



# **LDV Real Driving Emissions:**

**- Data Evaluation Method(s): Contribution to (Possible) additional elements -**

**RDE DE Task Force Meeting, March 20, 2014**

- **Fine-tuning of CO2 characteristic curve**
- **Driving Dynamics indicators**
- **Additional “backup” elements – Implementation?**

# Basic Principles



- **The CO2 emissions (or the energy consumption) of the vehicles provide the main reference for normal testing.**
- **The MAW CO2 (or energy consumption) is checked against the reference.**
- **The reference is not constant. EMROAD adopts a simple CO2 vs. average speed-based model.**
- **The reference curve is built from “agreed” and well defined reference testing situations: currently the phases of the WLTP cycle**

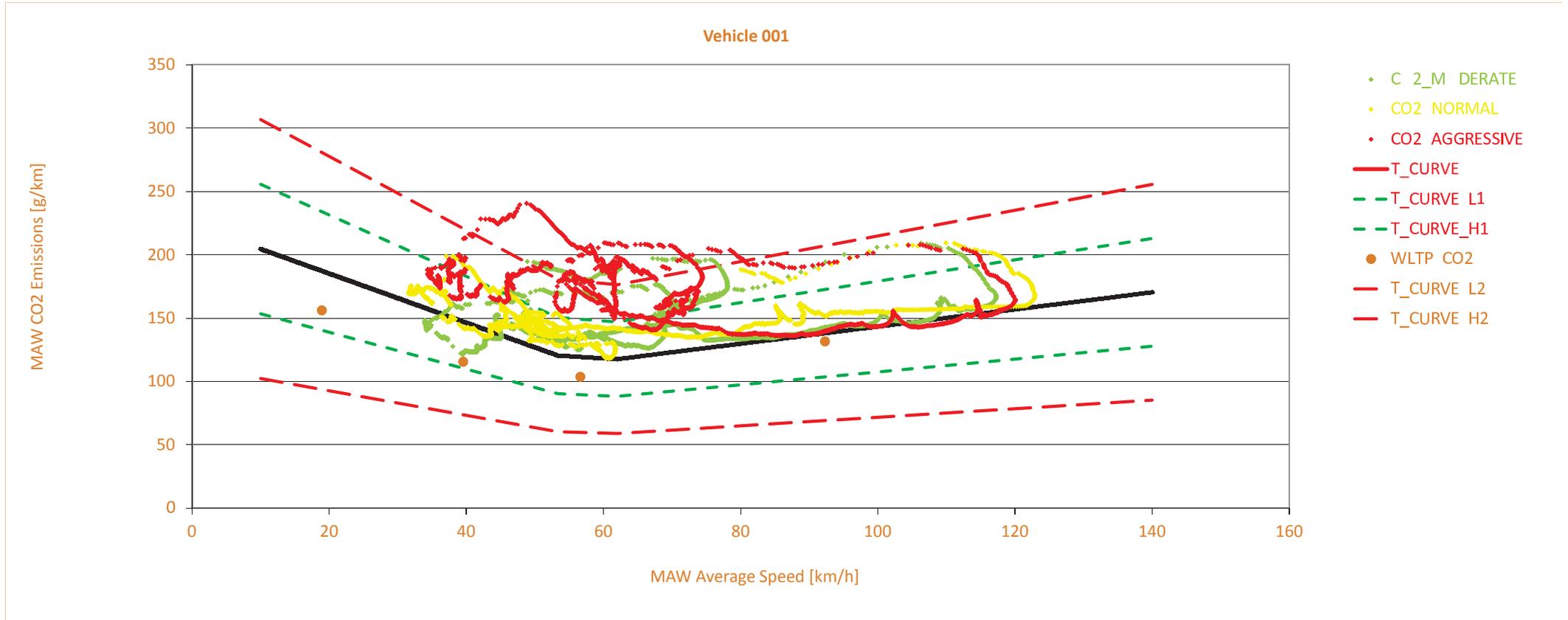
# Other considerations



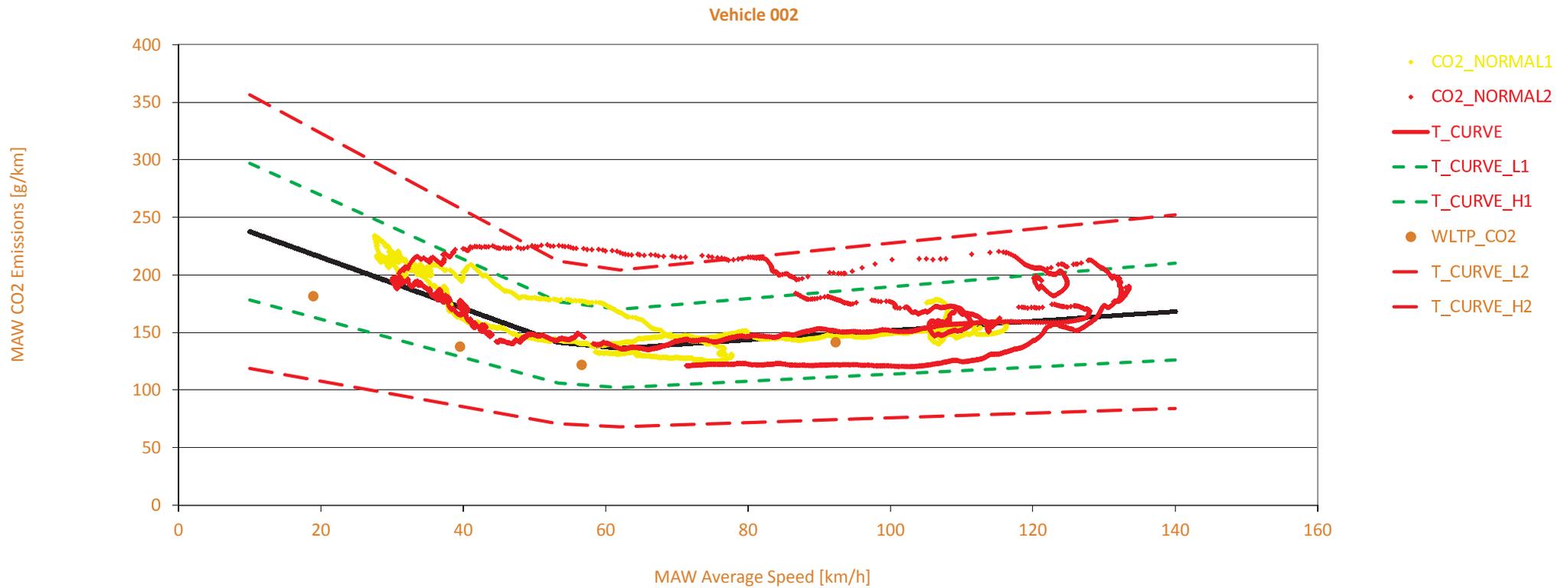
- **How much does the PEMS equipment (mass, aerodynamic modifications) influences the CO2 emissions of the vehicle?**
- **Do the proposed reference situations (WLTP phases) appropriately represent an average normal driving over the considered speed range?**

- **Average distance of the MAWs to the reference curve**
  - Calculated for the normal windows (within Tolerance 1, currently  $\pm 25\%$ )
  - Calculated for the Urban/Rural/Motorway categories
  - Normality index = 0 => All MAWs on the reference curve
  - Normality index = 25 => All MAWs at 25% above the reference curve, etc..

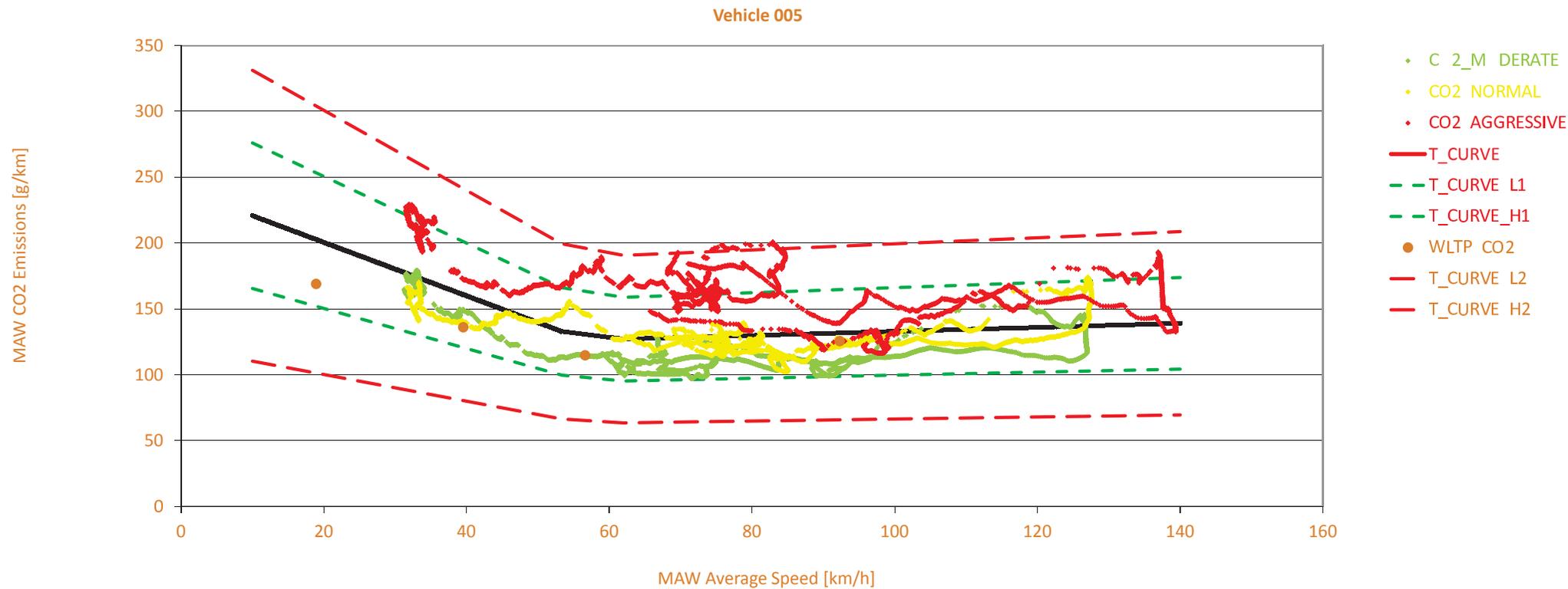
# Effect of routes upon MAW CO2 / Reference



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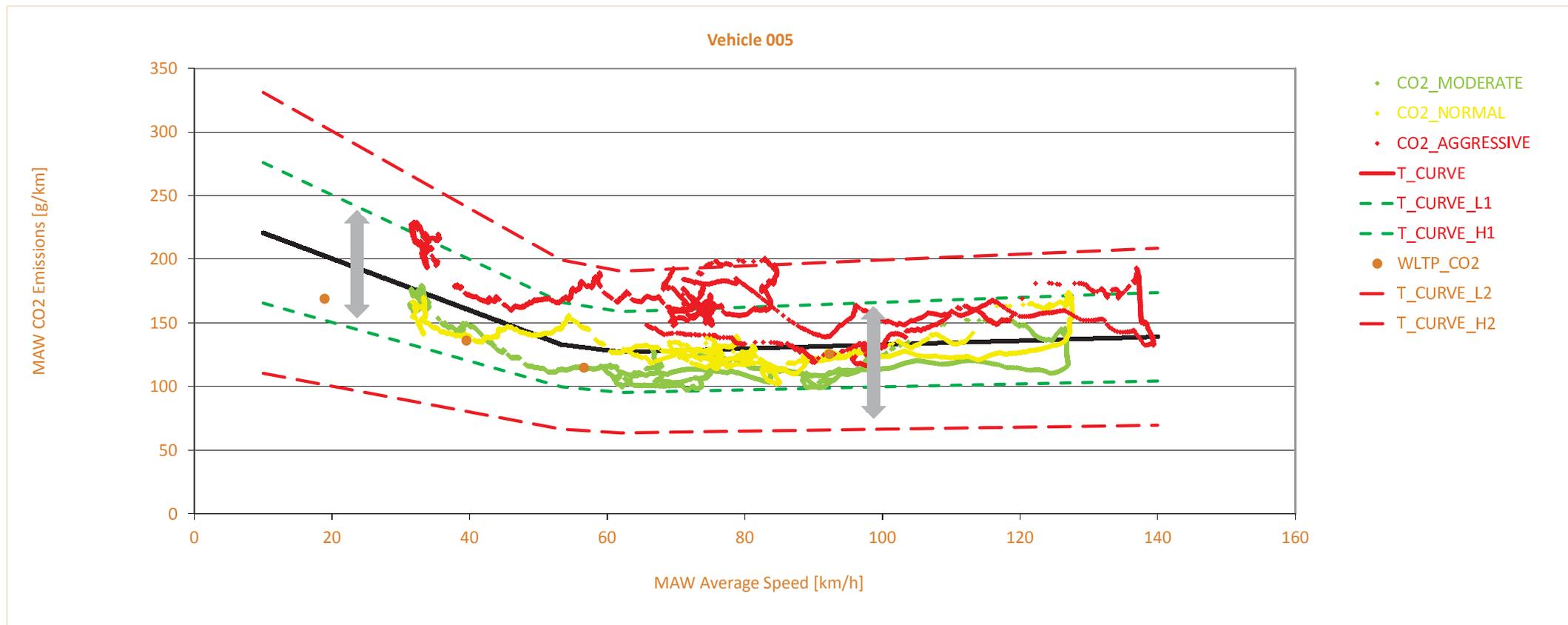


# Effect of routes upon MAW CO2 / Reference



# Effect of routes upon MAW CO2 / Reference

**Current approach: Empirical fine tuning, i.e. optimization of CO2 reference curve (including mathematics and WLTP PEMS correction factors) – for the normal routes and several vehicles**

