

# **Test Procedure on Exhaust Gas Entering into Vehicle Cabin**

2017. 4. 25

Korea Transportation Safety Authority

Korea Automobile Testing & Research Institute

## **1. Defect Investigation in 2011**

## **2. Development of Test Procedure in 2013-2015**

## ➤ Background

- ✓ Consumer complaints “Exhaust Odor / Exhaust gas entering into vehicle cabin”
  - Exhaust smell can disturb driving and raises safety concerns
  - Total 318 complaint cases in 2011
  - Website: 158 cases, telephone: 20 cases, Korea Consumer Affairs Institute: 140 cases
- ✓ Ministry of Land, Infrastructure and Transport had launched an investigation into this issue



< KBS news regarding “exhaust gas entering into vehicle cabin” >

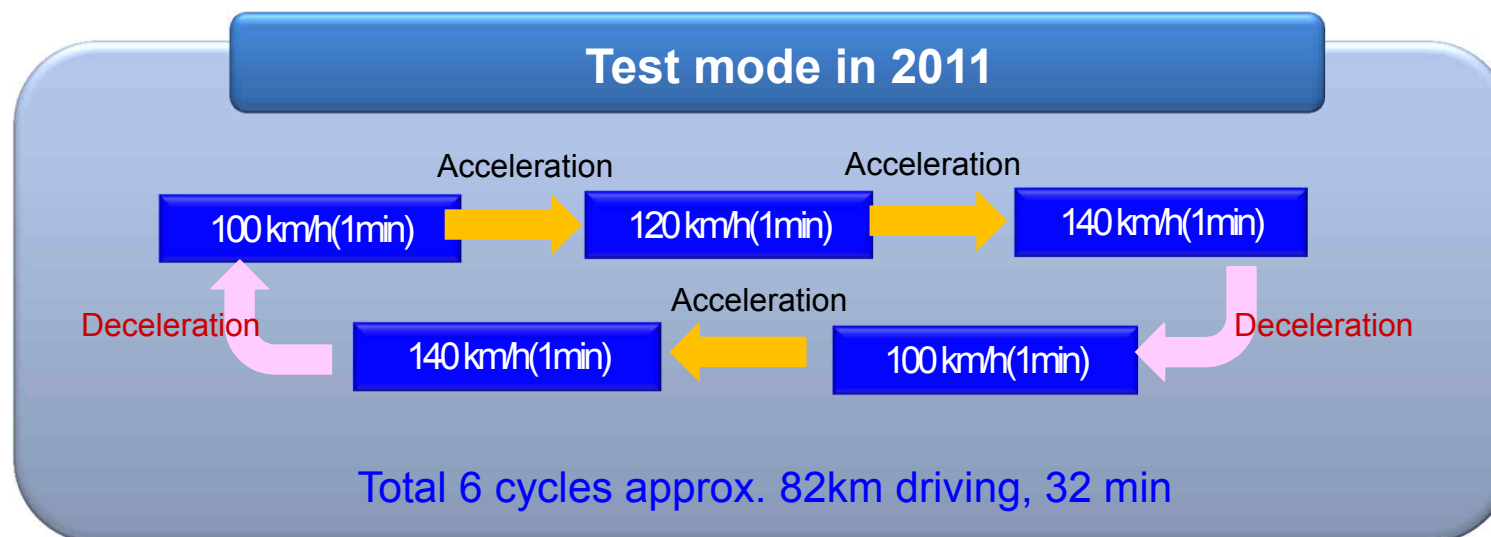
# Defect Investigation in 2011

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## ➤ Test Mode based on consumer complaints

- ✓ Test mode to see if the CO gas was entering into cabin while driving
- Test mode configuration with high speed and acceleration / deceleration
- HVAC setting in recirculation mode, sunroof tilt open / closed



< Test mode used in defect investigation in 2011 >

# Defect Investigation in 2011

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## ➤ Vehicle testing

### ✓ Testing devices and vehicle testing in proving ground

- Measuring point : Head position of driver and passenger seat, center position of trunk



### ➤ Test Device : Testo 330 LL

- CO Low Range : 0~500 ppm
- Resolution : 0.1 ppm
- Accuracy :  $\pm 2$  ppm(0.0 ~ 39.9 ppm), Other range  $\pm 5\%$

# Defect Investigation in 2011

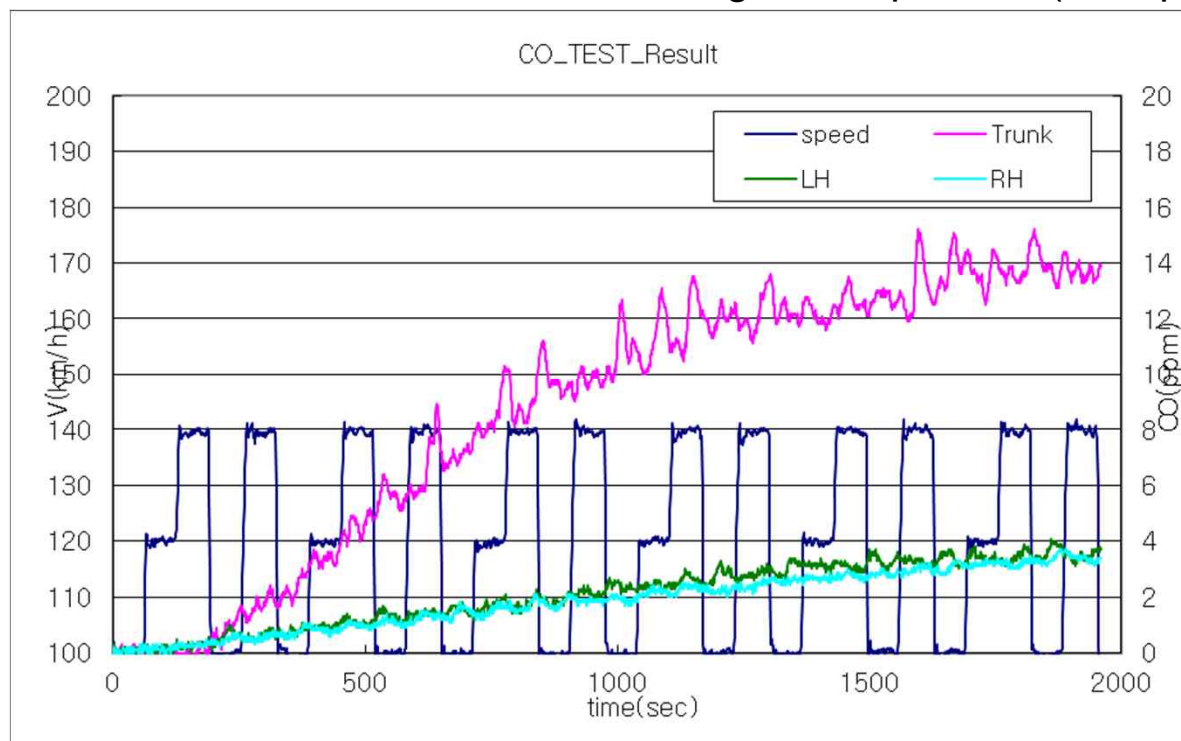
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## ➤ Testing Results

