GAST Automotive Industry & Technology Research Report
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Subject: Development Trends of City NOA Technologies

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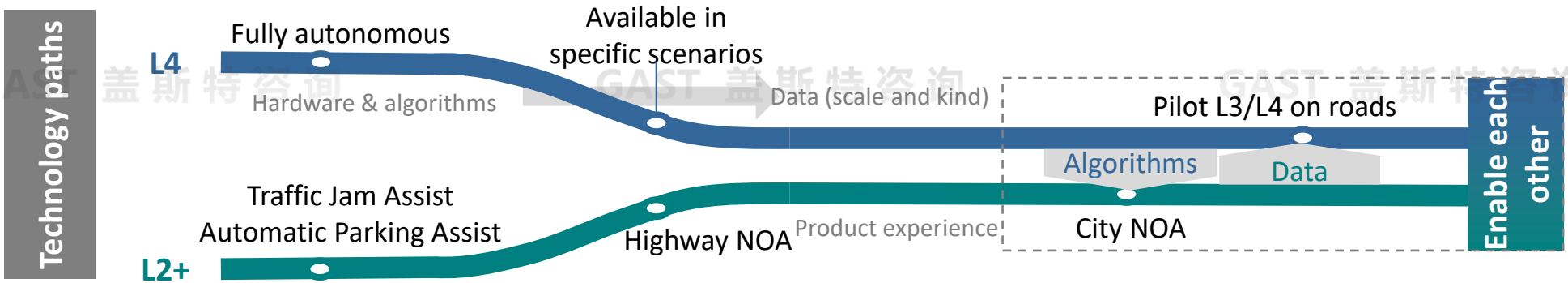
Evolution Trends of AD Technology and Insights into Players' Strategies

■ A gradually clear AD technology path: L2+ and L4 enable each other and get integrated



OEMs upgrade intelligent driving technologies faster and bring solutions to urban roads: AD companies migrate to L2+ AD solutions for business purposes

L2+ AD players (OEMs)	➢ Pay more attention to user experience + make full use of production vehicles to collect massive data → empower L2+ AD and develop L4 AD technologies • Cooperate with AD companies on technologies via production vehicles (SAIC + Momenta; GAC + Pony.ai/WeRide) • Amass data to drive the evolution of self-developed technologies (Haomo.ai HPilot; NIO NOP+; XPeng NGP)
L4 AD players (AD companies)	➢ Develop L2+ solutions with the L4 methodology and leverage more advanced technologies to enable advanced driver assistance to make profits and drive the evolution of L4 technologies in return • Baidu ANP3.0 (city/highway pilot + parking); QCraft NOA & Pony.ai NOA (highway pilot + driving assistance on urban roads)

The overall development of the AD industry: focus on the commercialization of L2+ AD solutions; develop L4 AD technologies against a rainy day; highlight intelligent driving functions for travelling in urban areas

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Intelligent Driving Moves to Urban Areas and City NOA Become a New Arena

■ City NOA is far more difficult than Highway NOA, which is also a direction for players to allow users to better experience AD products and functions

As the next priority, City NOA is the sure-fire way

① User experience	② Business development	③ Technology advance
➢ Experience in specific scenarios → running on highways and urban roads + parking: allowing users to experience more comfortable, safer, and smooth intelligent driving ➢ High demand for mobility services in cities • Distance travelled on urban roads: 71%; Time of travelling on urban roads: 90%	➢ Realize large-scale applications, improve profitability, and collect massive data to enable the evolution of L4 AD functions • Large-scale applications: obtain massive data → accelerate the evolution of technologies • Improve profitability: the progressive development road would deliver greater business value	➢ The improvement and adoption of core SW & HW lay a foundation for the evolution and availability of intelligent driving functions in more scenarios • HW: high-performance chips and LiDAR products have been applied to production vehicles • SW: HD map permits are gradually issued

The intelligent driving industry has developed to a point where delivery matters → pay more attention to products and technologies for production vehicles

Intelligent driving solutions for urban areas are the sure-fire way to fully autonomous driving, which would accommodate technological innovation and commercialization

Drive technological innovation	Apply intelligent driving functions to production vehicles running on urban roads to collect massive data → update and upgrade algorithms
Promote business profitability	Make profits via the application of intelligent driving functions to production vehicles

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Cruxes of City NOA and Corresponding Solutions

- Compared with Highway NOA solutions, City NOA solutions would face more complex scenarios and difficulties in technologies, cost, supervision, etc. when applied to production vehicles

		Difficulties	Solutions
Complex scenarios make it hard to sense	Massive long-tail cases	➢ Ordinary sensor solutions for driver assistance: insufficient performance	➢ **Increase the use of LiDAR or 4D MMW radars to improve the performance**
		➢ Sensors: massive data to be collected; low efficiency of data processing	**Vehicles** ➢ Adopt larger computing power **Cloud** ➢ Data acquisition: Shadow Mode + cloud-based simulation ➢ Data processing: automatic data closed-loop toolchain ➢ Necessary pillar: intelligent computing centers + toolchains
	Difficult to handle cases	➢ Algorithms: low efficiency of evolution; insufficient for complex situations	
		➢ It is hard to strike a balance between the utilization of algorithms and the accuracy of perception	➢ **Multi-sensor fusion: front-forward fusion; BEV feature fusion algorithms**
Slow release of HD map permits	Strict geographic data supervision and maintenance	➢ Surveying and mapping: hard to obtain the qualifications; stringent review requirements ➢ Map data collection: massive data; low update frequency	➢ **Improve the performance of sensing hardware + mapping lightweight maps** ➢ **Strengthen perception algorithms to no longer rely on HD map**
High costs	Hardware installation	➢ Advanced technologies: require numerous LiDAR + high cost	➢ **Enhance vision algorithms to reduce the number of LiDAR**
		➢ Pre-install high-performance foreign chips → high cost	➢ **With a domestic chip vendor service ecosystem initially established, automakers and chip providers can get deeply involved in the customization**
	Software improvement	➢ Algorithm evolution: high requirements on data quality; Data labeling: mainly rely on human workers → high cost	➢ **Combine manual labeling with automatic labeling**

