



Challenges, solutions and industry practices of SOTIF for Autonomous Vehicles in China



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SOTIF of Autonomous Vehicles

Chinese Solutions of SOTIF

Industry Practice of SOTIF in China

Current Status and Future Prospects



1.1 Safety vision of AV— Eliminate or reduce traffic accidents caused by human driving



94% of traffic accidents caused by human errors

Automatic driving system 2.0: safety vision



US DOT announces the development of autopilot while DOT-NHTSA also releases the vision of self driving car safety

Automatic driving brings new traffic accidents to humans



In 2016.1, the world's first automatic driving accident occurred in China



In May 2016, Tesla hit a white truck and the driver died



In March 2018, Uber in the United States killed a woman crossing the road



In 2021, 9, China's own brand smart car collided with a truck on the highway

Expectation: The purpose of developing an autopilot is to reduce traffic accidents caused by 94% driving errors.
 Reality: AV has the perception, measurement and verification technology problems in the development process, and brings new traffic accidents.



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1.2 Safety of AV— Three aspect of safety



Problem of functional safety is caused by the failure of electronic and electrical appliances in the vehicle, and there are clear standards and specifications. Cybersecurity is finally solved by the government's legal constraints.
 SOTIF problem is mainly caused by the performance limitations of AI algorithms, insufficient system functions or misuse by personnel, which is one of the biggest problems in commercialization.



1.2 Safety of AV— Definition and R & D objectives of SOTIF



SOTIF is caused by insufficient function, limited performance or reasonably foreseeable misuse of personnel.
 The Research and Development objective of SOTIF is to take appropriate measures to reduce the residual risks to an acceptable level.



1.2 Safety of AV— Typical cases of SOTIF



Trigger Condition: white truck

Trigger condition: irregular truck

Trigger Condition: sudden acceleration

Insufficient algorithm performance, human misuse and unexpected traffic participant behavior are the induceme nts of SOTIF.

SOTIF of AV, like the battery fire of new energy electric vehicles, is very important to the safety of people's lives and property.



1.3 Long tail effect of AV safety — SOTIF problems

In the research and development of AV products, nearly 80% of safety problems can be solved quickly, and the remaining 20% of SOTIF problems need 80% energy to be solved



Analysis: 20% of the safety problems in the process of AV R & D cannot be solved, which belong to the problems of SOTIF, resulting in the long tail effect. **Conclusion:** SOTIF problems are caused by insufficient perception, inaccurate measurement and incomplete verification of intelligent vehicles.





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SOTIF of Intelligent Connected Vehicles

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2. Chinese Solutions of SOTIF

2.1 SOTIF system's "Safety entropy"

1. Unknown-insecurity obeys entropy increasing principle in SOTIF system

- Random scene
- AI black box
- Random HMI
- 2. How to realize the entropy reduction of intelligent connected vehicles?
 - Enhanced on-board enabling
 - Introduction of external empowerment
 - Vehicle interior and exterior enabling fusion

3. How to measure SOTIF?

• Safety entropy





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2. Chinese Solutions of SOTIF

2.2 Roadmap for SOTIF Solutions in China





Active on-going Learning



2. Chinese Solutions of SOTIF



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2.3 CAICV-SOTIF Technical Alliance







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3.1 CAICV SOTIF Technical Alliance - Organization



In order to solve the SOTIF problems of intelligent connected vehicles, Academician Jun Li led the establishment of the SOTIF working group to propose solutions for China's SOTIF.

3.2 CAICV-SOTIF Technical Alliance - Objectives



Goal 2: Promote technical research and innovation of SOTIF



Goal 3: Organize and promote China's test and verification system and capability building



Goal 4: Form large databases, scenario libraries and standards related to SOTIF



• Working group objective: to promote the standardization process of SOTIF in China, to build certification center and test laboratory, and to form large database, scene database and standards related to SOTIF.





3.3 CAICV-SOTIF Technical Alliance - Five Year Plan





3.3 CAICV-SOTIF Technical Alliance - Five Year Plan

Project	2020	2021	2022	2023	2024
WP1: SOTIF Scenario Database Construction		/1 V	/2 V	/3 V	V4 V:
WP2: SOTIF Frontier Technical Report		/1 V	/2	/3	/4 V:
WP3: White paper on intelligent connected Vehicle safety		/1 V	/2 N	/3	/4
WP4: SOTIF test and certification system	(
WP5: SOTIF optimization scheme design	(
WP6: SOTIF Safety Analysis Tool Chain					
WP7: Research on SOTIF Typical Driving Assistant System					
WP8: OEM SOTIF Research Report	•				



3.4 SOTIF Scenario Library



Analyzing the data provided by each member of the research group from different perspectives to conclude limita tions and elements of the SOTIF system, and further summarize 7-Layers SOTIF scenario architecture.