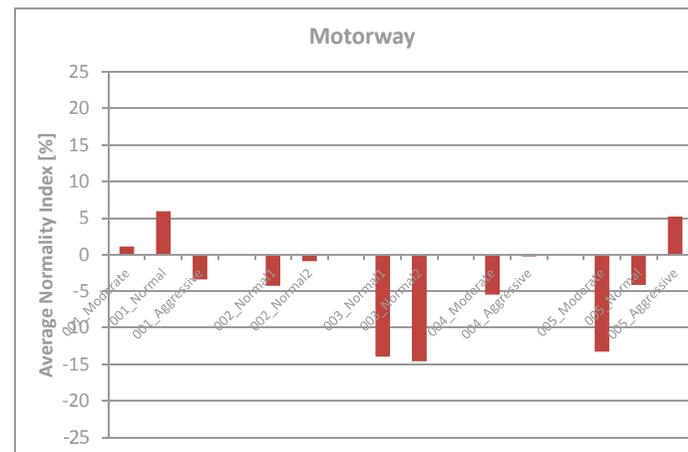
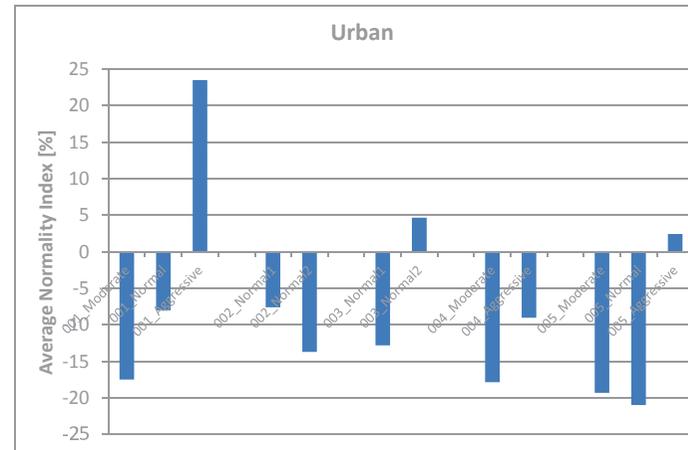


# Normality indices for different vehicles & routes



## Numerical example: normality indices for a bi-linear CO2 curve and WLTP correction factor of 1.2 for urban driving

Vehicle_Route	Urban	Rural	Motorway
001_Normal	-8.03	1.61	5.94
002_Normal2	-13.72	-10.85	-0.89
003_Normal2	4.66	-11.79	-14.59
004_Aggressive	-9.03	1.30	-0.24
005_Normal	-20.99	-8.38	-4.15



## ➤ (Current) Empirical

- Using the available data from different vehicles
- Optimizing the curve mathematics (2 types currently tested)
- Optimizing the empirical correction factors to minimize the “normality indices”

## ➤ Semi-empirical

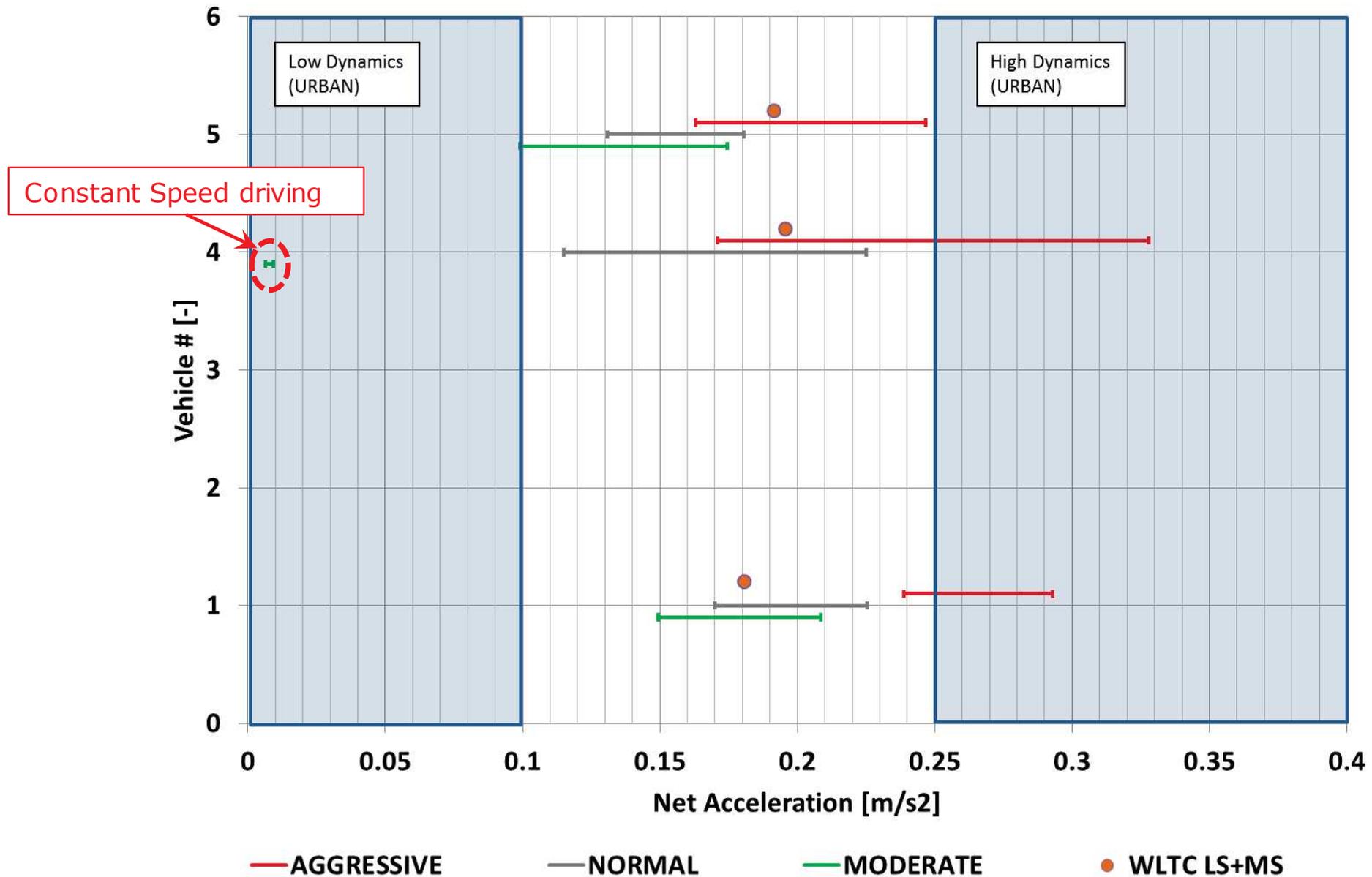
- $CO_2 = f(m, v, a, F_0, F_1, F_2)$  for each WLTP phase
- Extrapolation of the WLTP results using empirically calibrated equations: effect of PEMS mass ( $m > m + \text{PEMS mass}$ ) or estimated  $CO_2$  at constant or high speeds

- Design and fine-tuning of CO<sub>2</sub> characteristic curve
- **Additional “backup” elements – Implementation?**
- Speed-acceleration indicators

- **Vehicles Summary**
- Vehicle 001
- Vehicle 004
- Vehicle 005

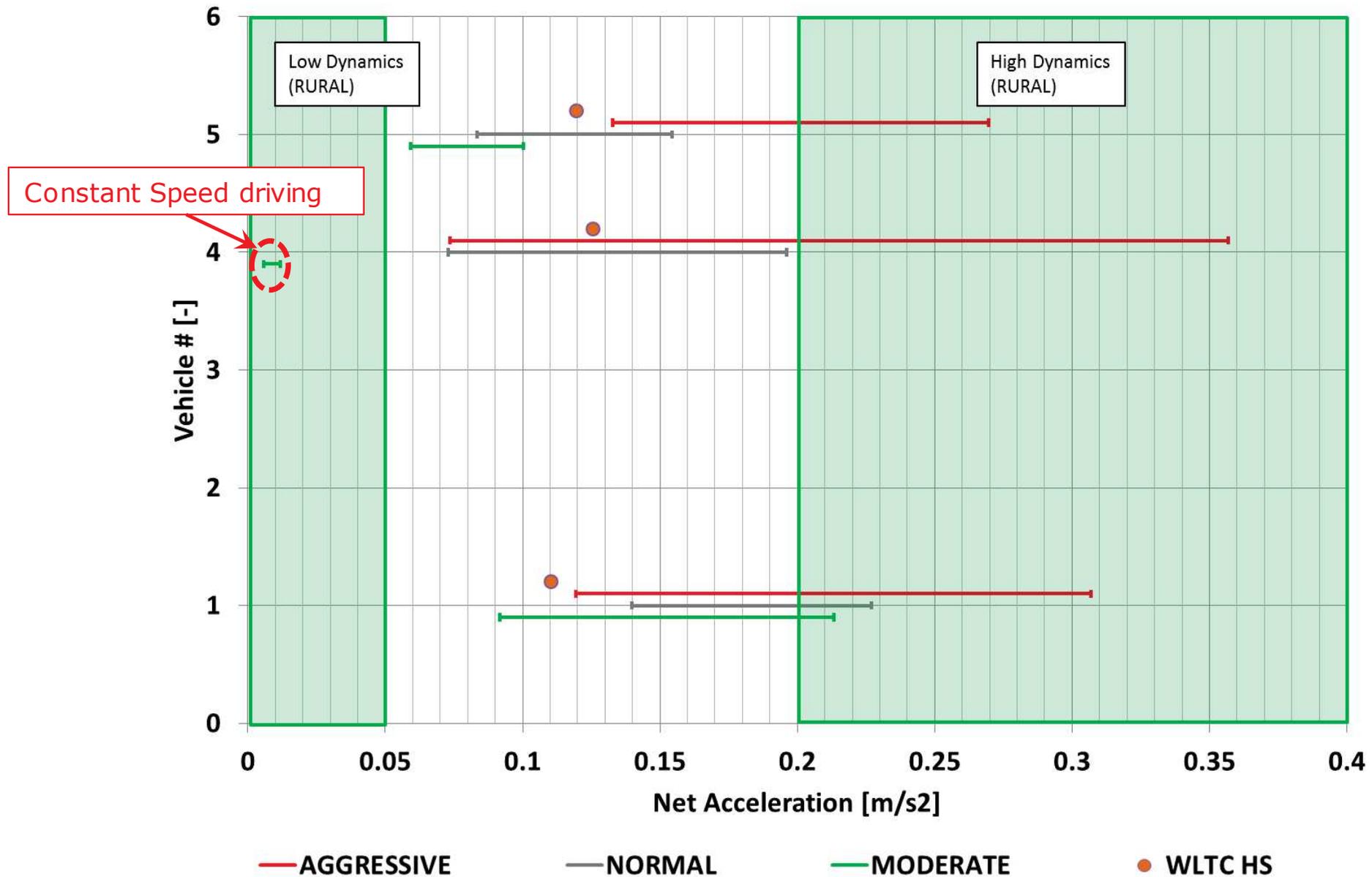
# Acc. Indicator1 vs. Vehicles (1/3)

## URBAN



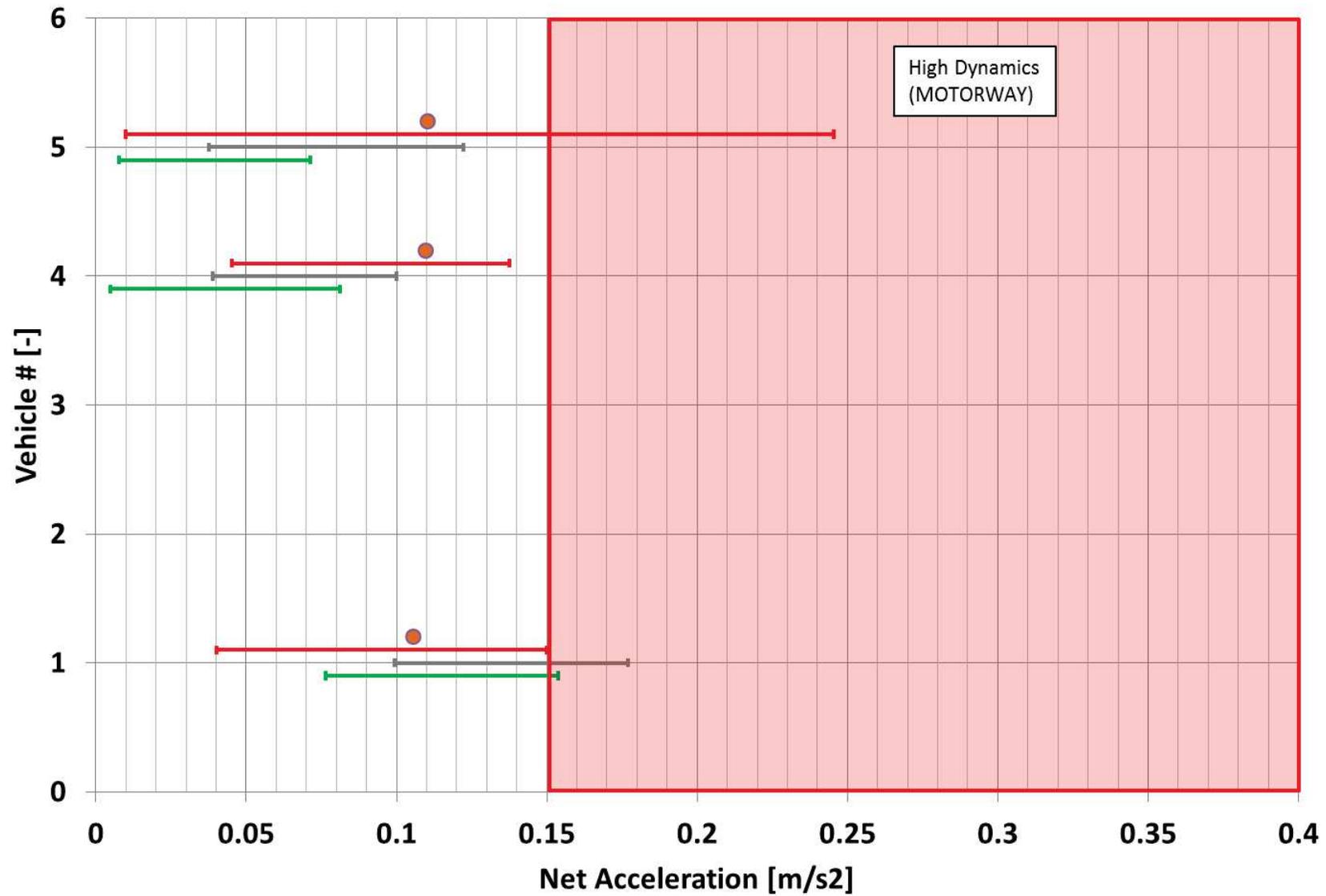
# Acc. Indicator1 vs. Vehicles (2/3)