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Players Seize Opportunities in the Intelligent Driving Market in 2023

- It is far more difficult to apply city NOA solutions to production vehicles than highway NOA systems, but they can meet most consumers' commuting needs. Therefore, players vie with each other

City NOA can lead AD product experience

Seize market: vie to apply solutions to production vehicles ahead of others to accumulate more data and update algorithms faster → "snowball effect"

Improve brands: help players to widen the gap between themselves and rivals in the driver assistance game, which is becoming increasingly stiff, and showcase their technologies suitable for assisted driving in all scenarios → help to build high-end brand images

City NOA solutions would become the core of relevant players in 2023

Player	Company	Name of City NOA solutions	Planned time	Actual time
New entrants	Tesla*	FSD	2020	Nov. 2022 (North America)
	XPeng	CNGP	Q1 2022	Sep. 2022
	ARCFOX	NCA	May 2022	Test in Sep. 2022
	NIO	NOP+/NAD	Q1 2023	Under test
	Li Auto	NOA	End of 2023	/
Traditional OEMs	GWM WEY	NOH	Q1 2023	Under test
	SAIC iM	IM AD	End of 2022	Test in Q4 2023
	Jidu Auto	ANP3.0	Q3 2023	/
	Changan Automobile	Zhuge Intelligence	2024	/
Suppliers	Freetech	/	Q3 2023	/
	iMotion	IDC HIGH	End of 2023	/
	DJI Automotive	/	2023	/
L4 AD companies	IDRIVERPLUS	C-INP	Q3 2023	/
	Baidu	ANP3.0	Summer of 2023	/
	QCraft	NOA	Middle of 2023	/
	Pony.ai	NOA	H1 2023	/

*Note: Tesla's FSD City NOX solution was available in North America

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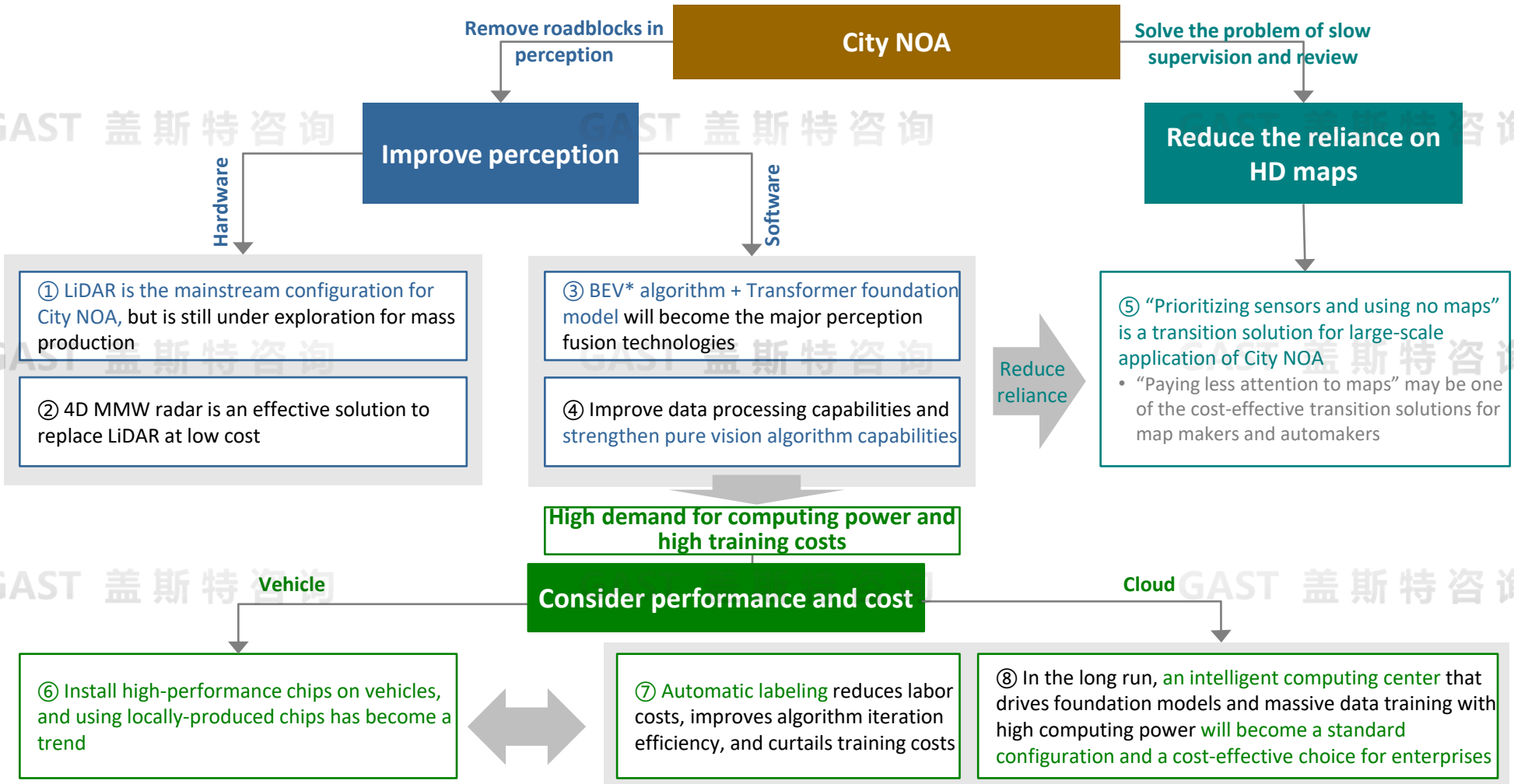
Technical Elements and Paths for City NOA Solutions



*BEV: Bird's-Eye-View

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① As a Major Enabler for City NOA Solutions, LiDAR is Under Exploration for the Application to Production Vehicles

■ LiDAR can make up for the shortcomings of the perception algorithm and improve the perception performance of the overall solution in urban scenarios

Less difficult analysis of algorithms

- Through active detection technology, LiDAR can directly build a road condition model, reducing the difficulty of analysis

Excellent performance → solve most long-tail issues in cities

- Distinguish multiple obstacles on the same occasion (such as people next to parked vehicles), and use point cloud imaging technology to identify traffic lights floating in front of the vehicle, etc.