✓ Vehicle testing results using the test mode in 2011

- CO concentration increases gradually in trunk area ( 10~14 ppm )
- CO was detected in vehicle cabin at the left and right seat position ( 2~4 ppm )



# Defect Investigation in 2011

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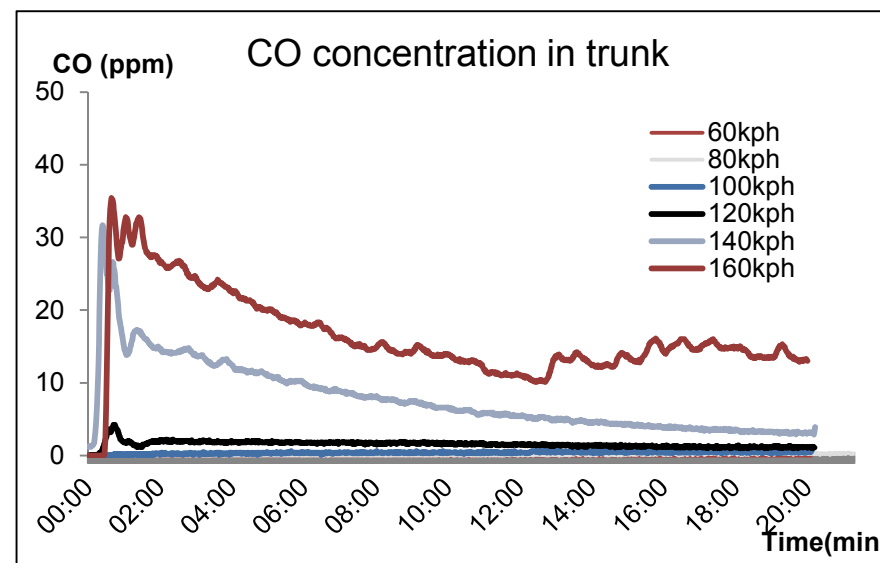
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## ➤ Testing Results

### ✓ Vehicle testing result using the constant speed test

- CO concentration increases gradually depending on vehicle speed
- CO was detected in high speed more than 140 km/h

Vehicle Speed	CO concentration (unit : ppm)	
	Cabin	Trunk
60 km/h	0.7	0.1
80 km/h	0.6	0.4
100 km/h	1.0	0.7
120 km/h	1.8	4.2
140 km/h	4.3	31.7
160 km/h	11.3	35.4



# Defect Investigation in 2011

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## ➤ Testing Results

✓ Vehicle testing results in 18 test vehicles

- CO was detected in several cars in vehicle cabin and trunk

Test Vehicle	CO concentration in cabin (unit : ppm)		Remarks
	Cabin	Trunk	
A	70.7	81	Sunroof tilt open
B	25.4	60	Sunroof tilt open
C	21	72	
D	17.9	61	
E	15.9	71	Sunroof tilt open
F	9.8	9	
G	7.3	53	
H	5.7	29	
I	4.1	23	Sunroof tilt open
J	2.5	18	Sunroof tilt open
K	2.4	9	
L	2.2	18	
M	2	11	
N	1.8	9	
O	1.4	54	
P	1.1	10	
Q	1	3	Sunroof tilt open
R	0	20	



## ➤ Defect Investigation conclusions

- ✓ Ministry of Land, Infrastructure and Transport had launched an investigation into this issue
- Possible leakage of exhaust fumes and exposure to carbon monoxide inside the vehicle
  - 49 vehicles were tested in the defect Investigation in 2011
  - MOLIT recommend the free repair services to consumer regarding 3 vehicle models

## ➤ Future works

- ✓ Need to develop management standards including test procedures, test mode, harmful substance and limits to prevent future cases
- Develop the test mode taking into account cause and effect of exhaust gas incursions
- Exhaust gases should not be entering into cabin
- Other gases and harmful substances should be considered when testing for CO and exhaust odors leaking into the cabin
- Determine the harmful substances and limits

## 1. Defect Investigation in 2011



## 2. Development of Test Procedure in 2013-2015

## ➤ Development of Test Procedure in 2013-2015

- ✓ How could the exhaust gas enter into vehicle cabins
- ✓ Exhaust gas inflow into vehicle cabin and the rear of vehicles using CFD
- ✓ Exhaust gas sources from vehicle tail pipe
- ✓ Which driving conditions most likely to cause exhaust to enter into cabin
- ✓ Review existing test procedures, and collect similar cases
- ✓ Testing in chassis dynamometers, proving grounds and real roads with various conditions
- ✓ Develop test procedures taking into account causes and effects on exhaust gas incursions
- ✓ Consideration of CO gases as well as other exhaust gases regarding exhaust odors
- ✓ Determine the harmful substances and limit values

## ➤ How could the exhaust gas enter into vehicle cabins?

- ✓ When cars pick up speed with the air conditioning system on recirculation mode, exhaust gases could enter the passenger compartment due to pressure difference in cabin and vortex flow in rear part of the vehicle.
- High acceleration or wide open throttle(WOT) with recirculation mode HAVC setting
- Very high speed driving on highway (more than 140 km/h)
- In some circumstances, hatch door sealing problems, air extractor design, sunroof tilt open is a major factor in leakage into the cabin
- ✓ **Warning in vehicle owner`s manual :** The boot lid must always be completely closed when the vehicle is moving, otherwise exhaust fumes can be drawn into the interior

Display messages	Possible causes/consequences and ► Solutions
	Sedan: the trunk lid is open. ► Close the trunk lid.
	Wagon: the tailgate is open.  <b>⚠ WARNING</b> When the engine is running, exhaust gases can enter the vehicle interior if the tailgate is open. There is a risk of poisoning. ► Close the tailgate.