## ➤ RURAL



# Acc. Indicator1 vs. Vehicles (3/3)

## ➤ MOTORWAY



— AGGRESSIVE

— NORMAL

— MODERATE

● WLTC EHS

# Outline – Driving Dynamics Indicator



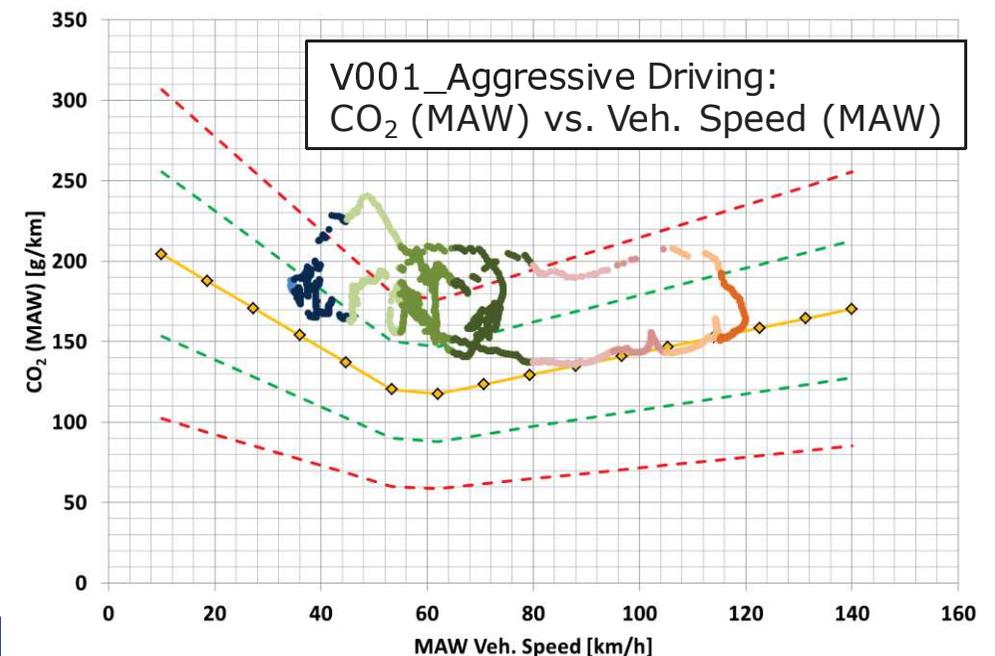
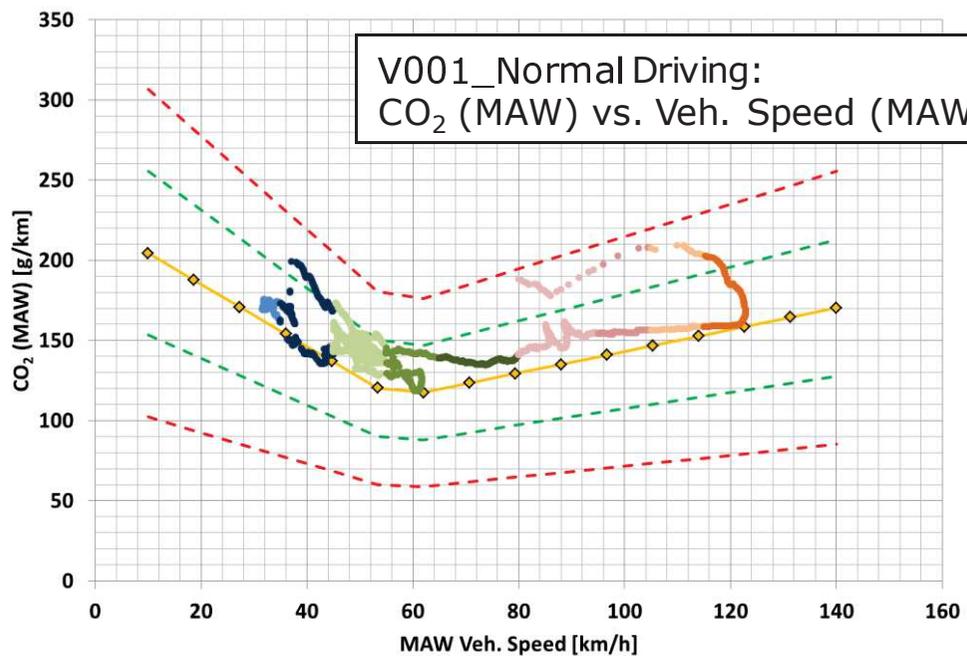
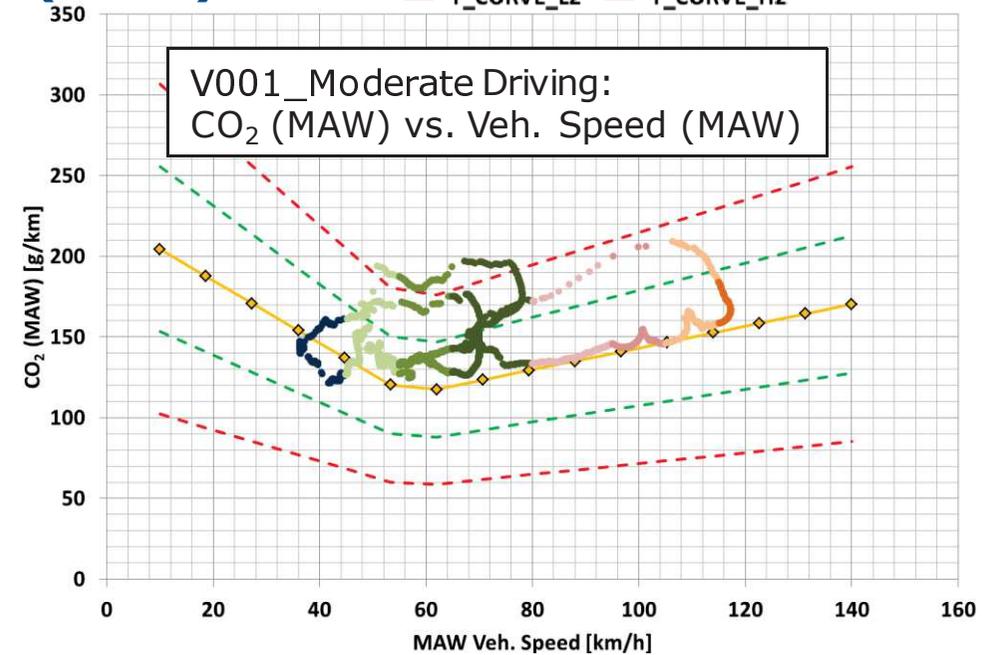
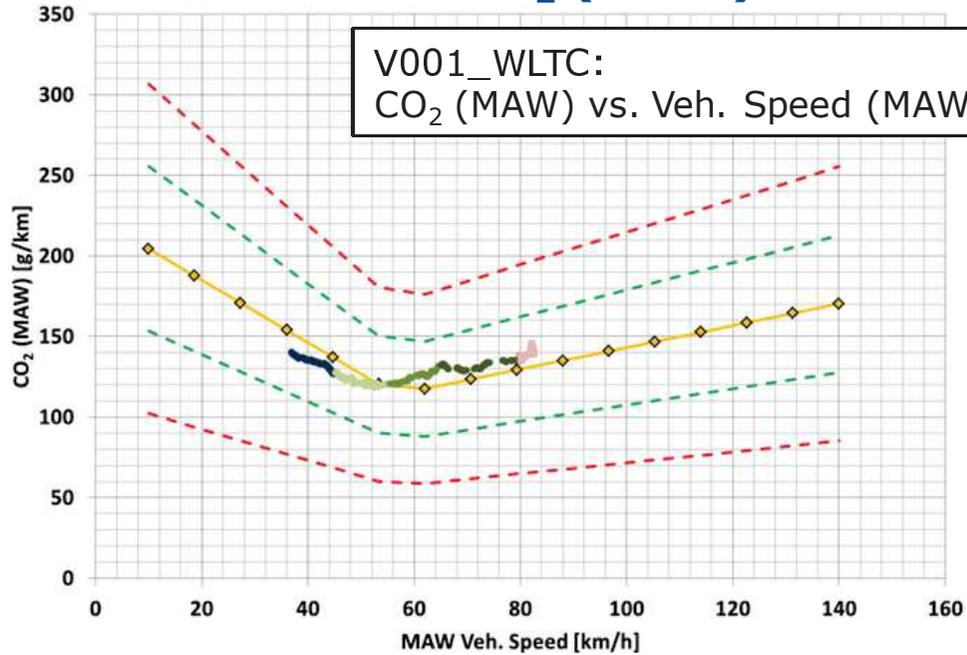
- Vehicles Summary
- **Vehicle 001**
- Vehicle 004
- Vehicle 005

# V001 – Comparison of Driving Styles (1/3)



## Vehicle 001 – CO<sub>2</sub> (MAW) vs. Veh. Speed (MAW)

— T\_CURVE    - - - T\_CURVE\_L1    - - - T\_CURVE\_H1  
- - - T\_CURVE\_L2    - - - T\_CURVE\_H2

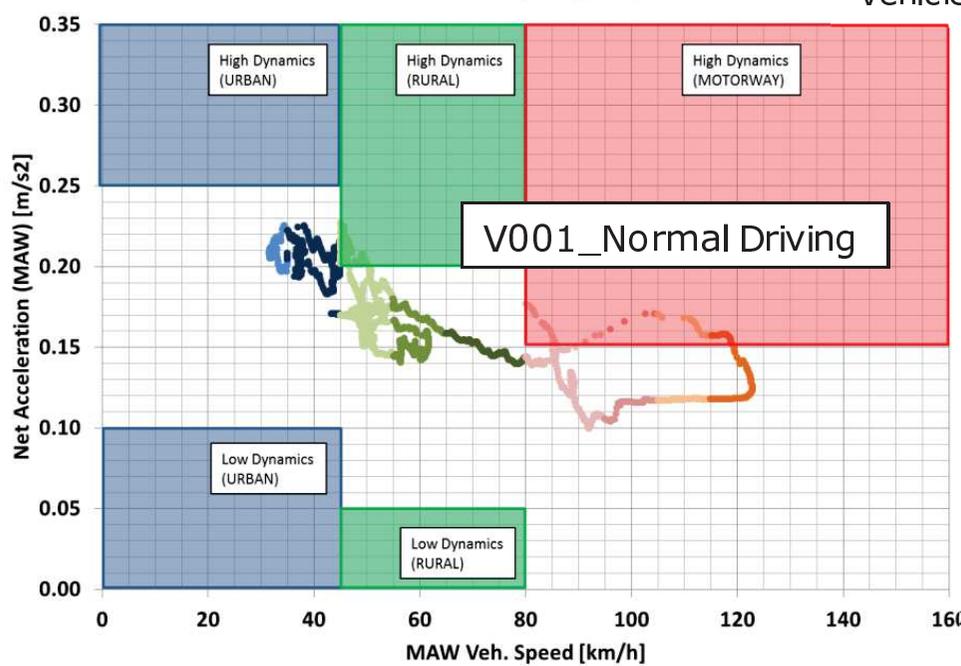
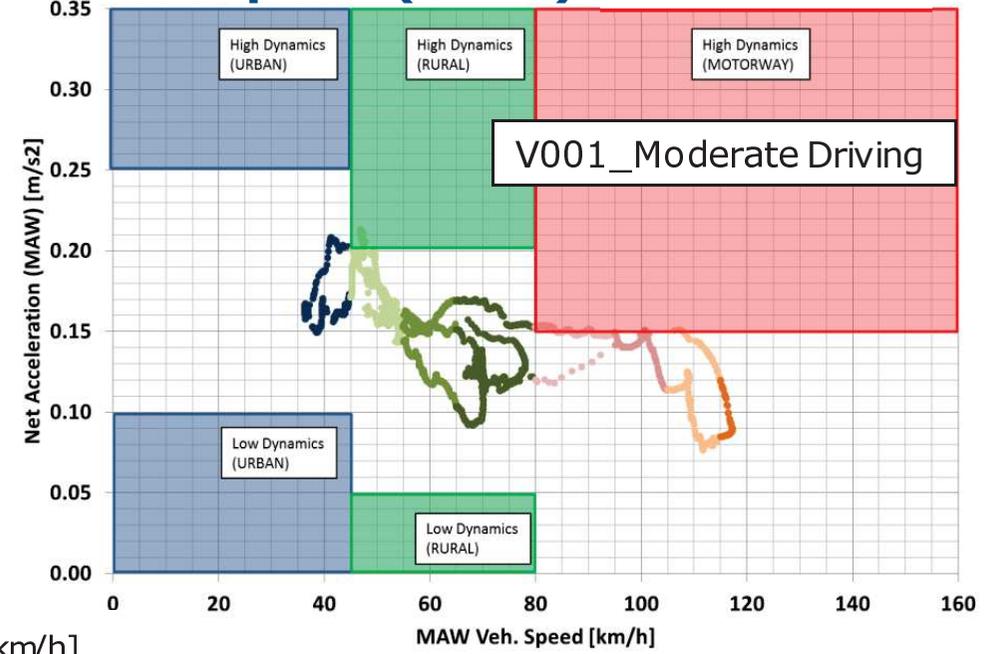
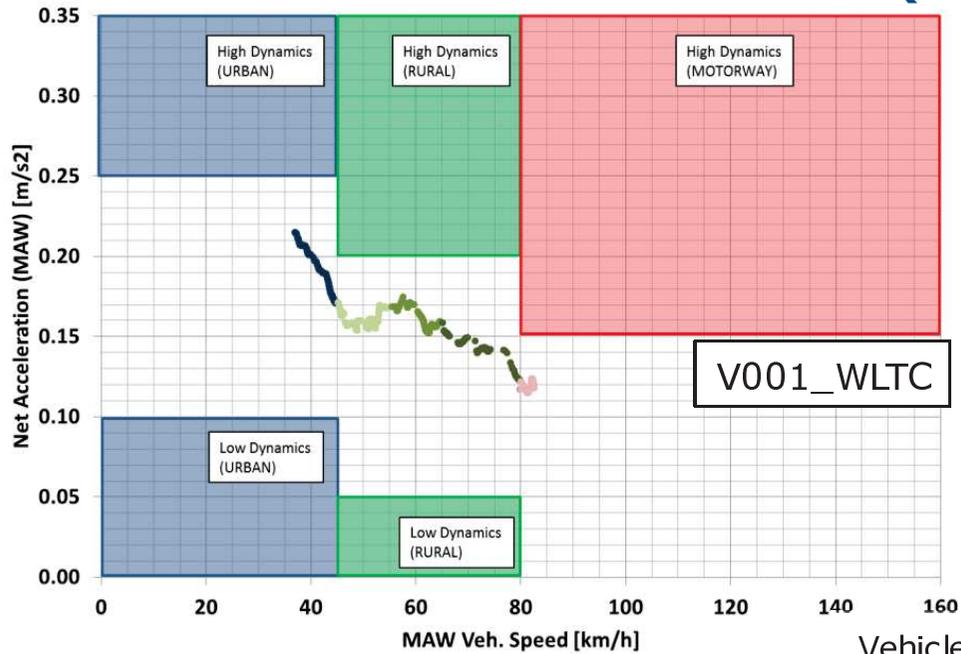