Currently, one or more high-channel LiDAR units are gradually becoming the basic configuration of City NOA solutions*

- The data of urban scenarios is small in volume, and the algorithm is less competitive
- Adding one or more LiDARs can improve perception performance + brand premium

Model	LiDAR	MSRP (CNY)
XPeng P5	2	200,000+
ArcFox αS HI	3	~400,000
WEY Mocha LiADR Edition	2	300,000+

Automakers should focus on the cost and stability of LiDAR products, rather than only on performance

The large-scale application of LiDAR would depend on the speed of cost reduction

LiDAR costs high at this stage

- The price of a LiDAR is about 5 times that of a 4D MMW radar
- The price of a LiDAR is about 10-20 times that of a camera

Made into a chip

Fast cost reduction

- LiDAR will enter a period of rapid growth and become cost-effective perception hardware for City NOA

Slow cost reduction

- Data accumulation drives software algorithms to reduce their dependence on hardware. At that time, cost performance will become the main consideration, and LiDAR may be replaced as a transitional product

□ **LiDAR has obvious advantages in complex urban scenarios, of which automakers should focus on cost and stability. With the accumulation of data, the speed of cutting the cost of LiDAR would be the key to the large-scale application to production vehicles**

*Note: for detailed parameters of the models equipped with LiDAR, see the Appendix

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② 4D MMW Radar is a Low-Cost and Effective Alternative to LiDAR

■ The high-quality application of City NOA requires full-spectrum perception capabilities, while 4D MMW radars can overcome the limitations of traditional radars

4D MMW radars can solve some problems in urban scenarios

- Perform higher-level detection of targets in ordinary scenarios, improve scenario coverage and processing power
  - Identify objects floating in front of the car, people nearby parked vehicles, two vehicles 300 meters away, etc.
- Maintain good performance in urban corner cases
  - Prevent continuous rear-end, brake of the car in front of the front car, high light ratio, etc.

Outperform 3D MMW radars and replace low-channel LiDAR

- VS. 3D MMW radars: provide more characteristic information in a more accurate way and replace ordinary long-range MMW radars
  - Solve the problems that 3D MMW radars cannot handle (e.g. identification of floating objects, etc.)
- VS. LiDARs: ① good penetration → detect the target in front of the obstacle; ② not affected by the environment and light; ③ far lower price than LiDAR

Visual algorithms + 4D MMW radars → effective fusion and safety redundancy: likely to become a basic sensing portfolio for City NOA solutions

4D MMW radars + DL algorithms → improve the richness of perception

- Software: provide more safety redundancy for the development of core competitiveness
- Deep learning: increase the accuracy of detecting small objects, improving safety redundancy
  - Reduce missed detection by 70% and detect fragments of small objects

Different from the perception solution of LiDAR: 4D MMW radars can be applied to production vehicles at a large scale

- L2+ AD: a 4D MMW radar in the front = MMW radar + LiDAR
- L3 & L3+ AD: more than two 4D MMW radars → higher safety redundancy

The verification of real-world applications is rare, but algorithms would be upgraded with the accumulation of data, which may further facilitate the large-scale application of City NOA solutions to production vehicles

□ **In addition to performance and point-cloud quality of radars, automakers can consider 4D MMW radar algorithms when selecting products, which would help OEMs to better develop functions as a key factor**

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③ BEV + Transformer Algorithms Would Become the Major Solution for Multi-Sensor Fusion

■ With the evolution of visual algorithms, BEV perception algorithms have become the core solution for OEMs and AD companies to bring AD functions to urban roads

XPeng	The perceptual architecture XNet can fuse the data collected by cameras before multi-frame timing, and output 4D dynamic information under BEV	Pony.ai	Self-develop BEV perception algorithms to minimize computing power requirements, and only use navigation maps to achieve Highway and City NOA
Li Auto	The AD Max system applies BEV, using pure vision for perception prediction + multi-sensor fusion and HD maps for information input	QCraft	The OmniNet perceptual fusion foundation model performs pre-fusion and BEV spatial feature fusion of the data perceived
NIO	The NAD system will have the underlying perceptual architecture switched to the BEV model in the first half of 2023	Baidu Apollo	The timing BEV technology enables end-to-end obstacle detection, trajectory and intent prediction, and road structure perception

BEV solves the problem of multi-sensor fusion, provides multi-time and multi-perspective perception information, and enhances the effectiveness of decision

① Easy to realize timing fusion Realize the fusion of temporal information and build a 4D space	③ End-to-end optimization Use neural networks for end-to-end optimization to avoid error accumulation, reduce the influence of algorithm logic, and use data to drive learning
② Easy to enable multi-modal fusion Make the algorithm analysis simple and visually display objects	④ Save computing power resources and achieve accurate perception Fewer perceptual errors compared with the post-fusion algorithm; lower computing power requirements compared with the pre-fusion algorithm

① Create an AI algorithm foundation model*
Promote the continuous iteration of algorithms with the AI foundation model as support and Transformer as the subject of the perception algorithm

Automakers should build a data intelligence system and an AI algorithm foundation model to upgrade and optimize BEV technology

② Build a data intelligence system
Foster a full-stack autonomous data closed-loop capability from data acquisition, analysis, verification, to mass production practice

□ **BEV marks another step after deep learning. BEV would develop to integrate multi-sensor fusion and space-time fusion, solving the difficulty in applying heterogeneous sensors to vehicles. In the future, technologies would rely on the data-driven mode to get further developed**

Foundation model: involve tens of millions to hundreds of millions parameters + require massive data training

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④ Pure Vision Technology Path: Low-Cost Algorithms are the Key

■ The visual path and big data promote each other and data accumulation drives software to reduce dependence on hardware

The visual path is the core of the rapid accumulation of data

➢ The perceptual hardware solution features the most cameras, and the large-scale commercialization of the intelligent driving solution accelerates data accumulation