### Closing boot lid

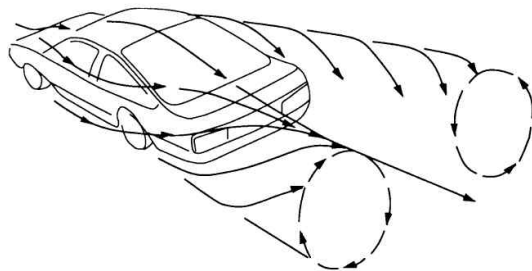
- Pull down the boot lid by the handle on the inside and let it drop into the latch = ⚠

<b>⚠ WARNING</b>
<ul style="list-style-type: none"> <li>• After closing the boot lid, always check that the catch has engaged properly. The boot lid could otherwise open suddenly when the vehicle is moving - this could result in an accident.</li> <li>• The boot lid must always be completely closed when the vehicle is moving, otherwise toxic exhaust fumes can be drawn into the interior.</li> </ul>

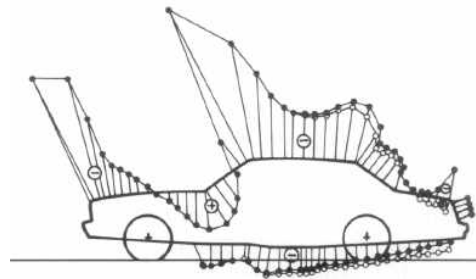
# Study on CFD(computational Fluid Dynamics)

## ➤ Computational Fluid Dynamics(CFD)

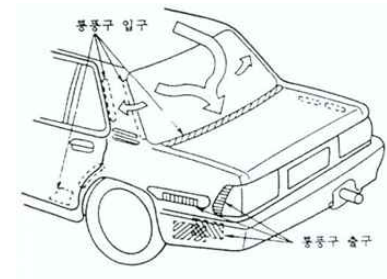
- ✓ Simulation for exhaust gases entering into cabin using the CFD method



<Vortex flow in back part of vehicle>



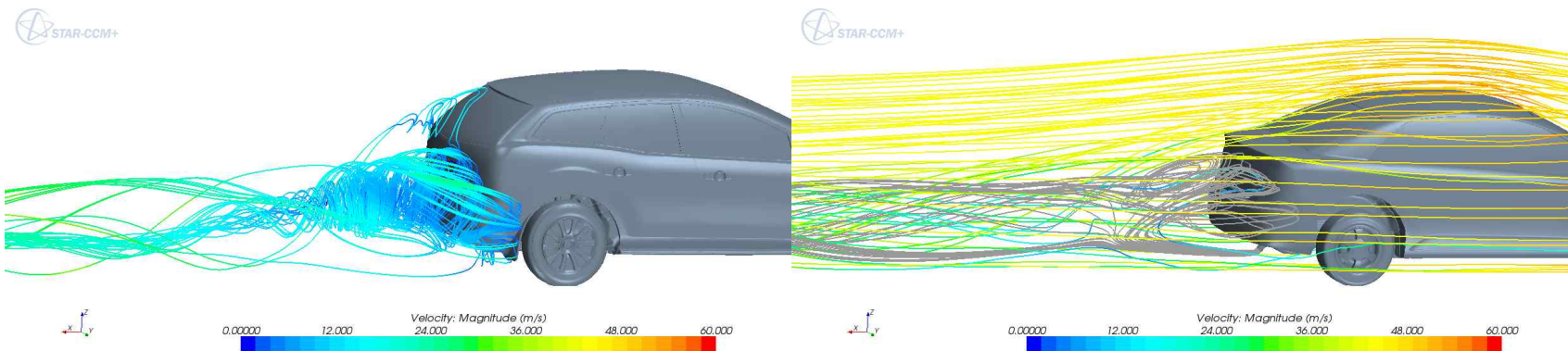
< Pressure of vehicle surface in high speed >



< position of extractor >

\* Source : Fundamentals of Vehicle Dynamics, Thomas D. Gillespie

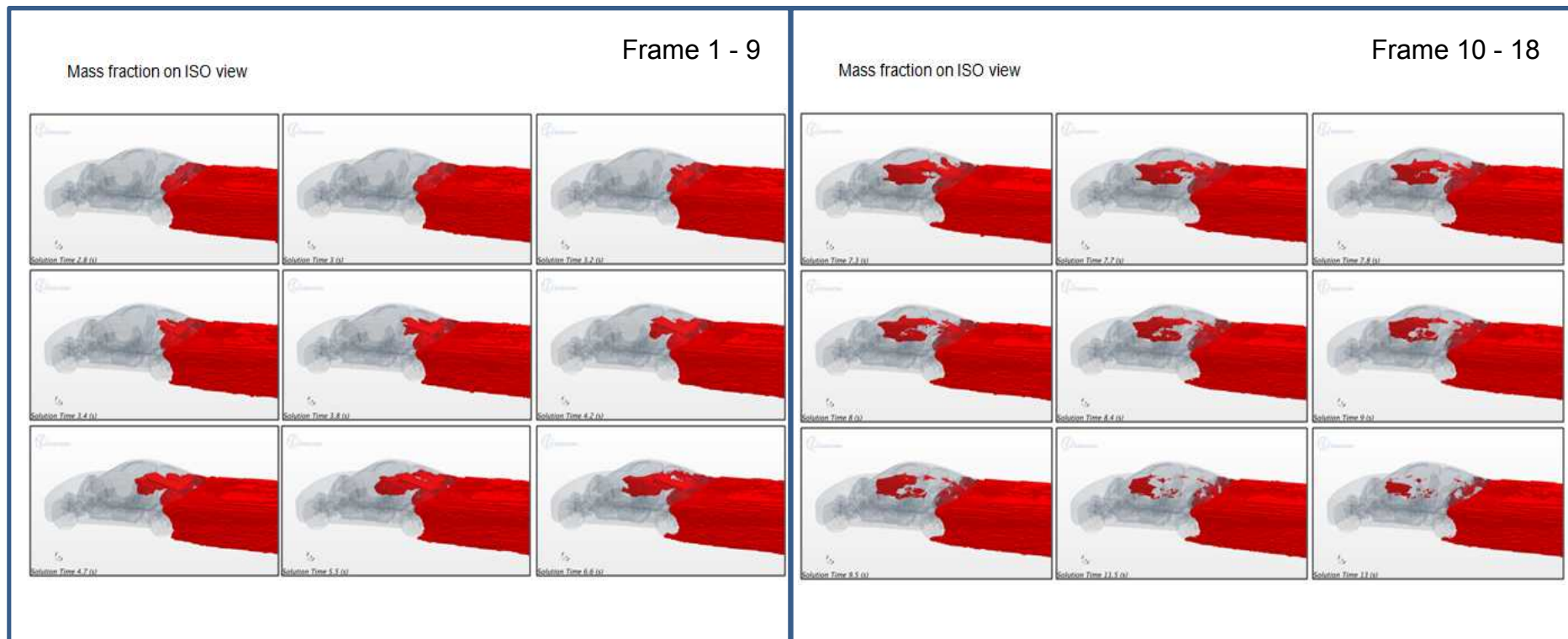
- ✓ The vortex flow occurs in the back part of sedan vehicles depending on vehicle speed



# Study on CFD(computational Fluid Dynamics)

## ➤ Computational Fluid Dynamics(CFD)

- ✓ Simulation for exhaust gases entering into cabin using the CFD method





# Exhaust gas sources

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## ➤ Test on exhaust gases on chassis dynamometer