# V001 – Comparison of Driving Styles (2/3)



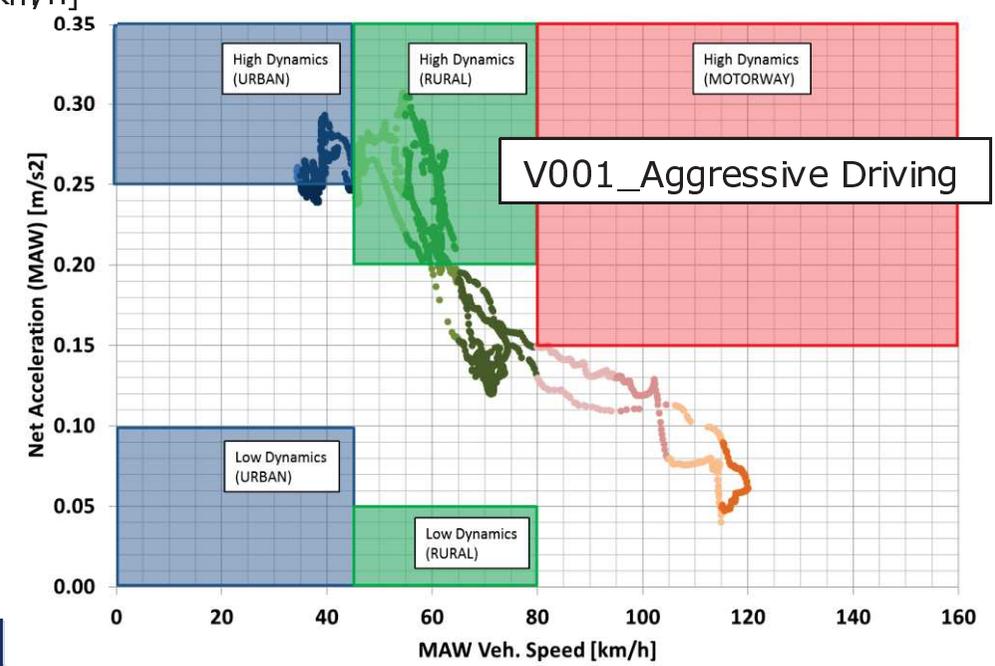
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## Vehicle 001 – Acc. Indicator1 (MAW) vs. Veh. Speed (MAW)



Vehicle Speed [km/h]

- 0-15
- 15-25
- 25-35
- 35-45
- 45-55
- 45-55
- 55-65
- 65-80
- 80-95
- 95-105
- 105-115
- 115-125
- 125-135
- 135-145
- 145-155



Net Acceleration (MAW) [m/s²]

- 0-15
- 15-25
- 25-35
- 35-45
- 45-55
- 45-55
- 55-65
- 65-80
- 80-95
- 95-105
- 105-115
- 115-125
- 125-135
- 135-145
- 145-155

# V001 – Summary



## ➤ Vehicle 001 – Summary:


			SUMMARY MODERATE DRIVING			SUMMARY NORMAL Driving			SUMMARY AGGRESSIVE Driving		
			Urban	Rural	Motorway	Urban	Rural	Motorway	Urban	Rural	Motorway
VEH 001	Acc. Indicator 1	Average	0.165	0.148	0.127	0.203	0.170	0.131	0.257	0.209	0.101
		Dev.St.	0.011	0.029	0.024	0.012	0.021	0.017	0.013	0.055	0.032
		10CP	0.156	0.116	0.086	0.187	0.146	0.108	0.244	0.135	0.059
		90 CP	0.172	0.196	0.151	0.216	0.209	0.156	0.276	0.277	0.139
		Min	0.149	0.092	0.077	0.170	0.140	0.100	0.239	0.119	0.040
		Max	0.208	0.213	0.154	0.225	0.227	0.177	0.293	0.307	0.150
		Max-Min	0.059	0.121	0.077	0.055	0.087	0.077	0.054	0.187	0.110
	Acc. Indicator 2	Average	0.126	0.116	0.099	0.149	0.127	0.100	0.210	0.175	0.089
		Dev.St.	0.002	0.013	0.013	0.004	0.002	0.014	0.004	0.049	0.030
		10CP	0.123	0.101	0.080	0.144	0.124	0.086	0.203	0.105	0.050
		90 CP	0.129	0.137	0.112	0.154	0.130	0.123	0.214	0.232	0.128
		Min	0.122	0.097	0.074	0.142	0.124	0.082	0.198	0.092	0.045
		Max	0.134	0.173	0.114	0.158	0.131	0.125	0.218	0.246	0.135
		Max-Min	0.013	0.076	0.040	0.016	0.007	0.043	0.020	0.154	0.090

# Outline – Driving Dynamics Indicator



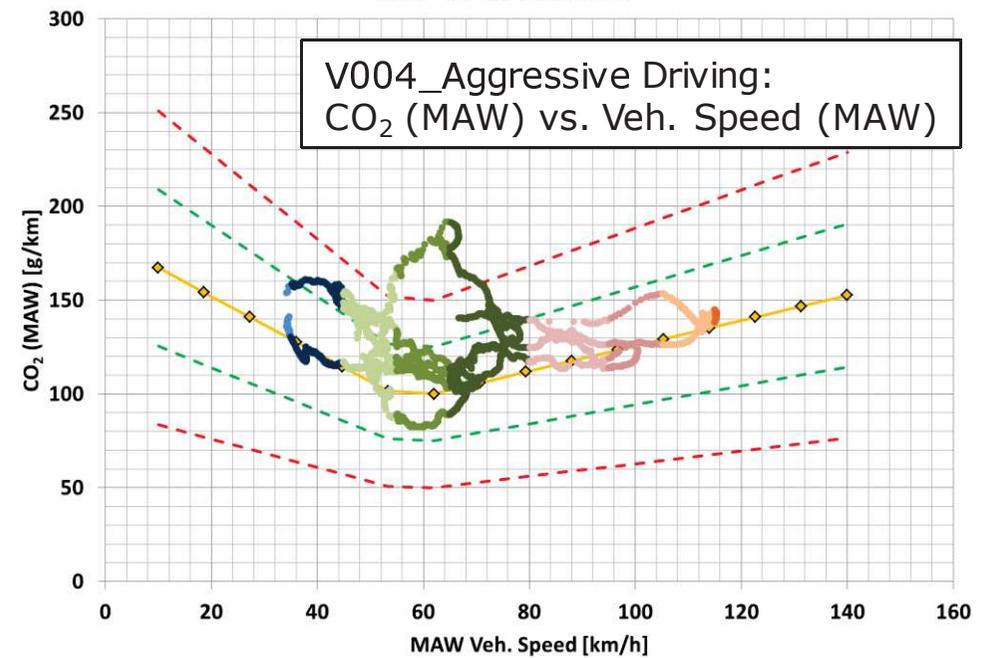
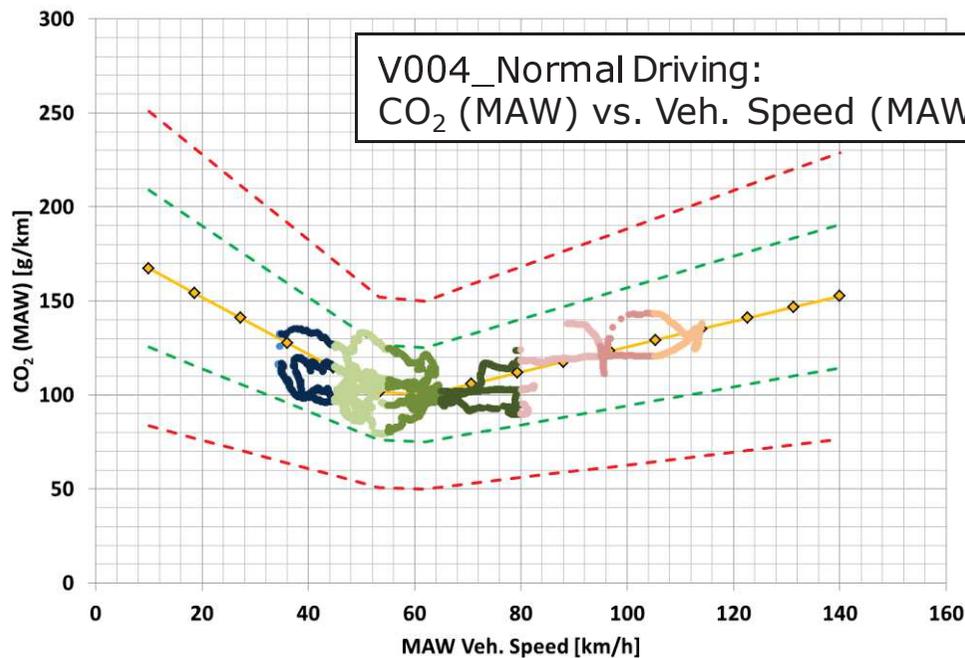
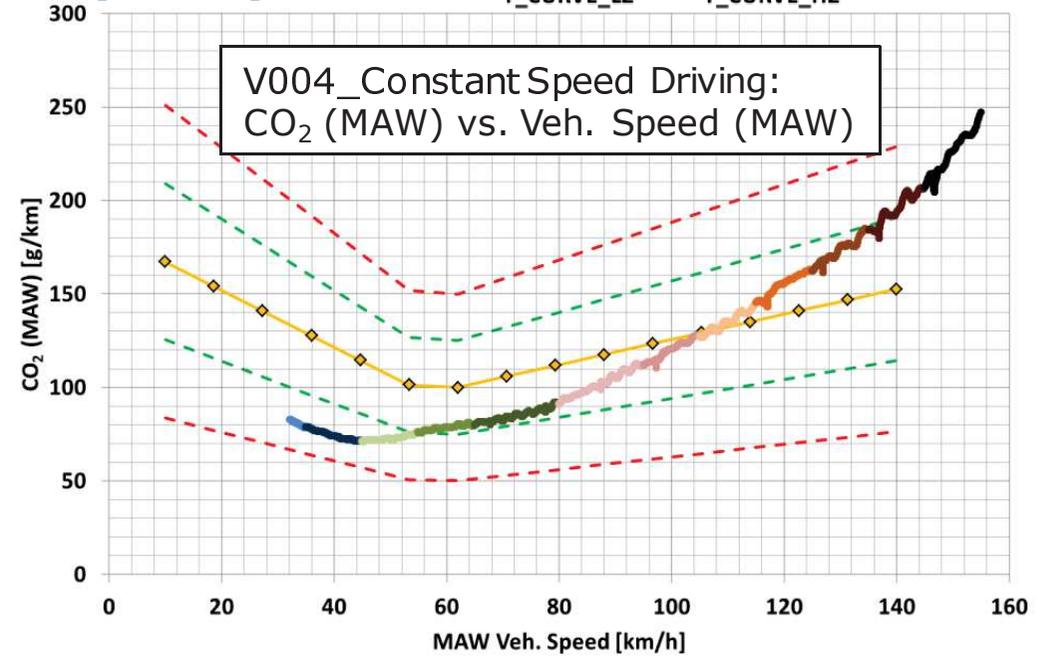
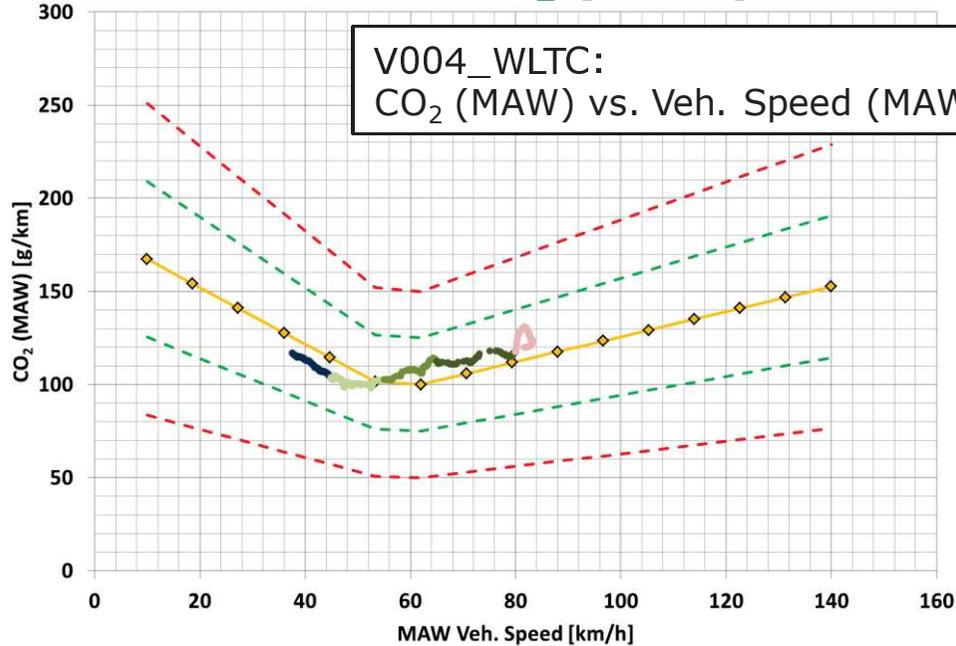
- Vehicles Summary
- Vehicle 001
- **Vehicle 004**
- Vehicle 005