Data accumulation drives software to reduce reliance on hardware

➢ As the amount of data grows and the software matures, the use of expensive hardware will be reduced
- Relying on the data of hundreds of millions of miles, Tesla has gradually shifted from a multi-sensor fusion solution to a pure visual perception solution

The vision-based perception solution may become the core solution for scale application of City NOA to production vehicles

Vision solution + data can solve most problems in urban scenarios

➢ Vision + data = 4D spatio-temporal perception → realize the effect of LiDAR, and solve urban problems such as road construction response, overtaking detours, and steering processing at intersections

A low-cost vision solution can better promote the scale application of algorithms

➢ The visual algorithm solution costs low and allows the application of advanced intelligent driving functions to low-end models
- The cost of a LiDAR and MMW radar is about 10 times and 4 times that of a camera

Players in all links along the AD industrial chain build their own product or technology ecosystems around visual algorithms

AD player	Haomo.ai	Mainly follow the vision path, and integrate the Transformer neural network effectively with massive data
	Baidu	Rely on BEV surround-view perception technology to create a perception solution that is based on visual algorithms and can solve problems in multiple urban scenarios (LiDAR as a redundant solution)
New player	XPeng	Build a City NOA solution that does not rely on HD maps based on BEV perception and Transformer model
Production-oriented enterprise	Horizon Robotics	Develop a visual perception algorithm based on its own chip to provide a software and hardware integrated solution
	DJI	Apply the NOA system enabled by binocular vision on Wuling Hongguang KiWi EV priced at about 100,000 CNY, which is combined with hardware to realize intelligent driving on complex urban roads
	Mobileye	Become the world's largest AD company by shipments relying on the vision solution
Traditional JV	Dongfeng Nissan	Venucia has forged cooperation with Horizon Robotics to develop advanced autonomous driving functions based on the latter's chip-level vision algorithm
	Toyota	From 2023 onwards, models under its brands will successively adopt the master vision technology solution "Mobileye + ZF" to enable advanced intelligent driving functions

□ **In the data-driven stage, massive data can be accumulated quickly, algorithm capabilities will gradually be enhanced, and visual algorithms will become the key to low-cost perception solutions**

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⑤ "Prioritizing Sensors and Using No Maps" is a Tentative Solution for the Large-Scale Application of City NOA

- In 2022, automakers still relied on HD maps to bring AD technologies to production vehicles. To that end, automakers will have two strings to their bow in 2023

The development of HD maps face great challenges, and the authorization of HD maps is slow (only available in Shenzhen, Shanghai and Guangzhou) → difficult to meet the expectations of automakers

HD map data collection: large workload and high cost
- Low frequency and freshness of monthly/quarterly collection
- The data collected and surveyed from some roads is sensitive and only covers some areas

Strict supervision → difficult to pass the qualification review
- The 31 players with Grad-A surveying & mapping qualifications in 2021 was cut to only 19 by 2022

Map crowdsourcing mode is not permitted
- China clearly stipulates that crowdsourcing methods belong to surveying & mapping activities and should be subject to the constraints and management of surveying and mapping-related regulations and systems

Two-pronged strategy for automakers

① Use HD maps
- In cities where map permits are granted: use HD maps as an effective supplement to perception solutions to enhance the intelligent driving experience

② Develop a technical solution "free of HD maps"
- In cities where map permits are not granted: take the route of prioritizing sensors over maps → roll out quickly across the country

Supporting technologies are maturing
- High-performance computing platforms are applied to production vehicles
- high-performance sensors are applied to production vehicles
- Software algorithms are becoming more mature

The HD map-free path gradually emerges and automakers are moving faster to apply City NOA
- XPeng plans to use no HD maps in its X-NGP and expand the City NGP to 50 cities in 2023
- Haomo.ai plans to launch City NOH that does not rely on HD maps in 2023, and expand it to 100 cities in the first half of 2024
- Li Auto plans to launch City NOA that does not rely on HD maps by the end of 2023

The uncertainty of policies and the challenges facing HD maps have forced automakers to have two strings to their bow to navigate. They should develop perception technologies without HD maps and accelerate the promotion of products to seize more market share

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⑥ Homegrown High-Performance Chips Would Lay a Foundation for the Application of City NOA to Production Vehicles as an Alternative

Complex urban scenarios and architectural trends require chips with high computing power, but the cost of high-computing-power chips is high

- Data processing needs: more high-performance sensors will lead to rising demand for processing massive data, and more complex algorithm models
- New architecture trends: as E/E architectures become increasingly centralized, computing power is mainly controlled by a few domain controllers or central computing platforms, which require high computing power for a single chip

Automakers pay more attention to chip cost and service than performance → domestic chip vendors move faster to replace foreign counterparts

For example, QCraft and Pony.ai rolled out their City NOA for production vehicles based on Journey 5

① Cost advantage: locally-produced chips have a cost advantage, which is conducive to the promotion of AD systems
- An Nvidia Orin costs 400+ USD, while the price of a Journey 5 chip is less than a half of the former

② Focus on dedicated chips: unlike Nvidia and Qualcomm that develop general-purpose chips, domestic chip manufacturers focus more on special algorithms in the field of autonomous driving

③ Supply chain security: affected by the ban on AI chips in the US, chip supply and demand in China have increased

④ Local service: it is more convenient for local chip makers to communicate with local OEMs, and the products defined by them after understanding the real needs of the local market can better be applied to production vehicles

⑤ Open and convenient service ecosystem: adopt an open co-creation approach and continuously provide new cooperation models and permissions to automakers to meet their needs for customizing and enhancing their software R&D capabilities
- Horizon Robotics builds a chip + tool open technology platform, which includes hardware reference design, tool chain, etc., to help ecosystem partners complete the development of full-stack functions from hardware to software in a short time

Automakers face great challenges in self-developing chips

- Weak design ability: weak ability in product definition, development speed, manpower, etc.
- High R&D cost: it is difficult for a single OEM to in-house develop tens of millions of chips at every turn, which requires high, continuous investment

Differentiated customization via in-depth cooperation with chip manufacturers may be a better choice