- ✓ Exhaust sources and measurements on Emission test mode

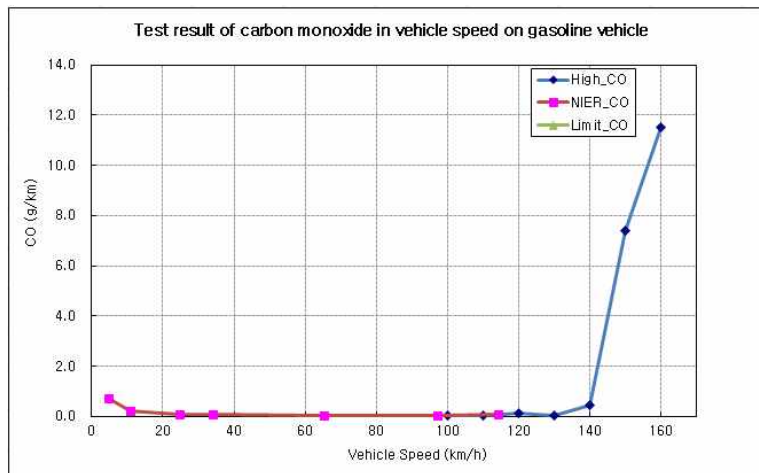


<Chassis dynamometer>

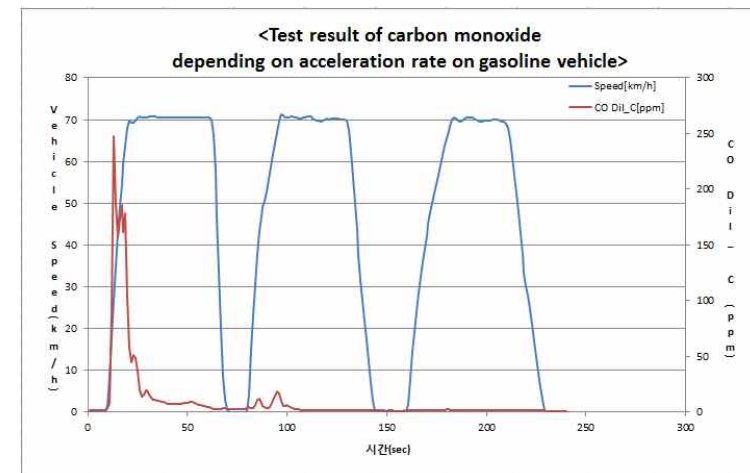


<Exhaust gas analyzer>

- ✓ Carbon monoxide occurring from high speed (over 140 km/h) and high acceleration(WOT)



<Test result of carbon monoxide in vehicle speed on gasoline vehicle>



<Test result of carbon monoxide depending on acceleration rate on gasoline vehicle>

# Exhaust gas sources

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## ➤ Test results on exhaust gases on chassis dynamometer

### ✓ Gasoline Vehicle, exhaust gas sources from vehicle tail pipe

- Substance concentration values estimated by dilution factor (Unit : ppm)

Average Speed	THC	NOx	CO	Benzene	Toluene	Ethyl benzene	m-p- Xylene	o- Xylene	Styrene	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene	Formaldehyde	Acetaldehyde
160 km/h	73.044	0.811	8434.749	0.522	0.323	0.025	0.069	0.052	0.029	0.012	0.047	0.009	0.020
34 km/h	5.210	2.480	87.105	0.004	0.122	0.003	0.003	0.000	0.001	0.001	0.021	0.009	0.063
4.7 km/h	6.565	0.471	163.567	0.098	0.863	0.034	0.066	0.065	0.001	0.001	0.034	0.009	0.000

### ✓ Diesel Vehicle, exhaust gas sources from vehicle tail pipe

- Substance concentration values estimated by dilution factor (Unit : ppm)

Average Speed	THC	NOx	CO	Benzene	Toluene	Ethyl benzene	m-p- Xylene	o- Xylene	Styrene	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene	Formaldehyde	Acetaldehyde
160 km/h	6.355	1359.254	14.069	0.021	0.012	0.002	0.002	0.002	0.007	0.002	0.000	0.042	0.152
34 km/h	24.886	331.447	18.463	0.023	0.102	0.002	0.002	0.000	0.022	0.002	0.022	0.158	0.204
4.7 km/h	72.393	190.197	2.519	0.170	0.097	0.002	0.044	0.002	0.000	0.002	0.042	1.102	0.000



# Develop a new test mode

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## ➤ New Test mode for exhaust gases entering into cabin in 2016

### ✓ Idling mode, (basic conditions)

- Engine idling in normal condition

### ✓ Cruising speed driving mode, (normal conditions)

- $80 \pm 5$  km/h,  $100 \pm 5$  km/h,  $120 \pm 5$  km/h,  $140 \pm 5$  km/h

### ✓ Acceleration mode, (worst-case conditions)

- Accelerate vehicles from 65 km/h to 130km/h, followed by an immediate coast-down (deceleration) to 65 km/h, then cruise drive 500 meters, repeat for 8 cycles

### ✓ Real-road driving mode

- Real-road driving mode with/without acceleration as traffic required

## ➤ Proving Ground Test

### ✓ Proving ground driving test

- Idling conditions, cruising speed conditions, acceleration conditions

### ✓ Test vehicle : Gasoline vehicle, 3,000 cc, sedan

### ✓ Measurement devices setting position :

- Nose position of front seat, back seat
- Center position of truck
- Rear of vehicle



〈front and rear seat〉



〈center of trunk〉



〈rear of vehicle〉

## ➤ Gas and Speed Measuring Devices

- ✓ Test Device : Vbox mini
  - Speed Range : 0.1 ~ 1,609 km/h
  - Resolution : 0.1 km/h
  - Accuracy : 0.2 km/h
- ✓ Test Device : Testo 330 LL
  - CO Range : 0~500 ppm
  - Resolution : 0.1 ppm
  - Accuracy :  $\pm 2$  pm(0.0 ~ 39.9 ppm), Other range  $\pm 5\%$
- ✓ Test Device : Testo 350K
  - NO Range : 0~300 ppm
  - Resolution : 0.1 ppm
  - Accuracy :  $\pm 2$  pm(0.0 ~ 39.9 ppm), Other range  $\pm 5\%$
  - NO2 Range : 0~500 ppm
  - Resolution : 0.1 ppm
  - Accuracy :  $\pm 5$  pm(0.0 ~ 39.9 ppm), Other range  $\pm 5\%$