3.4 SOTIF Scenario Library Data analysis and recording Data acquisition Data storage and operation Test case generation **Beijing & Shanghai SOTIF shared database of AV** THU → 数据共享平台 × + **SMVIC** ▲ 不安全 | scstsv.tech/info/edit CATARC C 🔟 partial的使用规则... 👩 get the area in sq... 📀 Gotchas/FAQ — p... 🔮 geometry - How t... 🦲 利用Python中的的. » 🖽 阅读清单 CAV Lotus 预期功能安全场景库 тни Я Pedestrians walked out ΗZ Analy from behind the car PATAC 其他信息 Expert HoloMatic 圓 基本信息 ⊟ **Chongqing & Chengdu** *城市: 请选择城市 🖓 and CMVR experience CAERI 吊 CA screening > 事件情况 Sudden lane change Changchun > 事件分析 FAW Suzhou **TSARI** Wuhan 返回 新增其他信息 DFM Left turn vehicle collision **Fourteen units SOTIF scenario shared database** Test cases 300+ **1000+ cases**

Build SOTIF shared scenario database, with more than 1000 cases and 300 test cases



3.4 SOTIF Scenario Library - Standard approval



Standard for the construction of SOTIF shared database of AV has been approved



3.5 SOTIF Research on test evaluation system







TWDAS TWDAS TWDAS TWDAS TWDAS TWDAS



TVDAS





Crossroads Hara analysis(STPA)



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SOTIF Evaluation System - Navigate on Pilot in urban intersection

Typical Hazard Analysis & Risk Identification Typical Scene Selection & Definition of Key Parameters

Data Collection & Annotation & Analysis

Quantitative Analysis System

Test process

UAV Data Annotation Real vehicle data collection & UAV data collection

YOLOv5 Rotating Rolabelimg IoU and Inter-frame target detection Marking Hungary matching Label data Correction trajectory Stabilize Original algorithm software Track video video data Eliminate Automatic Manual Automatic iitter labeling correction tracking

Video stabilization + Target Detection + Target tracking

Sample data calculation and analysis

Conflict Samples Analysis of Going Straight and Turning Left





Typica Analys Identi	al Hazard is & Risk ification	Typical Scene Selection Definition of Key Parameters	Data Colle Annota & Anal	ection & ation lysis	Quantitative Analysis System	Test process
Process	Safety	Traffic regulation compliance	Traffic efficiency	After leaving th intersection	he	
Before entering the intersection	 TTC Horizontal and vertical safety distance 	 Traffic sign and traffic marking discern and response Traffic light discern and response Traffic command gesture discern and response Priority judgment and response Use of motor vehicle signal lights 	 Speed before intersection Self-car delay error value Reaction time to triage conflict points 	<u> </u>	- In the intersection	
In the intersection	 Controllability Potential Field Potential collision severity index 	• Priority judgment and response	Time to pass the intersectionStart-up time of cross conflict point			
After leaving the intersection	• Horizontal and vertical safety distance	• Traffic marking discern and response	Speed after intersectionReaction time to Confluence point			d Before entering the intersection

SOTIF Evaluation System - Navigate on Pilot in urban intersection

Typical HazardTAnalysis & RiskIdentification	Typical Scene Selection & Definition of Key Parameters	Data Collection & Annotation & Analysis	Quantitative Analysis System	Test process
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Producer	Number
THU	5
TSARI	6
SMVIC	5
CAV	5
CAERI	4
CA	6
Total	31



Right hand vehicle forced



opposite pedestrians



Left turn blind area at intersection







Electric cars run red lights

NOP in city crossroads consists of 6 companies, generating a total of 31 VTD test cases

TVDAS States of the second se

SOTIF Evaluation System - Navigate on Pilot in urban intersection



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Motor vehicle snatching-UAV perspective

Motor vehicle rush-in-vehicle perspective





SOTIF Evaluation System - HWP in cut-in scenarios



SOTIF Evaluation System - HWP in cut-in scenarios



TVDAS



SOTIF Evaluation System - HWP in cut-in scenarios

System Function Definition & Trigger Condition Recognition Typical Scene Selection & Definition of Key **Parameters**

Data Collection & Analysis

Quantitative **Analysis Process**

Test Process



Definition of Key Parameters

Install data acquisition sensor system

UAV aerial survey data collection



SOTIF Evaluation System - HWP in cut-in scenarios





SOTIF Evaluation System - HWP in cut-in scenarios



Typical Scene Selection & Definition of Key Parameters

Data Collection & Analysis

Quantitative Analysis Process

Test Process

Performance boundary pre-compliance testing method





basic

case

dange

case

SOTIF Evaluation System - HWP in cut-in scenarios

System Function Definition & Trigger Condition Recognition

Typical Scene Selection & Definition of Key Parameters

Data Collection & Analysis

Quantitative Analysis Process

Test Process

HWP SOTIF scenario databases contain 26 basic cases and 16 dangerous cases





In the high-speed scene, there are billboards on the roadside, and there are portraits on the billboards



In the high-speed scene, the main vehicle speed is 27.8km/h in the fog environment



In the high-speed scene, under the heavy snow environment



In the high-speed scene, the target vehicle cuts in



In the high-speed scene, trucks in adjacent lanes cut in when the longitudinal distance is small