- Automakers use the technology platform of chip manufacturers to independently develop autonomous driving chips
  - Li Auto and Horizon Robotics co-develop AD Pro autonomous driving platform
- Tie-up with chip manufacturers (Volkswagen's CARIAD and Horizon Robotics set up a JV

Imported chips with high computing power are expensive and cannot meet the customization needs of automakers. Based on the cost and service ecosystem advantages, locally-produced chips would replace foreign peers at a faster pace and fuel the scale application of City NOA to production vehicles

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⑦ Automatic Labeling + Manual Labeling is an Effective Means to Cut Costs and Improve the Efficiency of Data Labeling to Navigate a Transition Period

■ In the data-driven stage, AD has high requirements on data labeling. Extensively used, manual labeling is costly

The rapid evolution of AD algorithms require data labeling to factor into quality and efficiency

➢ Autonomous driving performance is based on high-quality data
- The upgrading and iteration of L2+ AD systems needs to be driven by a large amount of long-tail scenario data. The higher the quality of the labeled data, the more adequate the model training and performance optimization

➢ The efficiency of data labeling is the key to rapid algorithm iteration
- In the data-driven stage, high data processing efficiency will accelerate the upgrading and iteration of technologies and promote the continuous improvement of functional experience

Cost reduction is the key

Manual labeling + automatic labeling would be a more cost-effective solution in a short term

Manual labeling: high quality, low efficiency, high cost
- The accuracy rate of data manually labeled is high, but many links still rely on human judgment and behavior at this stage
- 95% of AD data relies on manual labeling, but manual labeling efficiency is low

Automatic labeling: low quality, high efficiency, low cost
- Automatic labeling technology is not mature, mainly stranded in the pre-labeling link, and in other key scenarios, data is repeatedly labeled
- It takes a long time for automatic labeling technology to mature, requiring the support of foundation models and large computing power

All links of the data production process would be automatic in the long run → align the large-scale supply with cost effectiveness

□ **Automatic labeling is in its infancy and manual labeling is still necessary to AD data. Therefore, the combination of manual and automatic labeling will be a tentative solution for full automation and intelligent transformation → OEMs can pay attention to technologies and human operation & management capabilities of suppliers' labeling platforms, and forge stable cooperation with them to continuously enable stable and low-cost data production**

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⑧ Intelligent Computing Centers are Necessary for AD Players in an Era When Data Would Make a Big difference

- Data is the core element to determine different AD experiences and upgrade technologies, which is also the key to the next stage of development

Stage 3.0 data-driven stage

Stage 1.0: hardware-driven
The hardware solution is fixed → only need updates

Stage 2.0: algorithm-driven
The underlying architecture basically does not change → only need to modify the iteration process

Stage 3.0: data-driven
The amount and quality of data determine algorithm iteration pace → drive advanced technology iteration

The data-driven mode of "foundation models + big data" has become the key to AD technology evolution → require high computing power

① Massive computing data
multi-server collaboration requires high communication bandwidth

② Ultra-large-scale data training
Require high efficiency in the random storage of data

③ Application of foundation models
require high-performance storage bandwidth

Intelligent computing centers may become a standard configuration for Stage 3.0
For example, XPeng's Fuyao, Haomo.ai's MANA OASIS, Geely's Xingrui, Tesla's DOJO

Lay a foundation for urban scenarios
- Compared with highways, urban scenarios are more complex, and the scale of data sets for special AD scenarios has increased by hundreds of times

High cost performance in the long run
- As the amount of data stored and processed grows, the marginal cost of using public cloud services will continue to rise

High performance and high efficiency
- More adequate computing power and faster communication transmission
- Support more people to develop online at the same time → higher efficiency

Best match between algorithms and models
- The equipment of cloud service providers is versatile, and it is difficult to form the best match with the algorithms of autonomous driving companies

① Deliveries: more than 200,000 vehicles (XPeng and Haomo.ai)

Intelligent computing center should be built to enable appropriate deliveries and mileages → cost-effective

② Total mileage in the intelligent driving mode: over 100 million kilometers (XPeng and Tesla)

The AD industry has entered a critical data-driven stage, when the speed of acquiring and processing data is a key factor of algorithm evolution. Supercomputing centers that drive the training of foundation models and massive data would enable businesses to manage big data on a deeper level, upgrade algorithms at a faster pace, and advance AD technologies to a higher level

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Functions and Use Cases of NOA Solutions by Major Player in China (1)

- XPeng: aggressive → frequent sudden stops and system logouts; Arcfox: overall stable performance; Haomo.ai: too conservative → severely rely on rules

System	Special cases			Local cases							Running on the road			Conclusion
	Channel	Road under construction	Nighttime	ETC	Obstacle avoidance	Mixed traffic flow (pedestrians + cars)	Car following	Unexpected road hazards	Unprotected left turn / U-turn	Cut-in vehicle	Overtaking / lane changing	Sharp turn	Optimal lane	
XPeng CNGP	√	× Fail to identify roads under construction and drive into the zone	√	×	☆☆☆ Stop and wait; triggered by stepping on the gas; low efficiency	☆☆ Too sensitive to non-motor vehicles and pedestrians; stop to avoid; frequent brakes to a sudden stop	√	☆ Sudden brakes to a sudden stop	☆☆☆ Smooth ride	☆ Frequent sudden brakes to a sudden stop; forced lane changing	☆☆☆☆ Decisive lane changing + accelerate to overtake	√	☆ Inflexible options	☆☆☆ Frequent brakes to a sudden stop; aggressive on the whole
Arcfox NCA	√	√	√	×	☆☆ Stop and wait; manual take-over; low efficiency; inflexible behaviors	☆☆☆☆ Smooth ride; fewer brakes to a sudden stop	√	☆☆ Decelerate to a stop	☆☆☆ Smooth ride	☆☆☆ Brake to a sudden stop to wait; smooth ride	☆☆☆ Smooth overtaking; complex road conditions; lane changing requires acceleration	√	☆ Inflexible options; low success rates	☆☆☆ Smooth passing; require more intelligent handling of obstacles
Hao.mo NOH	√	√	√	×	☆ Brake to a sudden stop	☆☆☆ Slow down to avoid and stop to wait	√	☆ Sudden brakes to a sudden stop in case of crossings and large vehicles	☆☆ Decelerate to pass; low efficiency	☆☆ Slow down in advance; potential sudden brakes to a sudden stop; a strong feeling of abruption	☆☆ Slow down to change lanes; low efficiency	√	☆ Inflexible selection of roads	☆☆ Too conservative; low efficiency