**<Speed device>**



**<CO device>**



**<NO, NO2 device>**

# Proving Ground Test

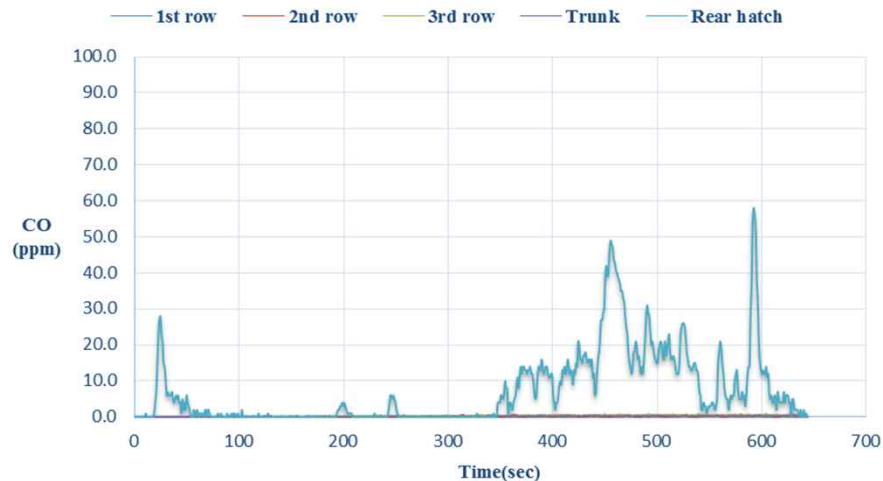
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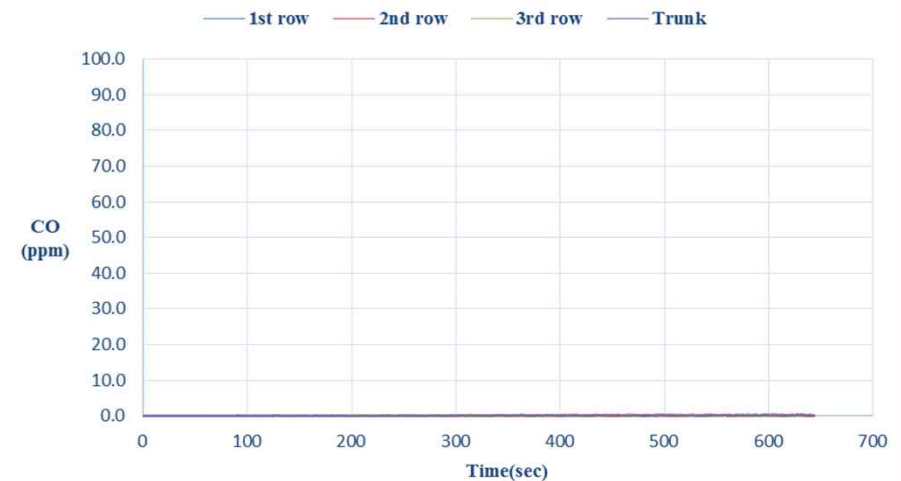
## ➤ Idling mode test

- ✓ Engine idling in normal conditions, not moving
- ✓ Total test time : 10 min
- Stabilizing time : 5 min, Measuring time : 5 min
- ✓ CO was detected in the rear hatch, but not detected in cabins

**Idle mode, CO test results in rear hatch**  
(Idle, Sunroof closed, recirculation mode)



**Idle mode, CO test results in cabin**  
(Idle, Sunroof closed, recirculation mode)



# Proving Ground Test

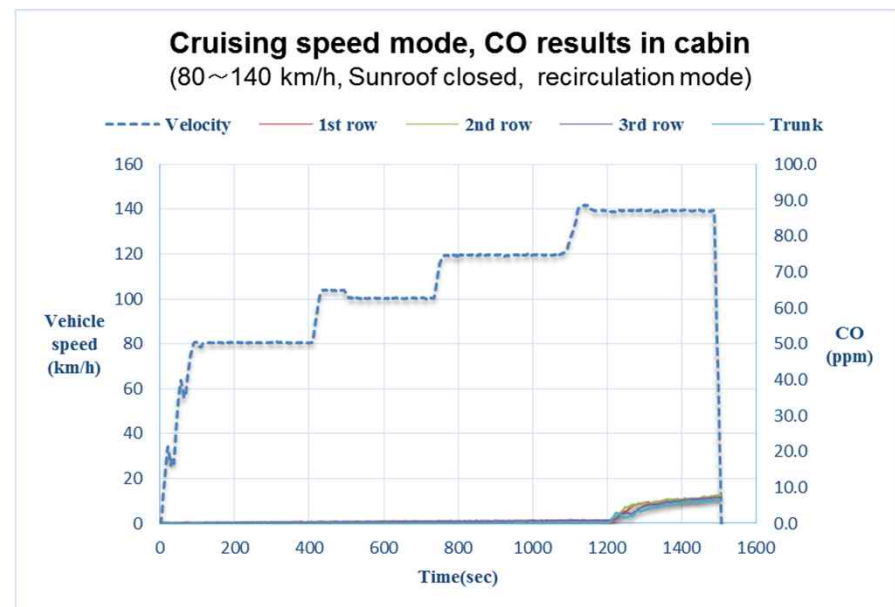
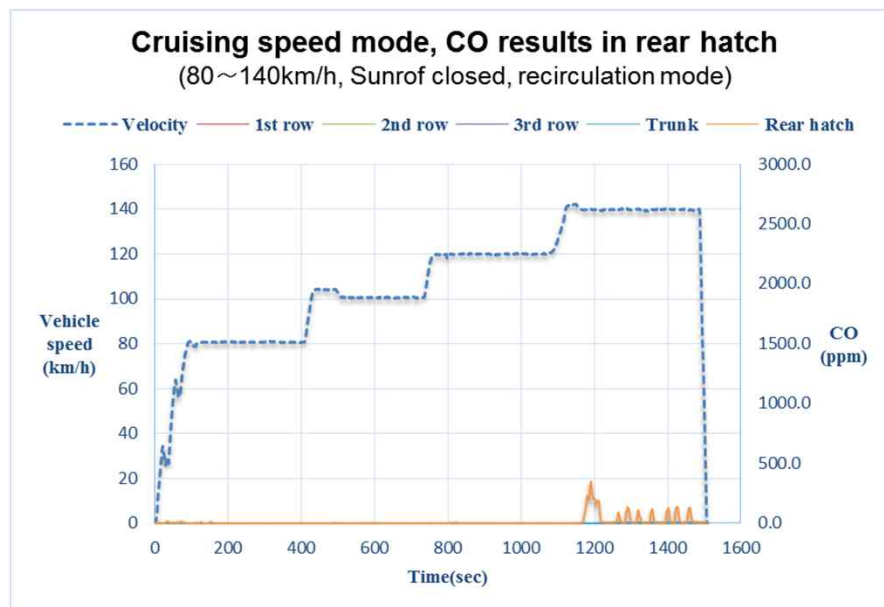
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## ➤ Cruising speed driving mode