In the high-speed scene, the motorcycle cuts through the central isolation $belt_{\circ}$

SOTIF Evaluation System - HWP in cut-in scenarios

System Function Definition & Trigger Condition Recognition Typical Scene Selection & Definition of Key Parameters

Data Collection & Analysis

Quantitative Analysis Process

Test Process

Field test - SOTIF safety performance of high-speed automatic driving / auxiliary driving function under cut in scenario

2	测试场景	测试用例	制试目的	试验条件						
3				道路类型	主车	车道	日标1	车道	其它条件	重复次素
5	主车直道匀速行 税,目标车加塞	主车成对相邻车 道目标车加塞。	测试主车应对 右侧车道目标 车以不同相对 横纵向车距加 寒的好坏程度。	直道、车道 宽度3.75m	GPS速度 VeO: 80 kph	中、车道 宽度 3.75m	GPS速度 VO: 75 kph	右、车道宽度 3.75m dx0:[3.5. 6.7.9. 10]m dy0: 3.5 ⁻⁴ m t: 4 ⁻⁵ s	时间, 10:00 [*] 12:00amk3:00 [*] 5: 00pn 天气:晴天 温度:10 ^{**} 35 [*] 大照:光照微度 (~=10 [*] 41ux) Note: 書提着标定自天光 照叠度,再选定具体光照 叠度宽用。	3
6	主车直道匀速行 税, 目标车加寒	主车成对相邻车 道目标车加宽。	测试主车应对 右侧车道目标 车以不问相对 横纵向车距加 寒的好坏程度。	直道、车道 宽度3.75m	GPS速度 Ve0: 80 kph	中、车道 宽度 3.75m	GPS速度 VO: 70 kph	右、车道宽度 3,75m dx0:[6, 7, 9, 10, 12, 14]m dy0: 3.5 ⁻⁴ m t: 4 ⁻⁵ s	时间; 10:00 [*] 12:00amb3:00 [*] 5: 00pn 天气:晴天 温度:10 ^{**} 35 [*] 大照:光照盈度 (^{**} 10 ^{**} 144) Note: 需提前标定白天光 图叠度,再选定具体光照 叠度度到4.	3
7	主车直道勾述行 较,目标车加寒	主车成对相邻车 道目标车加寒。	测试主车应对 右侧车道目标 车间和对 横纵向车距加 落的好坏程度 。	直道、车道 宽度3.75m	GPS速度 VeO: 80 kph	中、车道 宽度 3.75m	GPS速度 VO: 65 kph	右、车道宽度 3.75m dx0:[9, 11. 13, 15, 17. 20]m dy0: 3.5~4 m t: 4~5s	时间, 10:00 [*] 12:00nmk3:00 [*] 5: 000n 天 ⁴ (:晴天 温度:10 ^{**} 35 [*] 大照:光服强度 (~=10 [*] 4L级) Note: 需提前标定自天光 图器度,再选定具体光照 强度度制。	3
8	主车直道匀速行 税,目标车加率	主车应对相驾车 道目标车加赛,	潮试主车应对 右相车道目标 车以不同相对 模拟向车距加 变的GTF和度	直道、车道 宽度3.75m	GPS速度 VeO: SO kph	中、年道 宽度 3.75m	GPS這度 VO: 60 kph	右、牛道宽度 3.75m dx0: [12, 14, 17, 20, 23, 28]m	时间; 10:00~12:00am&3:00~5: 00pm 天气:晴天 温度:10~~35* 光照:光照强度 (~=10~41m)	3







Test case design, 9 working conditions, 27 tests Test preparation, multi device synchronous recording

Test execution





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4.1 Current work 1 - SOTIF Frontier Technology Research Report



SOTIF Frontier Technology Research Report was published in NOV. 2020.



4.1 Current work 2 - Intelligent Connected Vehicle SOTIF White Paper



Intelligent Connected Vehicle SOTIF White Paper will be published in 2021.



4.2 Future prospects 1– FISTIA Intelligent Safety Conference



Co-organized the SOTIF session of the FISTIA ISC conference in Changchun

FISITA ISC will be held in Beijing and co-organized by Tsinghua University around 2022.08.30-2022.08.31

4.2 Future Prospects- Construct a multi-functional integrated SOTIF comprehensive test system



Construct a comprehensive SOTIF test system with multi-functional integration of perception, planning, decision-making and control.





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Through key technology cooperation, exchanging of research results, sharing of SOTIF solutions, etc. to joint efforts for SOTIF archit ecture design.
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- 1. Is it possible regular meeting link to SOTIF technical Alliance in China to exchange idea and methodology regularly, such as in two months or three months?
- 2. I am very glad to invite participants in VVM to share their idea in FISITA Intelligent Safety Conference in August 2022.
- 3. Is there any opening to discuss international standard regarding the toolchains for verification and validation method?
- 4. We are looking for international cooperation project opportunity.



Thanks for your attention!



清华大学智能汽车设计与安全性研究中心 Tsinghua Intelligent Vehicle Design And Safety Research Institute