# V004 – Comparison of Driving Styles (1/3)



## Vehicle 004 – CO<sub>2</sub> (MAW) vs. Veh. Speed (MAW)

— T\_CURVE — T\_CURVE\_L1 — T\_CURVE\_H1  
— T\_CURVE\_L2 — T\_CURVE\_H2

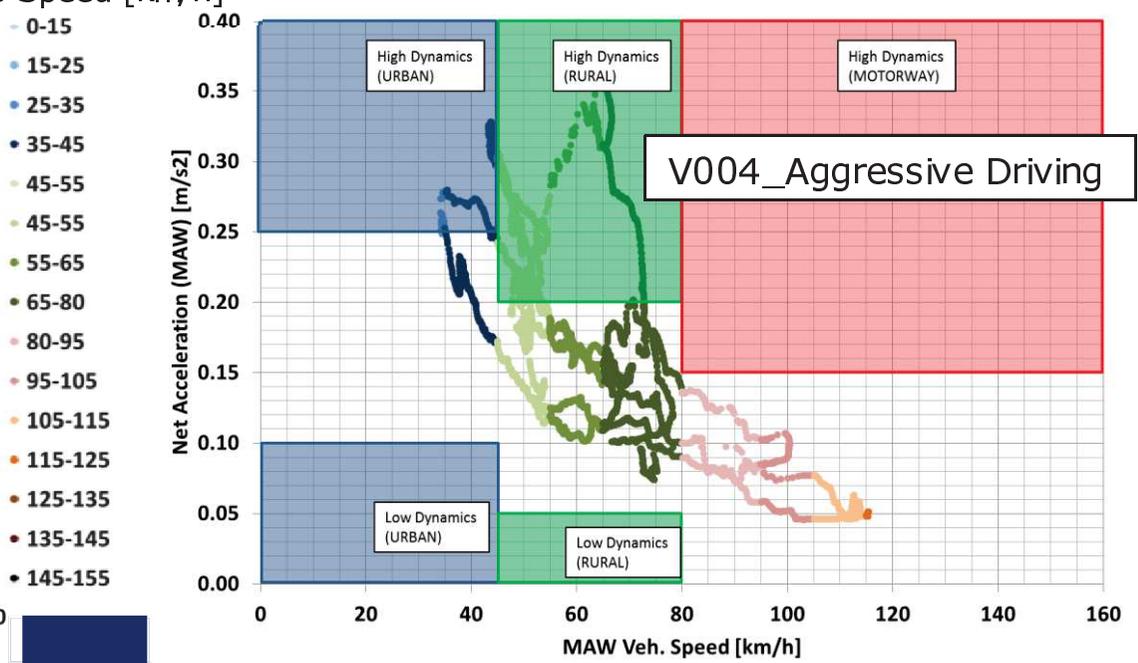
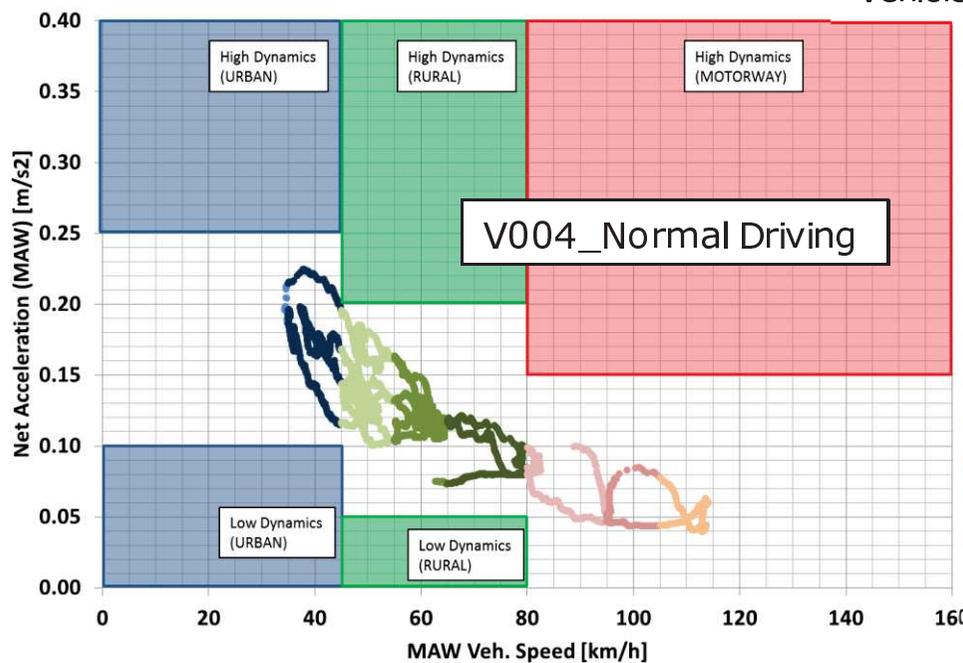
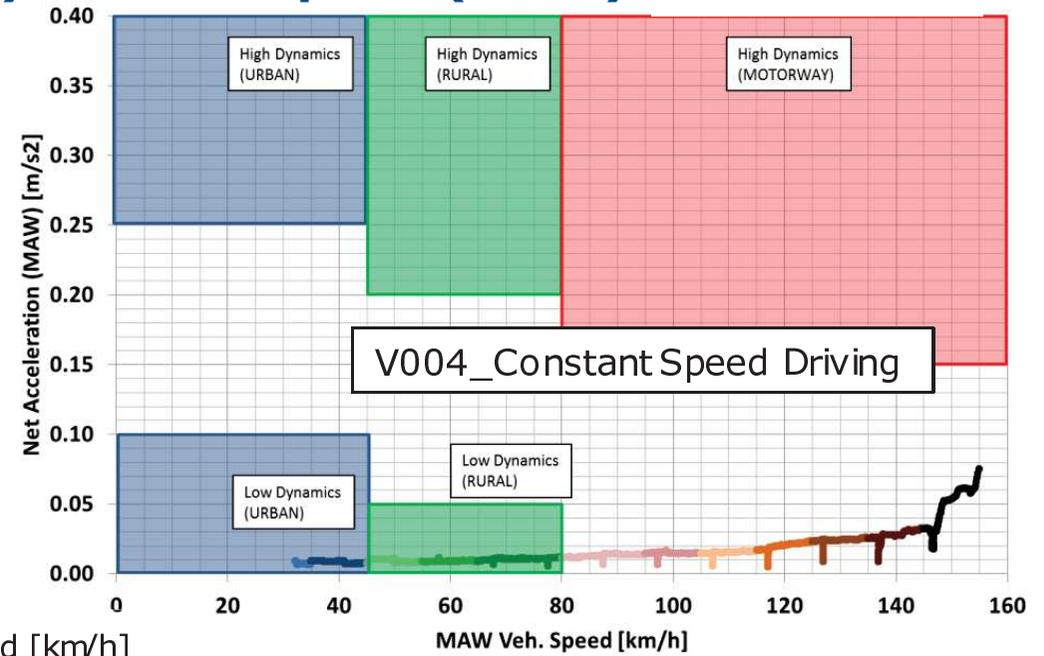
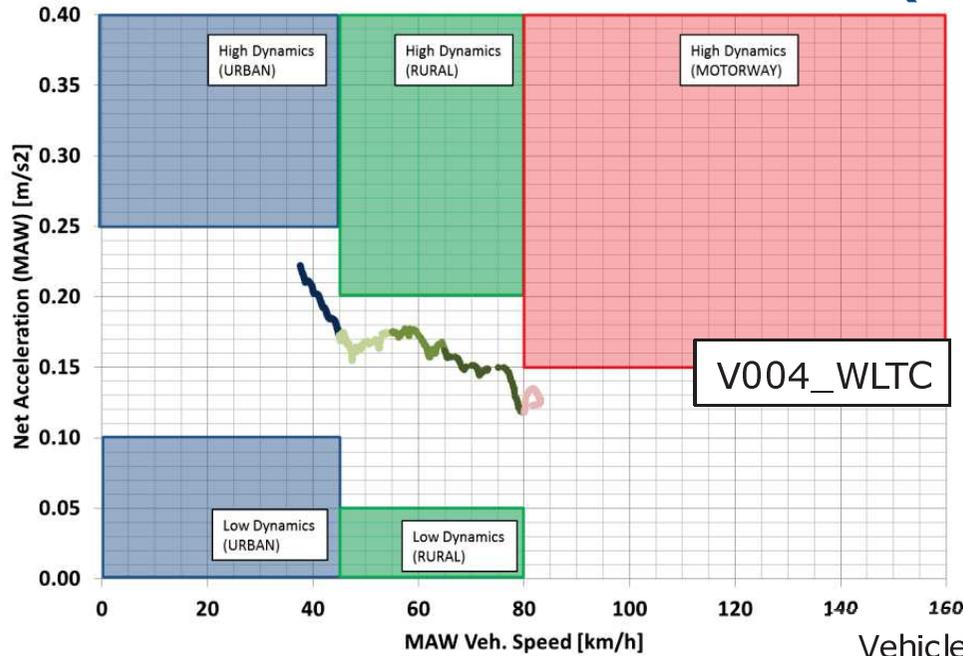