### ✓ Cruising speed driving mode, (normal conditions)

- $80 \pm 5$  km/h,  $100 \pm 5$  km/h,  $120 \pm 5$  km/h,  $140 \pm 5$  km/h
- Each test time in stated speed : 5 min
- If CO is detected in test speed, test again in that speed for 20 min duration
- CO was detected in 140 km/h,



# Proving Ground Test

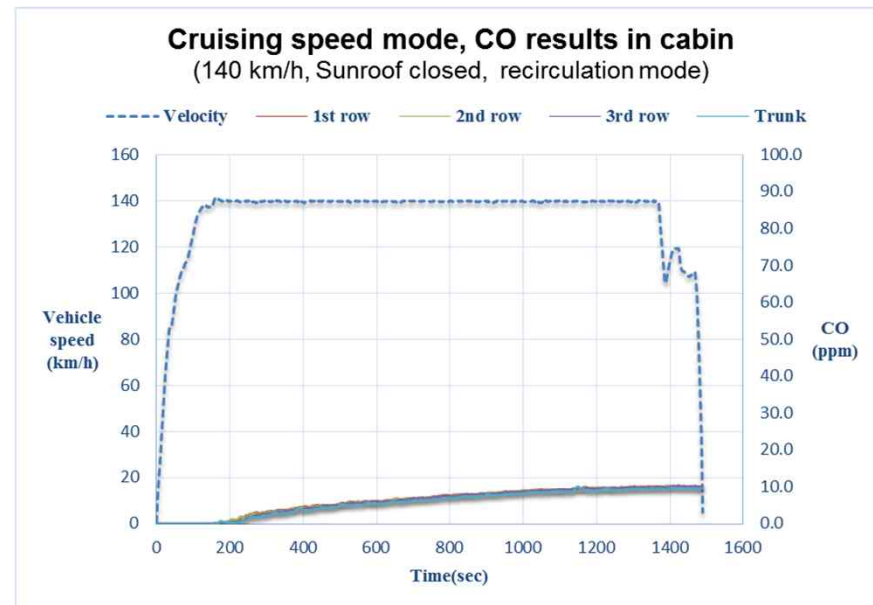
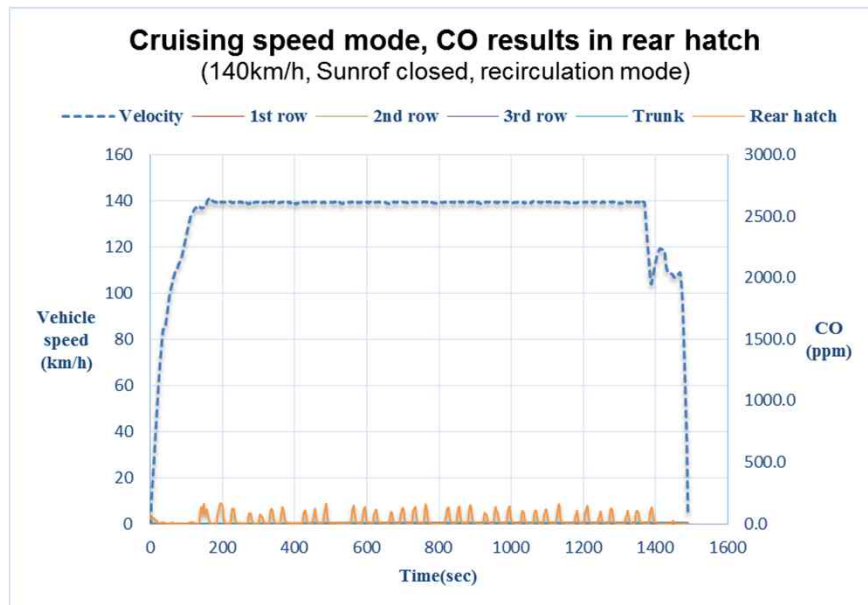
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## ➤ Cruising speed driving mode

### ✓ Cruising speed driving mode

- $140 \pm 5$  km/h
- Total test time : 20 min (stabilizing time 10 min, measuring time 10 min)
- CO was detected in cabin with 140 km/h ( 8 ~ 9 ppm)





# Proving Ground Test

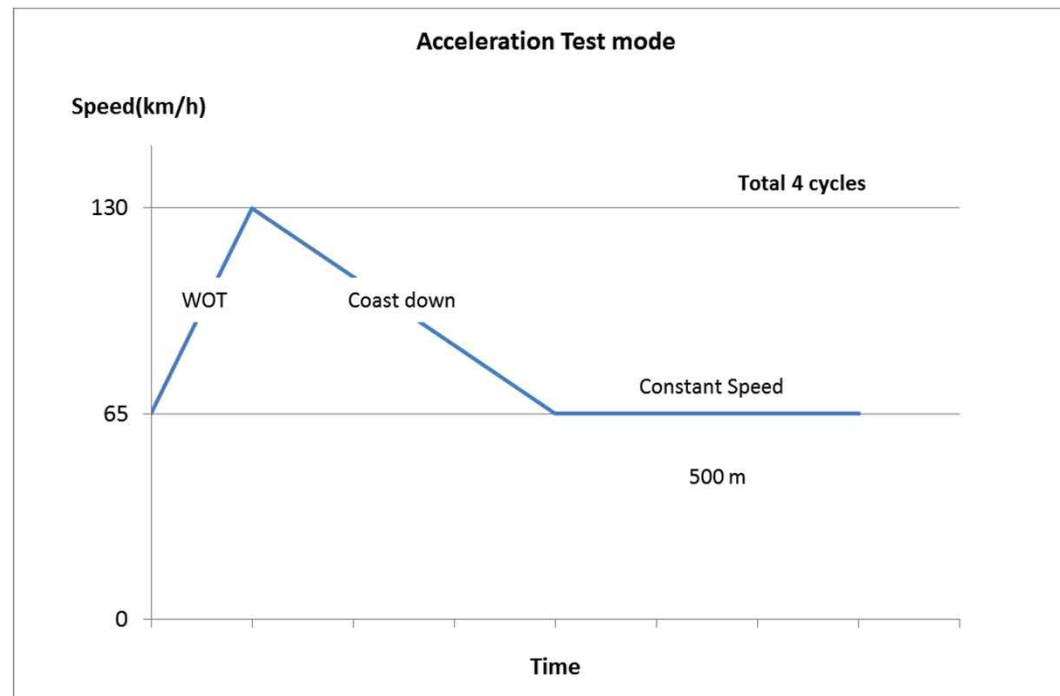
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## ➤ Acceleration mode

### ✓ Acceleration mode, (worst-case conditions)

- Accelerate vehicles from 65 km/h to 130km/h, followed by an immediate coast-down (deceleration) to 65 km/h, then cruise drive 500 meters, repeat for 8 cycles
- Total 8 cycle ( 4 stabilizing cycle, 4 measuring cycle)