√: Available ×: Unavailable ☆: Experience

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Functions and Use Cases of NOA Solutions by Major Player in China (2)

- QCraft's solution is aggressive, reflecting a weak recognition of road rules but flexible obstacle avoidance; Baidu's solution enables smooth rides and stable handling of complex road conditions

System	Special cases			Local cases							Running on the road			Conclusion
	Channel	Road under construction	Night time	ETC	Obstacle avoidance	Mixed traffic flow (pedestrians + cars)	Car following	Unexpected road hazards	Unprotected left turn / U-turn	Cut-in vehicle	Overtaking / lane changing	Sharp turn	Optimal lane	
QCraft NOA	√	√	√	×	☆☆☆☆ Automatic lighting to avoid obstacles; high success rate	☆☆☆ Few brakes to a sudden stop; stiff brake control	√	-	☆☆ Stop to wait; low efficiency; brakes to a sudden stop	-	☆☆☆ Active and flexible lane changing; likely to cross full lines	√	☆☆☆ Flexible and different options	☆☆☆ Too aggressive lane changing; cross full lines
Baidu ANP3.0	√	√	√	√	☆☆☆☆ Decelerate during driving with direction biasing	☆☆☆☆ Decelerate during driving; high efficiency	√	☆☆☆☆ Stable operation during deceleration and obstacle avoidance	☆☆☆☆ Stop to avoid obstacles; decisive gaming; flexible responses	☆☆☆☆ Slow down to avoid obstacles; smooth acceleration	☆☆☆☆ Stable operation during overtaking and lane changing	√	☆☆☆ Flexible lane selection	☆☆☆☆ Smooth driving; good user experience

- **Most intelligent driving systems available in the market are vexed by frequent brakes to a sudden stop, because of too inflexible or aggressive control algorithms → the safety and performance of intelligent driving solutions require further improvement on the whole**

√: Available ×: Unavailable ☆: Experience; "-": no information available yet

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Configurations of NOA Solutions by Major Player in China

- There is a small number of City NOA solutions available now, most of which adopt high-performance chips and multi-sensor fusion approaches

System	HD map	Chip	Computing power	Sensor solution	Perception algorithm	Control algorithm	Intelligent computing center	Conclusion
XPeng XNGP	√	Nvidia Orin X*2	508TOPS	LiDAR*2+MMW radar*5+Ultra-sonic radar*12+camera*13 (P5)/*12 (G9)	Xnet framework based on vision algorithms	-	Fuyao	Prioritize sensors to maps; plan to remove maps gradually
Arcfox NCA	√	Huawei MDC 810	400TOPS	LiDAR*3+MMW radar*6+Ultra-sonic radar*12+camera*13	Sensor-fusion algorithms based on LiDAR	-	Ascend	Plan to reduce the dependence on maps
Haomo.ai NOH	×	Qualcomm Snapdragon 8540 and 9000	360 TOPS	LiDAR*2+MMW radar*5+Ultra-sonic radar*12+camera*12	Transform neural network algorithms based on vision	DL	MANA OASIS	Prioritize sensors; focus on vision algorithms; gradually remove HD maps
QCraft NOA	√	Horizon Robotics Journey 5*2	256TOPS	LiDAR*1+MMW radar*5+camera*11	Sensor-fusion algorithms	DL + space-time data	-	Low HW cost + strong SW algorithm capabilities
Baidu ANP3.0	×	Nvidia Orin X*2	508Tops	LiDAR*2+MMW radar*5+Ultra-sonic radar*12+camera*11 (LiDAR as a redundant option)	Vision algorithms (the principal) + LiDAR (the secondary)	DL	Baidu Intelligent Computing Center	Gradually move towards the "pure vision" approach and reduce the dependence on LiDAR

- **With massive data and high-performance chips, algorithm models evolve at a faster pace. Vision algorithms would become the mainstream technology, reducing the dependence on HD maps and LiDAR. Meanwhile, DL-based control algorithms would be more human-like, enabling smooth rides with intelligent driving systems**

"-": no information available yet

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The Application of City NOA Solutions to Production Vehicles

- City NOA solutions would play a leading role in impressing consumers with AD functions before the application of L4 AD technologies to production vehicles. Currently, the driving experience requires further improvement

City NOA experience

Too conservative: Frequent sudden brakes (a strong feeling of abruption) to avoid obstacles and seize the right of way; inflexible option of the optimal lane; low efficiency of lane merging

Too aggressive: ignore road rules like crossing full lines; forced lane changing, reckless overtaking, etc.

→ **Improve the safety and comfort of driving**

Capability				Technology trend
	Module	Type		
Vehicle	Perception	HW	LiDAR	➢ LiDAR basically goes standard with existing perception solutions. Proven vision algorithms would reduce the dependence on hardware, turning LiDAR into a safety redundant part
		SW	Sensor-fusion algorithm	➢ Vision-based multi-sensor fusion algorithms become the mainstream technology
	Decision	HW	Chip	➢ High-performance foreign chips have the dominance. The application of city NOA solutions to production vehicles would drive the adoption of locally-made chips as an alternative
		SW	DL-based decision algorithm	➢ Rule-based decision algorithms are too inflexible, which would evolve to be DL-based
Basic enabler	HD map			➢ The existing major technology path is to prioritize sensors to maps; City NOA solutions without HD maps would serve as a transitional solution
	Intelligent computing center			➢ Intelligent computing centers are necessary for rapid updates of data-driven algorithms

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Summary

Development Trends of City NOA Technologies

☐ Intelligent driving moves to urban areas, with city NOA becoming a new arena for various kinds of players