# V004 – Comparison of Driving Styles (2/3)



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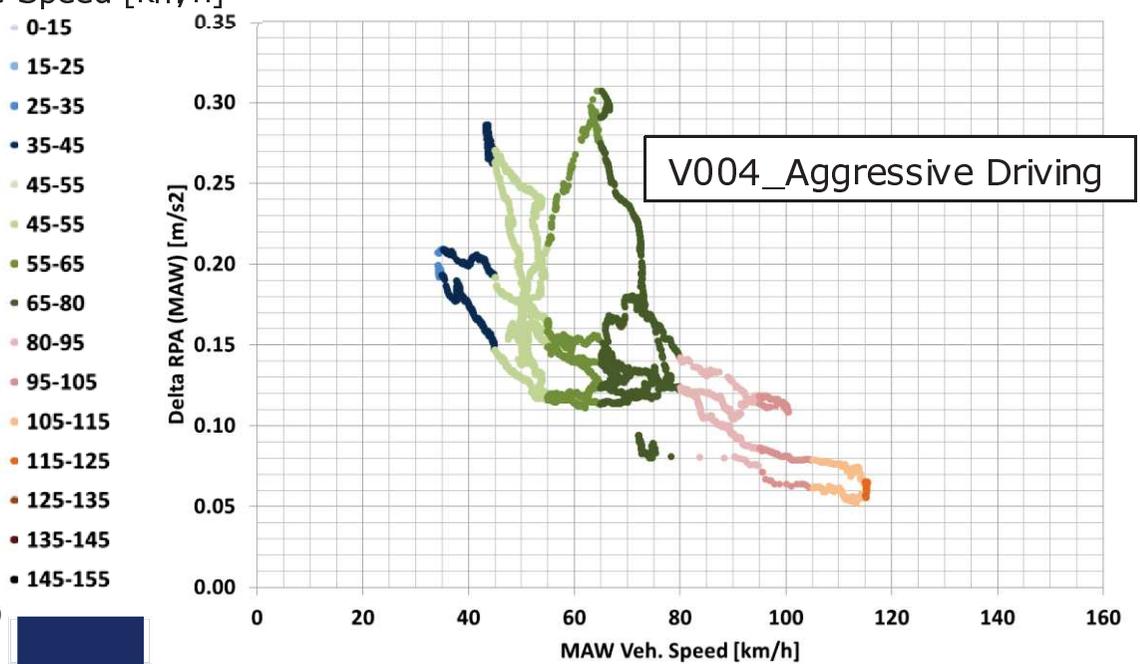
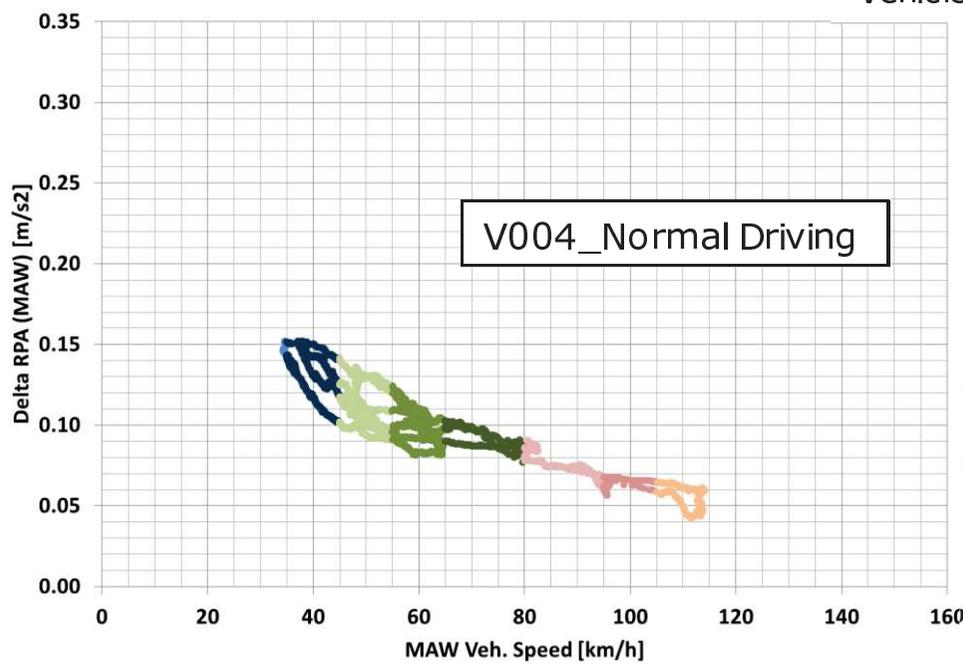
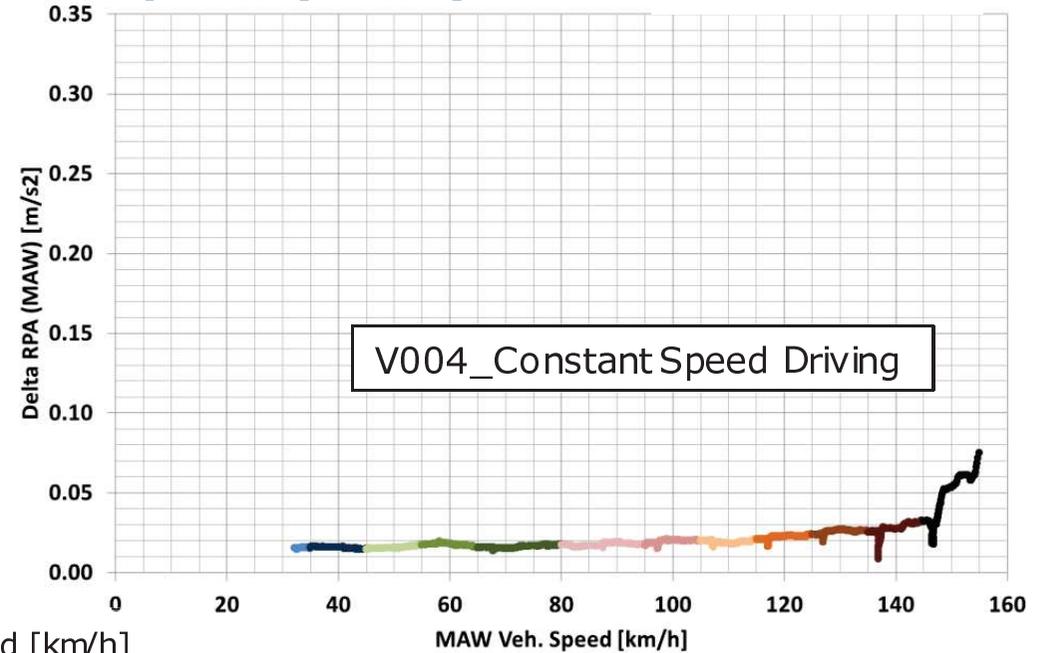
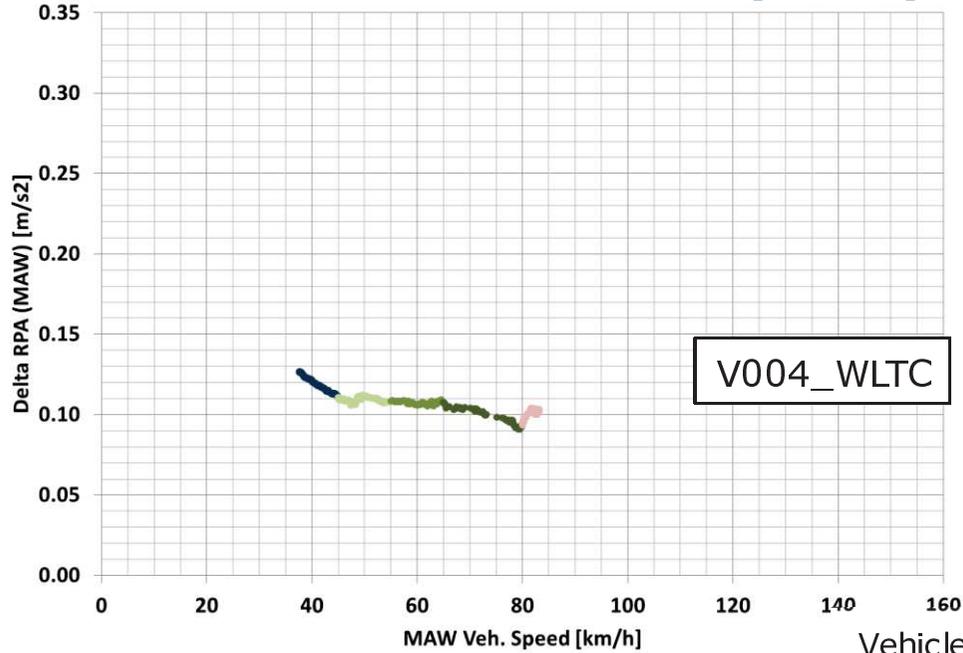
## Vehicle 004 – Acc. Indicator1 (MAW) vs. Veh. Speed (MAW)



# V004 – Comparison of Driving Styles (3/3)



## Vehicle 004 – Delta RPA (MAW) vs. Veh. Speed (MAW)



- 0-15
- 15-25
- 25-35
- 35-45
- 45-55
- 45-55
- 55-65
- 65-80
- 80-95
- 95-105
- 105-115
- 115-125
- 125-135
- 135-145
- 145-155

# V004 – Summary



## ➤ Vehicle 004 – Summary:


			SUMMARY CONST. SPEED Driving			SUMMARY NORMAL Driving			SUMMARY AGGRESSIVE Driving		
			Urban	Rural	Motorway	Urban	Rural	Motorway	Urban	Rural	Motorway
VEH 004	Acc. Indicator 1	Average	0.008	0.009	0.012	0.166	0.125	0.060	0.247	0.170	0.075
		Dev.St.	0.001	0.002	0.009	0.023	0.022	0.016	0.051	0.058	0.025
		10CP	0.007	0.007	0.006	0.131	0.104	0.043	0.176	0.109	0.048
		90 CP	0.009	0.011	0.023	0.193	0.159	0.085	0.320	0.258	0.105
		Min	0.007	0.006	0.005	0.115	0.073	0.039	0.171	0.074	0.045
		Max	0.009	0.012	0.081	0.225	0.196	0.100	0.328	0.357	0.137
		Max-Min	0.003	0.006	0.076	0.110	0.123	0.060	0.157	0.283	0.092
	Acc. Indicator 2	Average	0.015	0.016	0.019	0.132	0.104	0.064	0.207	0.156	0.093
		Dev.St.	0.001	0.001	0.004	0.013	0.013	0.012	0.045	0.045	0.026
		10CP	0.015	0.015	0.016	0.109	0.088	0.047	0.158	0.118	0.060
		90 CP	0.016	0.018	0.026	0.146	0.126	0.085	0.282	0.231	0.122
		Min	0.015	0.014	0.015	0.101	0.077	0.042	0.147	0.080	0.052
		Max	0.016	0.020	0.051	0.152	0.141	0.090	0.286	0.307	0.142
		Max-Min	0.002	0.006	0.036	0.051	0.064	0.048	0.139	0.227	0.090

# Outline – Driving Dynamics Indicator



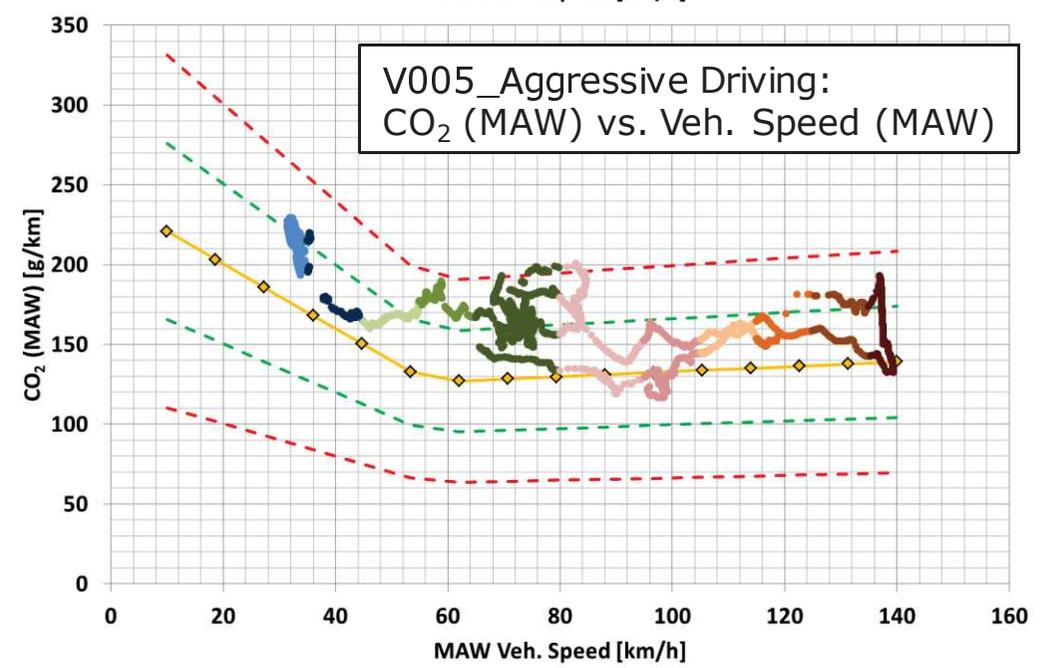
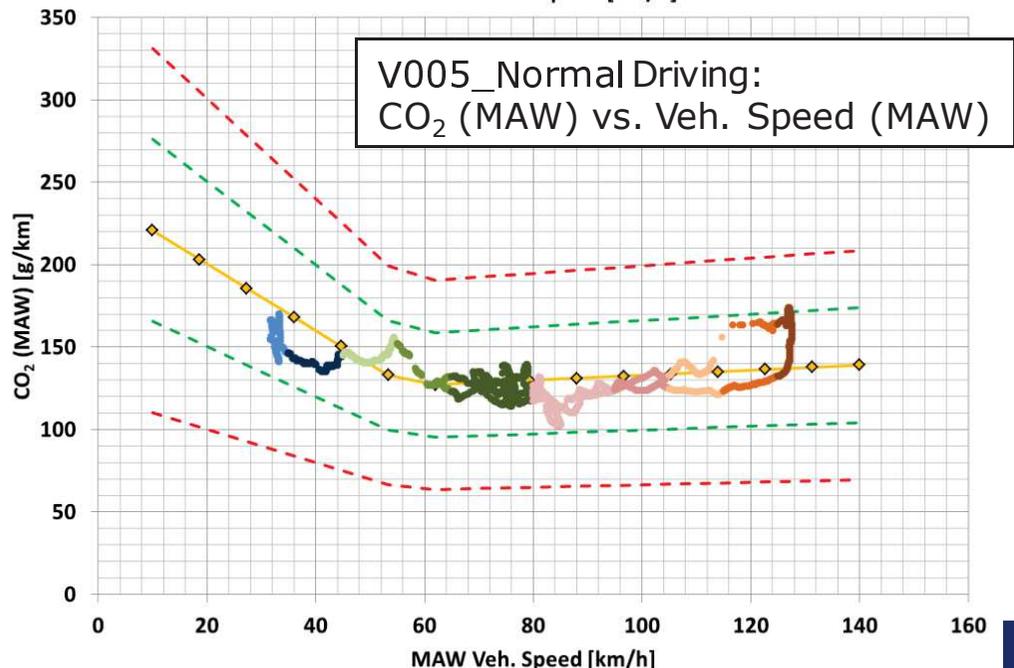
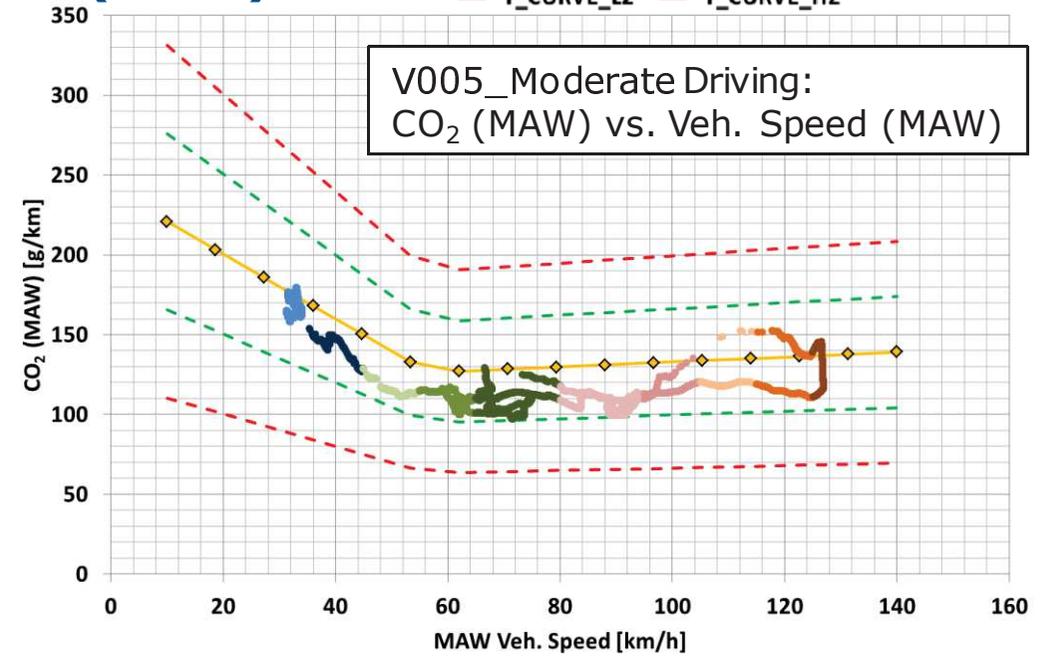
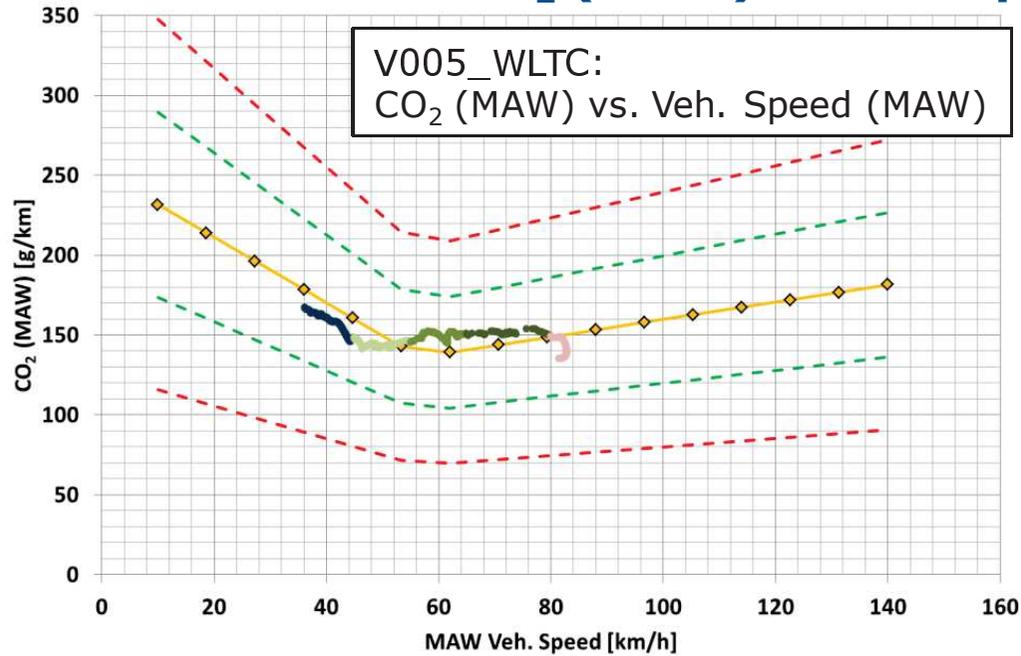
- Vehicles Summary
- Vehicle 001
- Vehicle 004
- **Vehicle 005**