# Proving Ground Test

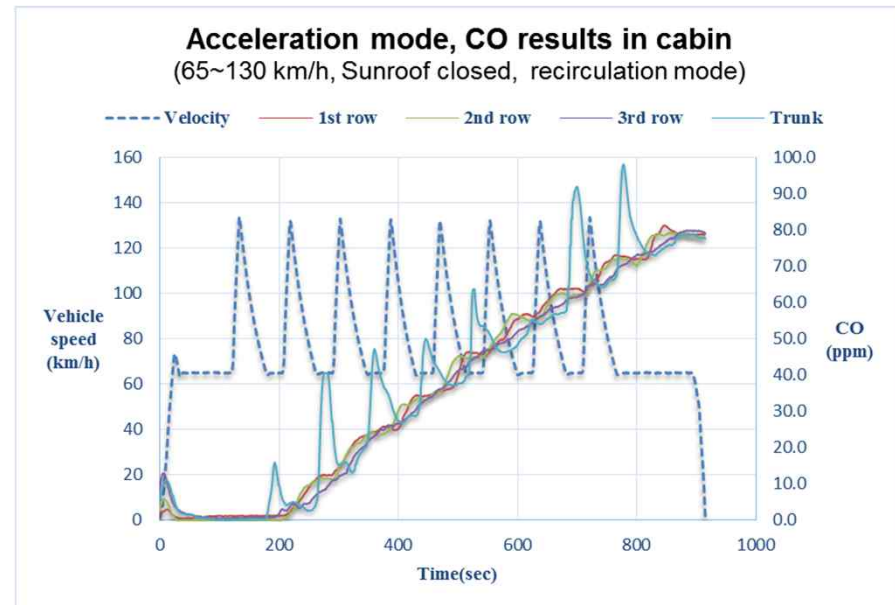
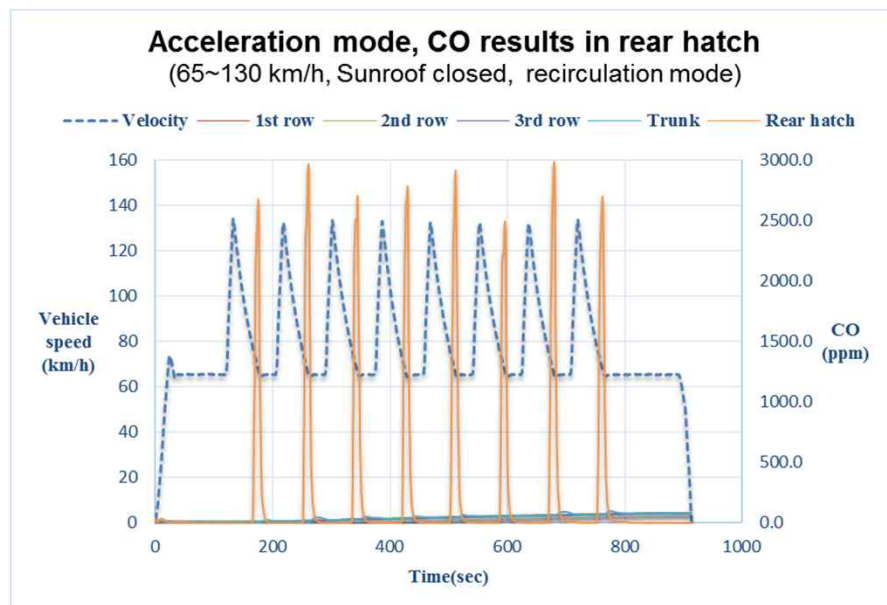
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## ➤ Acceleration mode

### ✓ Acceleration mode, (worst-case conditions)

- When accelerating, high concentration of CO was detected in rear area (max 3,000 ppm)
- When accelerating, CO entered into the trunk zone through the rear hatch (max 100 ppm)
- CO concentration was increased gradually from 40 ppm to 80 ppm in the cabin





# Real-road Driving Test

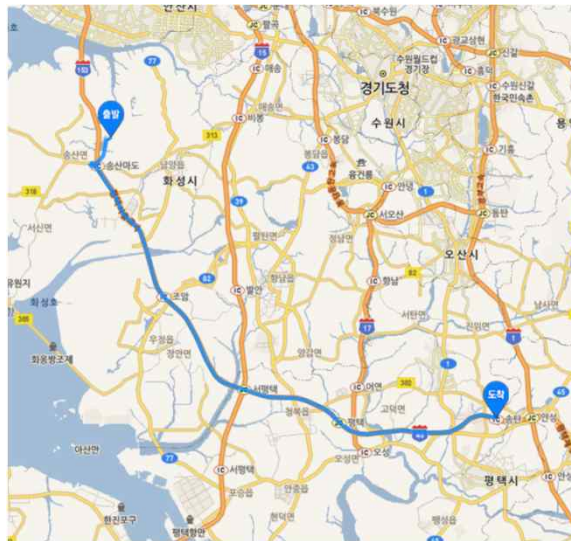
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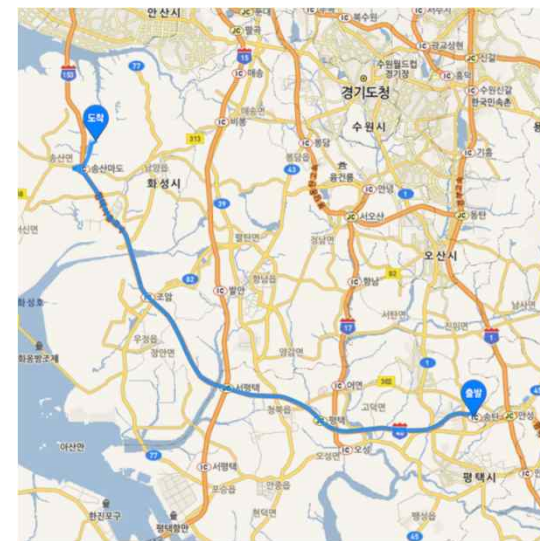
## ➤ Real-road Driving test

### ✓ Real-road driving mode

- Real-road driving test in same course with/without acceleration (2 mode)
- Driving course : 45 km (mostly of highway road)
- Average vehicle speed : approx. 80 km/h
- Driving time : approx. 40 min