✓ L2+ and L4 empower each other and gradually get integrated, with the City NOA technology as a confluence. Players would roll out City NOA solutions in 2023 to seize opportunities in the market and impress consumers with good product experience

☐ Applying City NOA solutions to production vehicles entails solutions to difficulties in perception, high costs, and a slow release of HD map permits

✓ LiDAR and 4D MMW radars can make up for the shortcomings of perception algorithms and improve perception performance, but how to apply them to production vehicles is still under exploration. Meanwhile, BEV algorithms would become the mainstream technology for multi-sensor fusion and intelligent computing centers would be necessary for data-driven algorithm upgrades

✓ Low cost is the key to the "vision technology" approach and players at all relevant links are gradually creating product ecosystems with a focus on vision algorithms. High-end chips with high computing power locally made in China are replacing foreign counterparts at a faster pace, which would lay a foundation for the application of City NOA solutions to production vehicles

✓ Considering the uncertainty of HD map supervision policies, automakers are forced to ramp up the R&D of technologies without the adoption of HD map as a transitional solution

☐ City NOA solutions require further improvement for the sake of user experience and the key is to upgrade algorithms

✓ Currently, City NOA solutions in the market are either too conservative or too aggressive, requiring further improvement of safety and comfort to allow users to better enjoy intelligent driving functions. In addition, there is a large space for decision algorithms to be improved

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☐ Development Trends of City NOA Technologies

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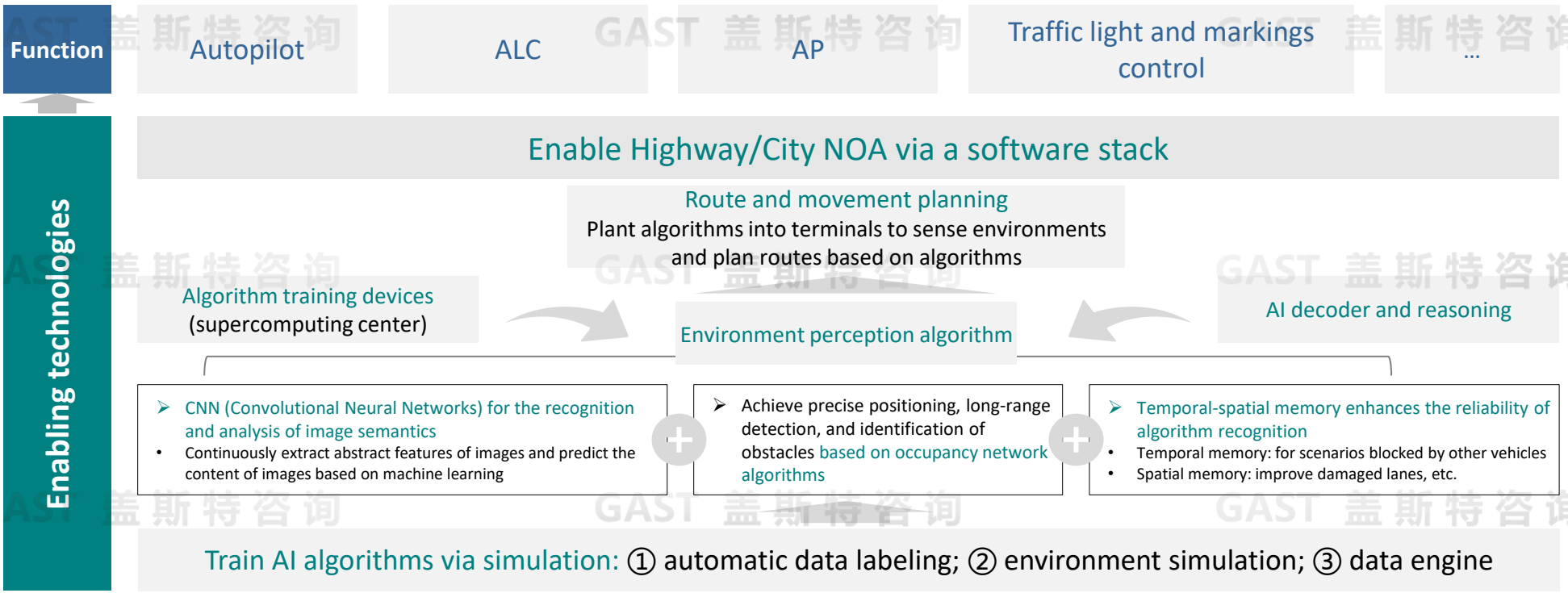
Tesla's "Pure Vision" Solution for its FSD

- Tesla abandoned millimeter-wave radars and ultrasonic radars, only placing 8 cameras around the vehicle body



Tesla drives the evolution of AI algorithms via data of driving in the real world and the virtual world, promoting the NOA solution with only 8 cameras → the "pure vision" approach is cost-effective

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QCraft Develops a City NOA Solution for Production Vehicles as a T1 Supplier

- City NOA solutions are vital to make AD available in all scenarios, which can satisfy the commuting demand and lead consumers to experience AD products. However, it is hard to apply City NOA solutions to production vehicles

Complex urban scenarios → drive the evolution of technologies
Numerous participants and long-tail scenarios in urban transportation → collect data to drive the evolution of technologies

High technology threshold

Good user experience

Urban NOA solutions can improve user experience
Urban NOA solutions can address the pain points of consumers and improve brand images since 90% of the most miserable driving scenarios lie in urban areas

QCraft has developed a production-oriented and low-cost City NOA solution based on L4 methodology → cost-effective

SW: AD super factory

A closed loop of data: data drives the formation of a closed loop
- ✓ Build a closed loop of data: data generation → data use → data generated from solutions

Higher efficiency: accelerate the closed-loop operation
- ✓ Efficient data: non-/semi-supervision + synthesis → reduce the use of massive labeled data
- ✓ Efficient model: ① sensor fusion and multi-task models → reduce the computing pressure on vehicles; ② decision-making models → minimize handwritten rules and adapt to moving obstacles

HW: DBQ V4

Low cost and high performance
- ✓ The cost of application to production vehicles: around 10,000 CNY → enable intelligent driving functions like L4 AD systems