# V005 – Comparison of Driving Styles (1/3)



## Vehicle 005 – CO<sub>2</sub> (MAW) vs. Veh. Speed (MAW)

— T\_CURVE — T\_CURVE\_L1 — T\_CURVE\_H1  
— T\_CURVE\_L2 — T\_CURVE\_H2

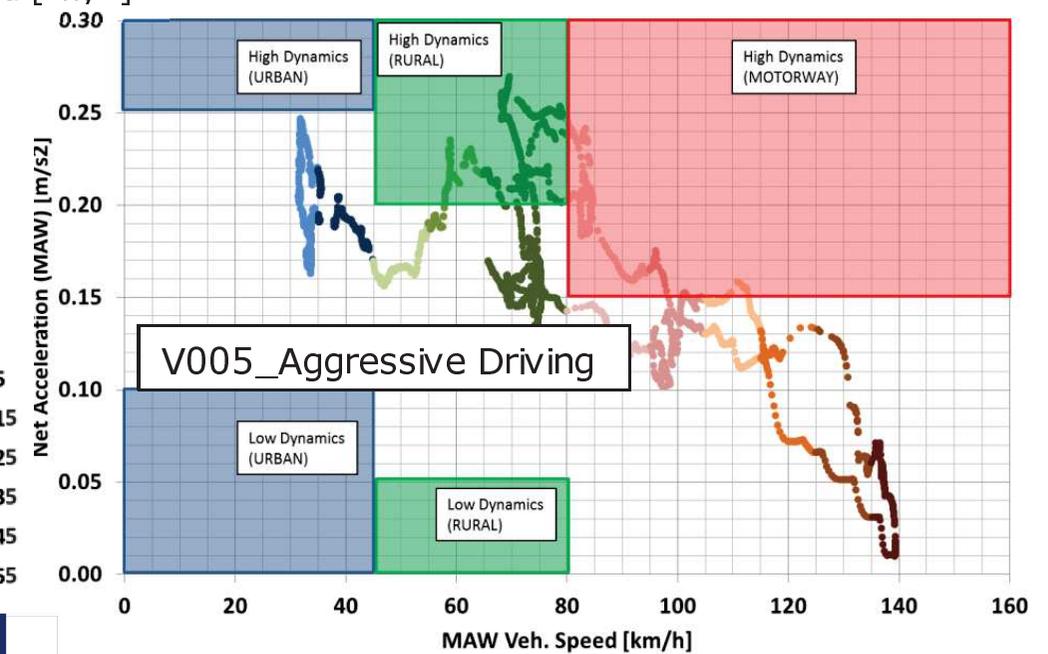
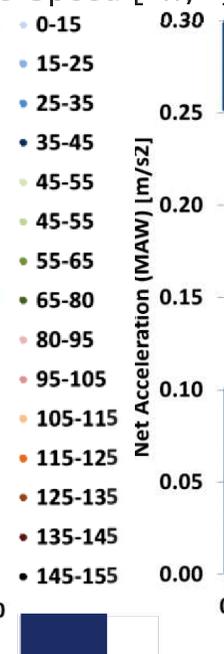
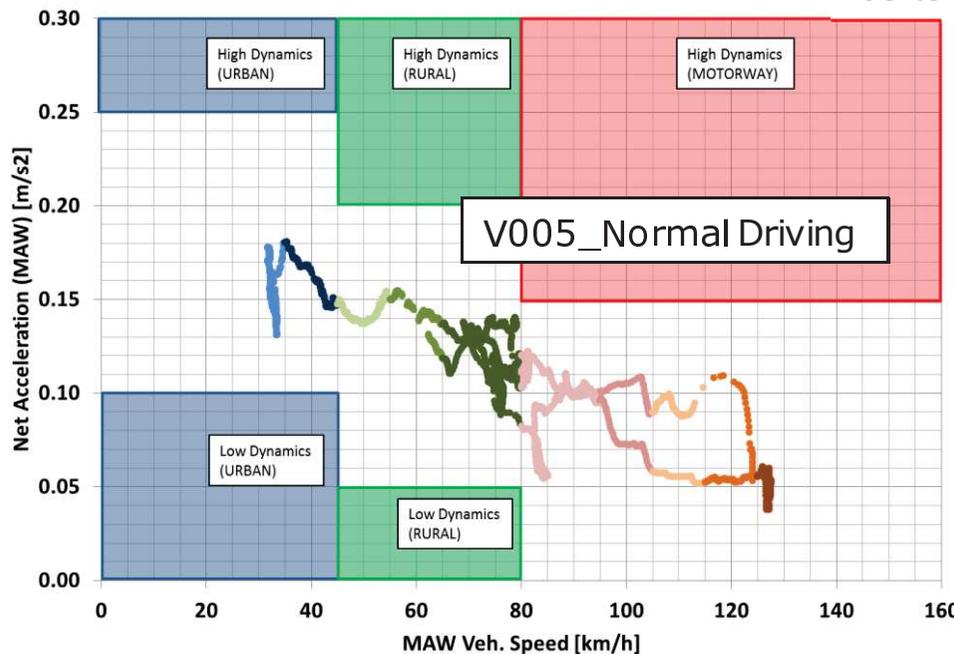
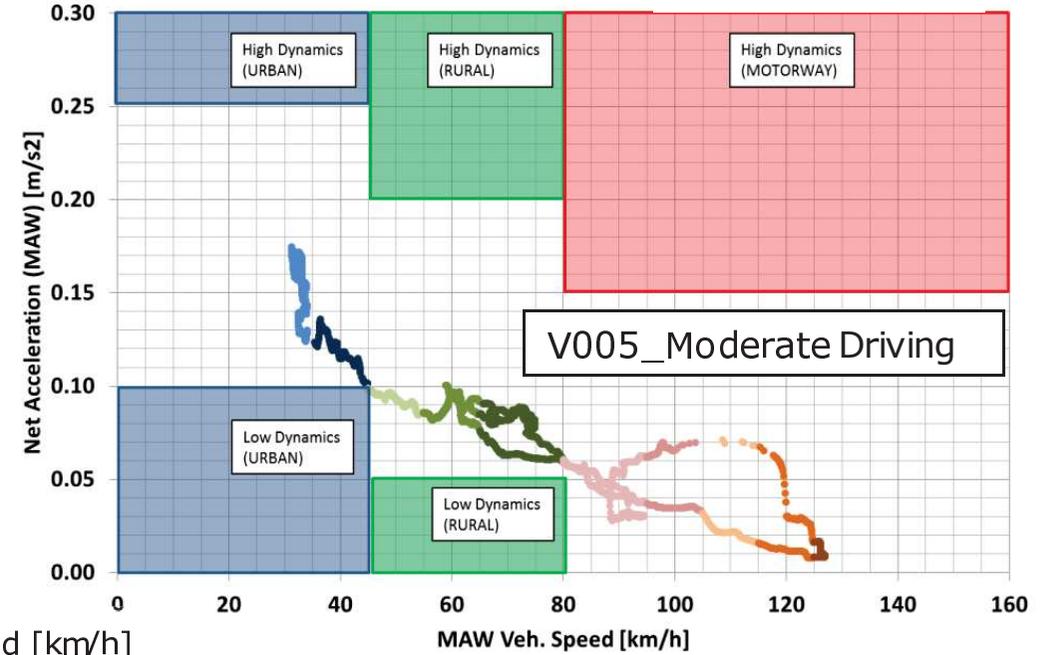
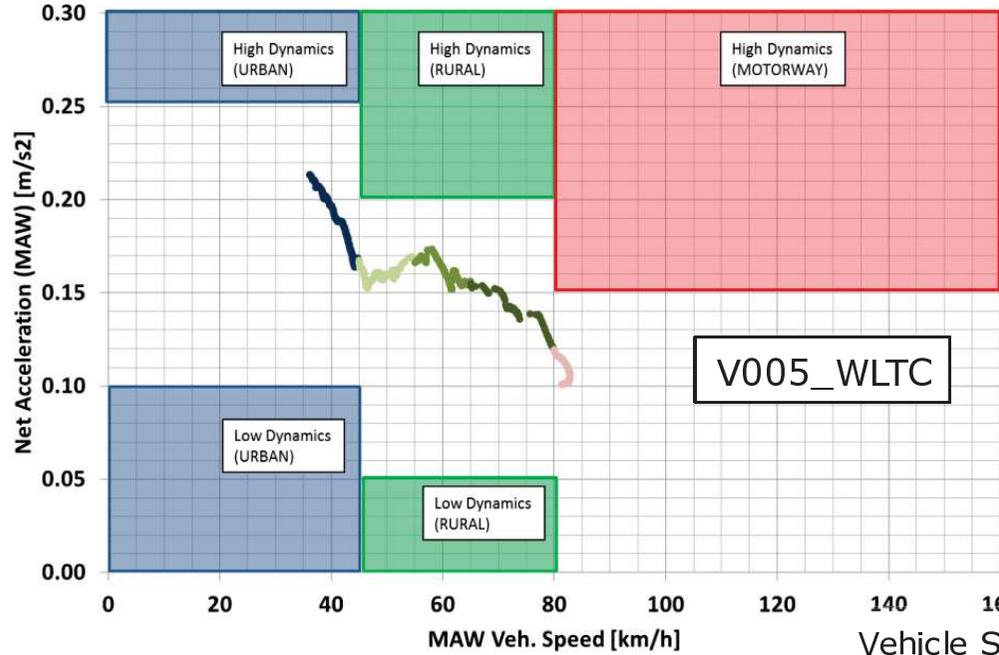


# V005 – Comparison of Driving Styles (2/3)



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## Vehicle 005 – Acc. Indicator1 (MAW) vs. Veh. Speed (MAW)



