inadequate machine learning and limited system effectiveness
  - ✓ At Stage 2.0 based on machine learning and data priority: break the limitations in algorithm performance at Stage 1.0 → increase the iteration efficiency and cut costs
- **Selection of advanced autonomous driving technology pathways**
  - ✓ The pathway of intelligent vehicles: insufficient perception + hard to realize large-scale commercialization
  - ✓ Camera-only and LiDAR-based solutions have their own merits → the combination of cameras and LiDAR systems may become a future trend
- **Smart vehicle security and product verification**
  - ✓ There are massive “unknown” problems in the SOTIF → one of the biggest problems facing the commercialization of AD technology
  - ✓ Intelligent vehicles and traditional vehicles vary greatly in terms of the test object and content + there are no relevant verifications standards in place → impact the commercialization
  - ✓ New product verification system (test technologies + traffic regulations) → underpin smart vehicles across the life cycle

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