Flexible solutions
- ✓ Three versions (standard, enhanced, and flagship): suitable for different prices

L4 AD companies leverage advantages in the development methodology and technologies to create cost-effective City NOA solutions → serve as T1 suppliers to make profits and prompt the evolution of AD technologies

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L4 Methodology of QCraft: Autonomous Driving Super Factory

■ The AD super factory is a set of systematic and automatic AD-oriented infrastructure

The core of the AD super factory: data-driven mode + improved efficiency → the data-driven mode forms a closed loop of data; higher efficiency enables faster operation of the closed-loop

QCraft matrix

- Simulated module
- Data platform
- Labeling platform
- Training platform

- Cut the cost of testing to 1% of that of road testing
- Generate millions of corner cases per day
- Finish the test and verification of algorithms for production vehicles within a week

Automatic utilization of data

Platform-level general full-stack technologies

Software
- Perception algorithm
- Map and positioning
- Prediction & control
- Cloud-based control
- 5G-V2X

Hardware
- Sensors
- X-by-wire control
- Computing platform

Large-scale output

Application scenarios

City public roads

Highways

Roads in industrial parks and scenic areas

Parking into a garage

Shuttle buses

...

Data generation: provide data of testing in various scenarios

Sensor data | System data | Driving behavior data

☐ **QCraft leverages its AD super factory to enable different business models to share data and support each other → help players to develop robo-bus, robo-taxi, and the application of solutions to production vehicles in an efficient and coordinated manner**

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Platform for Cooperation between QCraft and OEMs: QCraft Matrix

- Applying advanced AD solutions to vehicles just marks the beginning of system evolution, with more efforts made to collect data to drive technology upgrade

A closed loop of data is the key to upgrading and optimizing advanced AD → enable better experience and novel features of AD systems

QCraft Matrix:
data-driven toolchains for the whole process (R&D → test → operation)

Test vehicles in the real world, cut costs, and improve the efficiency of testing

Massive test mileage in the virtual world + Algorithm decoupling

Allow OEMs to use their own algorithms or adopt suppliers' algorithms

Close cooperation with traditional OEMs

QCraft Matrix helps traditional OEMs to forge data-driven AD system development capabilities

- Traditional OEMs develop technologies: tight schedule and daunting task
  - XPeng's NGP, NIO's NOP+, etc.: 3~4 years
- Technology R&D: heavy human and time costs; slow progress

Toolchains fuel technology advance

- Help to build a "moat" for closed-loop data assets → continuously drive technologies to advance

Data closed-loop toolchain is a key for cooperation between L4 AD players and traditional OEMs, which can help OEMs to achieve data-driven processes → cut R&D cost and increase the efficiency of developing AD technologies

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QCraft's Underlying Technology for the City NOA Solution

■ Utilize L4 AD methodologies and toolchains (planning, perception, data accumulation, etc.) to apply the city NOA solution to production vehicles

QCraft Chengfeng enables point-to-point driving assistance on urban roads, expressways, and highways

Unprotected left turn, pedestrian and vehicle avoidance, automatic lane change, automatic turning, traffic light recognition, narrow and congested road passing, automatic obstacle bypass, etc.

Planning & control

Adopt spatial-temporal planning algorithms
- Collect data from human drivers to train AI models
- Seek the optimal trajectory in space and time

→

More sensitive to fickle road conditions than traditional spatial or temporal algorithms
- Upgrade algorithms based on machine learning and the data-driven mode → avoid numerous manual rules
- Driving like veteran human drivers → higher efficiency and better experience in case of complex road situations

Sensor-fusion

Multi-sensor sequence fusion algorithms
- Apply data from different sensors at different stages → supplement information earlier

Neural network platform: OmniNet
- ① Save computing resources by two thirds; ② higher sensor-fusion accuracy and model iteration efficiency; ③ low-cost options accommodate different configurations

+

Sensor configuration: flexible + low-cost
- Three options for different customers
- Adopt One LiDAR to deliver L4 AD functions like an L4 AD system

Closed-loop data-driven

Massive data accumulation: hoard up massive data of L4 LiDAR and cameras accumulated via robo-bus and robo-taxi services + data of driving behaviors

Efficient data utilization: improve automatic toolchains and upgrade City NOA algorithms based on QCraft Matrix

□ **QCraft makes inroads into the game of City NOA with L4 AD technologies, migrating more advanced technologies and cutting costs to transform into a provider of general intelligent driving solutions**

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QCraft's Fourth-Generation AD Solution for Production Vehicles: DBQ V4

■ Priced around 10,000 CNY, DBQ V4 enables Highway NOA and City NOA, which would be available in 2023

Flexible options adapt to vehicles with different prices and AD levels

Standard version

- Cost: 10,000 CNY
  - Enable 99%* of L4 AD functions with only 10% of the L4 AD cost

→ ✓ Highway NOA + City NOA

- Hardware: 1*forward solid-state LiDAR + 5*millimeter wave radars + 11*cameras
- Software: visual solutions → deliver stable perception performance under different light conditions and vehicle motion states

Enhanced version → **Flagship version**

- Hardware: 5*LiDAR units + 4*BSM radars + 6* MMW radars + 12*cameras

→ ✓ L4 AD features

Functions

- ✓ Unprotected left turn
- ✓ Automatic lane changing and overtaking
- ✓ Automatic parking
- ✓ On-/off-ramp driving
- ✓ Active obstacle avoidance

Strong scalability of products → likely to meet expectations of OEMs and consumers

✓ Adapt to different vehicles
Sensor positions, models, etc. are suitable for different vehicle models

✓ Adapt to different models
Require no customization or re-design of hardware

✓ Appearance
No "cap" on the top of vehicles

□ **DBQ V4 can adapt to different models and application scenarios with a set of technology stacks, whose advantages in cost, scalability, and L4 AD capabilities would win certain market share**

*Note: 99% is based on QCraft's current capabilities

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- Provide a high-end sharing platform (CAIT) for industrial communication, exchange and in-depth research
- The company provides nearly 1,000 research reports in Chinese, English and Japanese at present

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