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# Real-road Driving Test

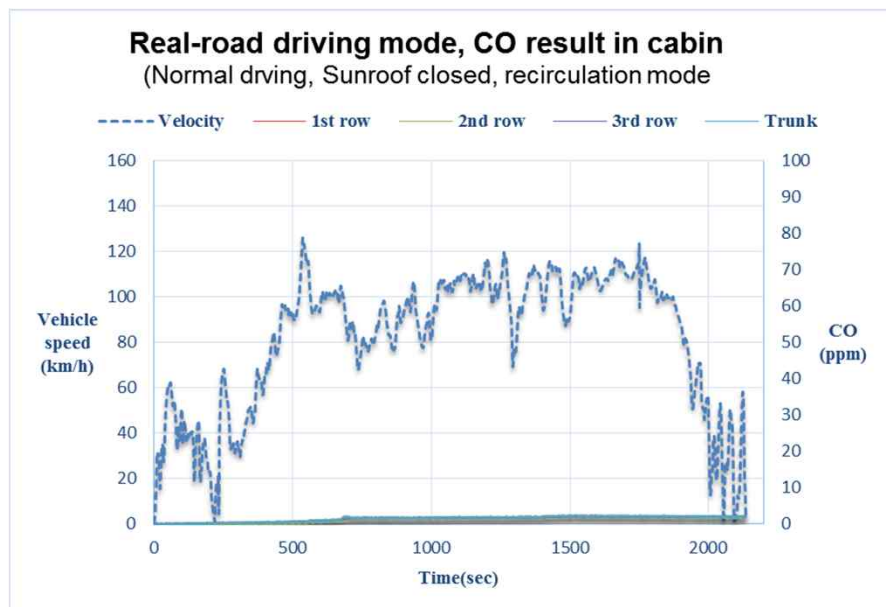
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## ➤ Real-road Driving test

### ✓ Real-road driving mode (careful driving)

- Real-road driving test in the same course without acceleration
- Smooth driving, Throttle open not more than 50%
- CO was not detected in cabin



# Real-road Driving Test

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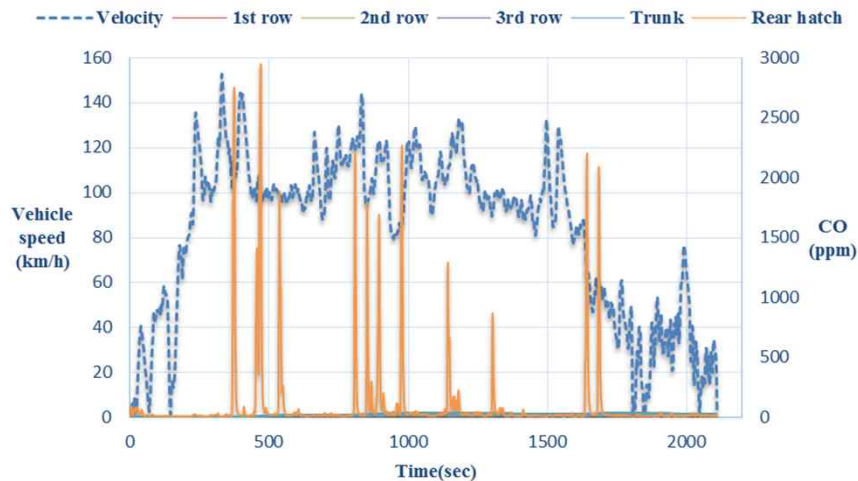
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## ➤ Real-road Driving test

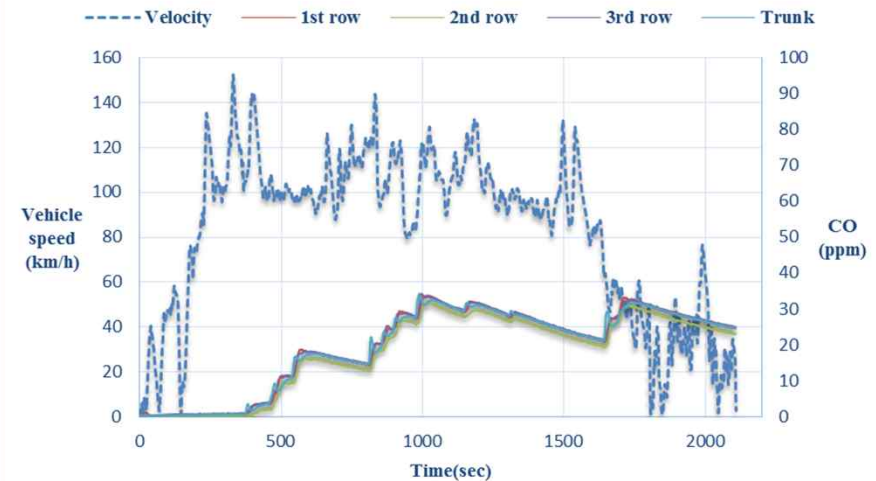
### ✓ Real-road driving mode (overtaking driving as traffic required)

- Real-road driving test in same course with acceleration (near WOT)
- Overtaking driving depending on road traffic as traffic required
- CO was detected in cabin 20 ~ 35 ppm, in response to acceleration
- Car acceleration : 11 times over 35 minutes

**Real-road driving mode, CO result in rear hatch**  
(Overtaking driving, Sunroof closed, recirculation mode)



**Real-road driving mode, CO result in cabin**  
(Overtaking driving, Sunroof closed, recirculation mode)



# Test Results

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## ➤ Test results

- ✓ CO gas enters into cabin in response to acceleration or high speed driving, especially for overtaking driving on highway, with HVAC in recirculation mode
- ✓ After repair, CO gas was not detected in most test modes, except acceleration mode with sunroof tilt open
- ✓ Hatch door sealing problems, air extractor design, sunroof tilt open, and tail pipe position may affect exhaust leaks into cabin

Test results for CO gas incursion		Before repair		After repair	
Sunroof		closed	tilt open	closed	tilt open
Idle mode		N.D.	-	N.D.	-
Cruising mode	80	N.D.	N.D.	N.D.	N.D.
	100	N.D.	N.D.	N.D.	N.D.
	120	N.D.	N.D.	N.D.	N.D.
	140	8~9 ppm	0~3 ppm	0~3 ppm	0~2 ppm
Acceleration mode		40~80 ppm	30~35 ppm	N.D.	10~15 ppm
Real-road driving mode	Careful driving	N.D.	-	N.D.	-
	Overtaking driving as traffic required	20~35 ppm	-	0~2 ppm	-

## ➤ Conclusions

- ✓ Korea has been working on developing the management standards including test procedures, test mode, and substance limit values, to prevent future cases
- ✓ If group members are interested in this issue, we are willing to share our ideas, results, technical data, and expertise with you

## ➤ Future Works

- ✓ Examination of exhaust and harmful substances other than CO
  - Identify other substances
  - Examine affect on human health
  - Update the draft of management standards
- ✓ Air pollutant (specifically fine dust) concentrations within the vehicle cabin
  - Measurement, filtration, purification, and driver notification systems / device

# Thank you

Jongsoon LIM

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Korea Transportation Safety Authority

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