# V005 – Summary



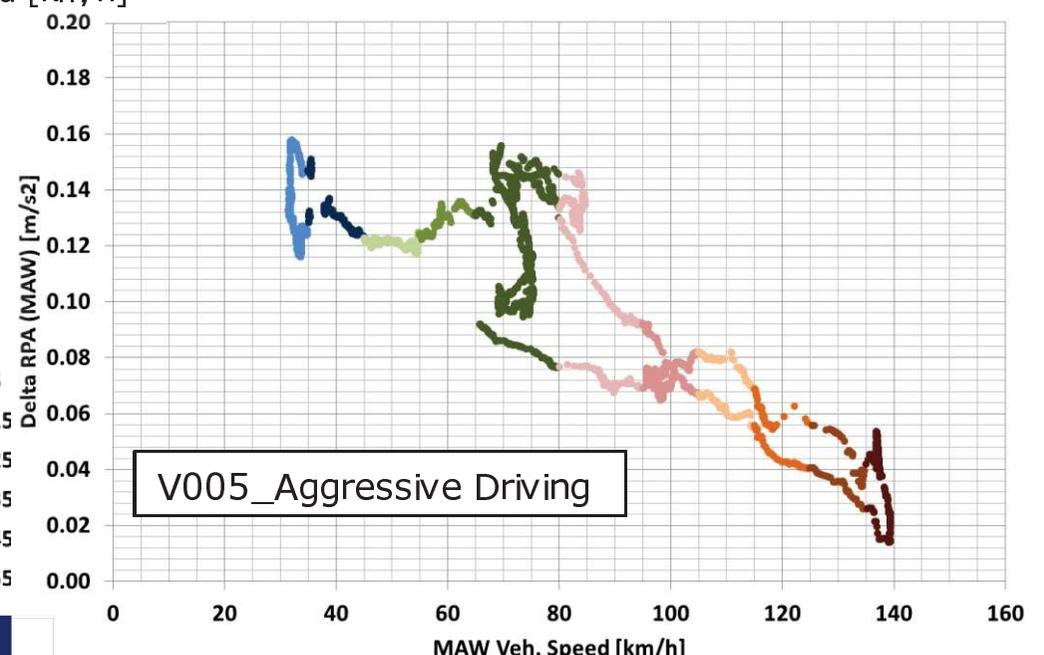
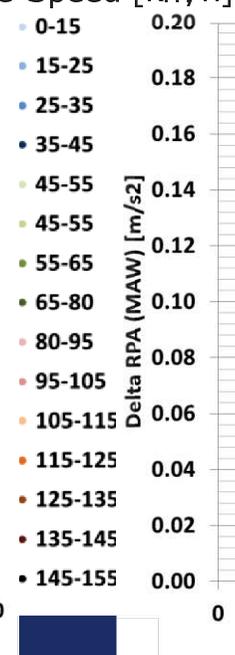
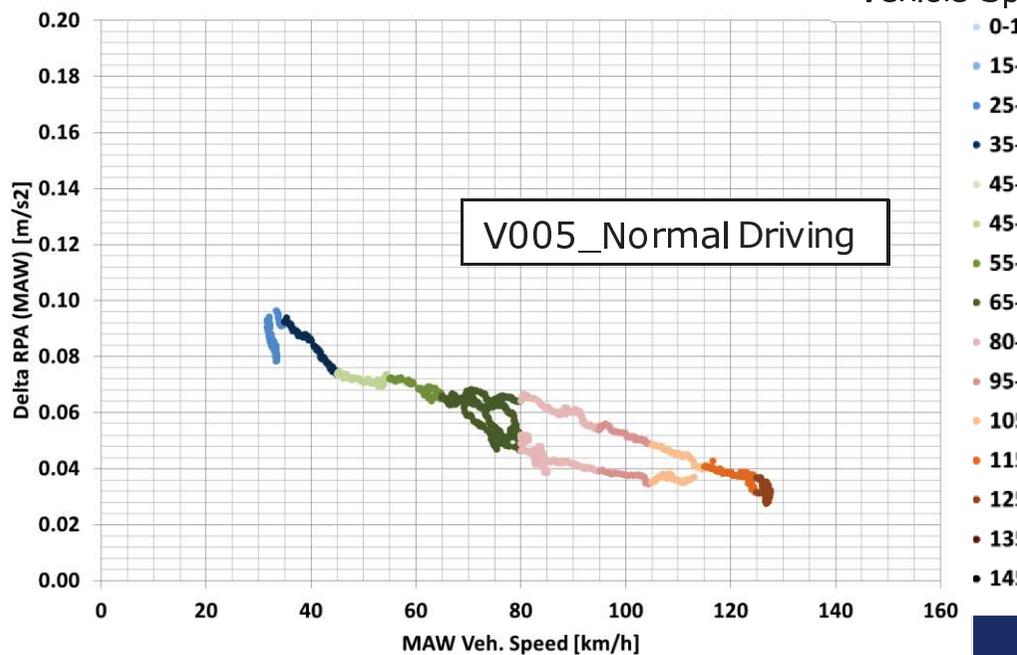
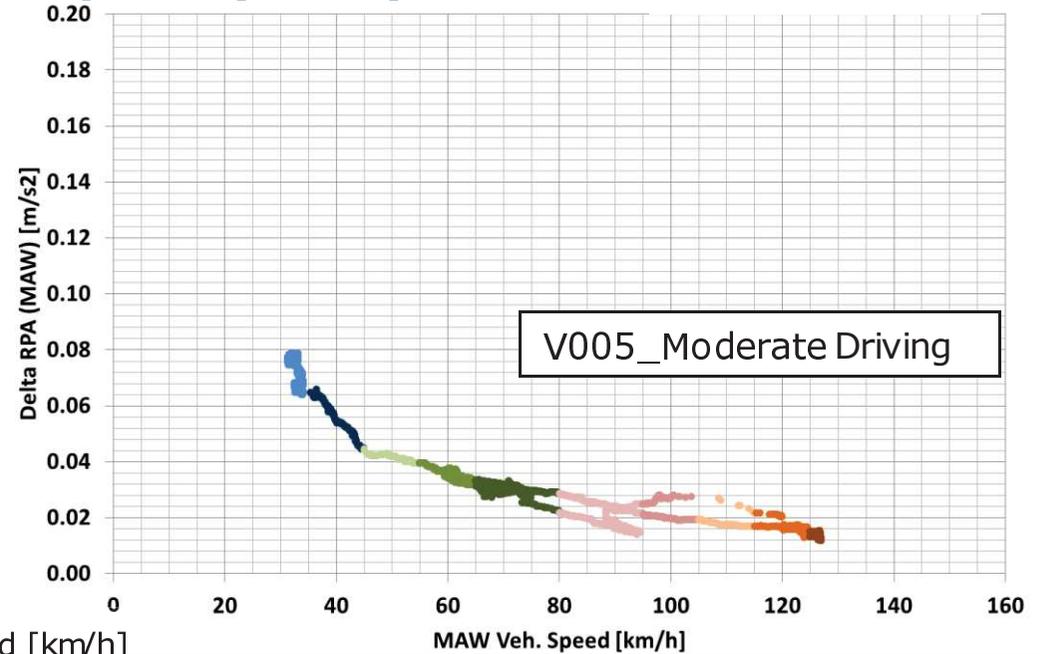
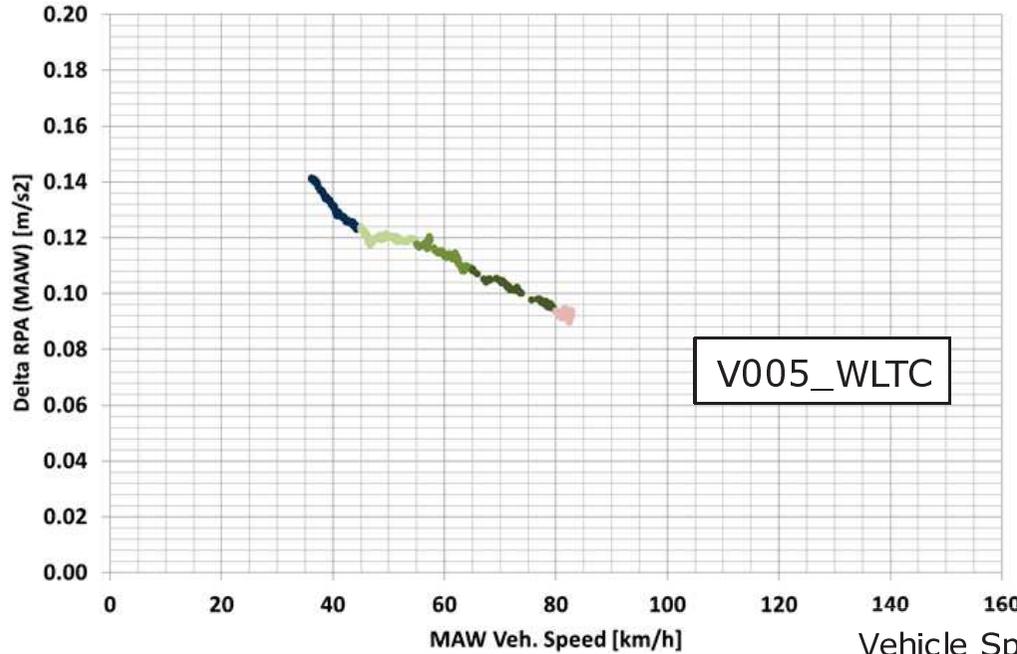
## ➤ Vehicle 005 – Summary:


			SUMMARY MODERATE DRIVING			SUMMARY NORMAL Driving			SUMMARY AGGRESSIVE DRIVING		
			Urban	Rural	Motorway	Urban	Rural	Motorway	Urban	Rural	Motorway
VEH 005	Acc. Indicator 1	Average	0.145	0.083	0.035	0.156	0.126	0.079	0.199	0.187	0.114
		Dev.St.	0.020	0.009	0.019	0.013	0.017	0.025	0.022	0.035	0.058
		10CP	0.119	0.064	0.009	0.138	0.104	0.047	0.172	0.149	0.043
		90 CP	0.167	0.094	0.059	0.174	0.148	0.109	0.235	0.245	0.201
		Min	0.099	0.059	0.008	0.131	0.084	0.038	0.163	0.133	0.010
		Max	0.174	0.100	0.071	0.181	0.155	0.122	0.247	0.270	0.246
		Max-Min	0.075	0.041	0.063	0.050	0.071	0.085	0.084	0.137	0.236
	Acc. Indicator 2	Average	0.069	0.032	0.019	0.084	0.061	0.043	0.132	0.121	0.070
		Dev.St.	0.009	0.005	0.005	0.005	0.008	0.010	0.012	0.018	0.033
		10CP	0.057	0.028	0.014	0.077	0.050	0.031	0.119	0.098	0.034
		90 CP	0.078	0.040	0.027	0.091	0.072	0.060	0.153	0.145	0.131
		Min	0.044	0.022	0.012	0.074	0.046	0.027	0.116	0.076	0.014
		Max	0.079	0.045	0.029	0.096	0.074	0.067	0.158	0.156	0.146
		Max-Min	0.034	0.022	0.017	0.023	0.028	0.039	0.042	0.079	0.132

# V005 – Comparison of Driving Styles (3/3)



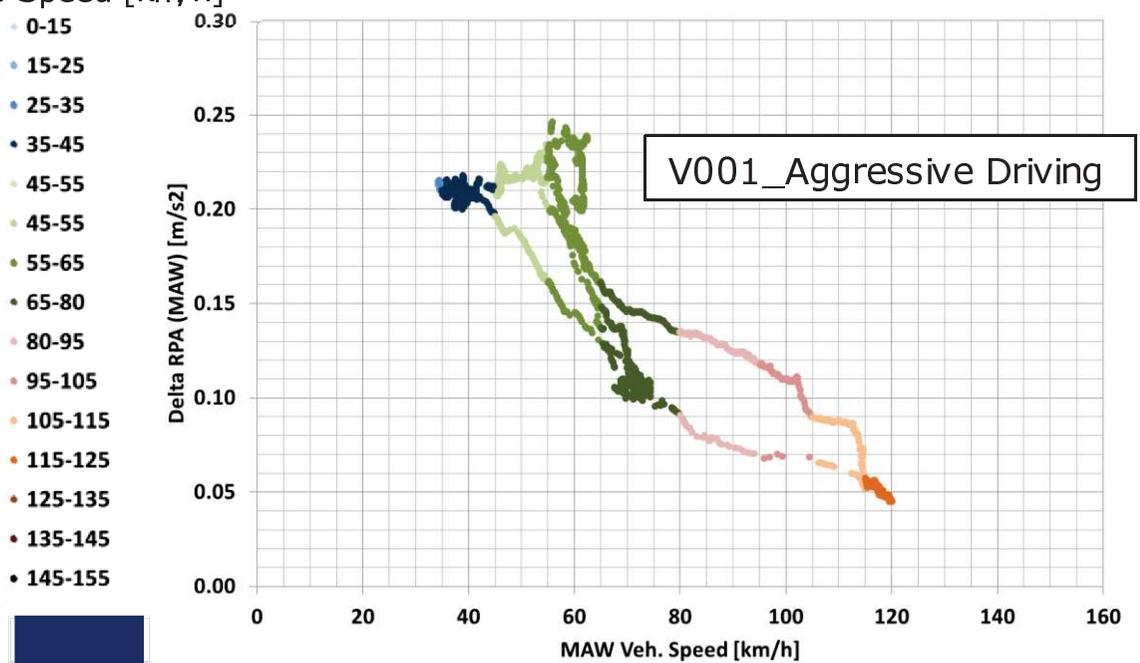
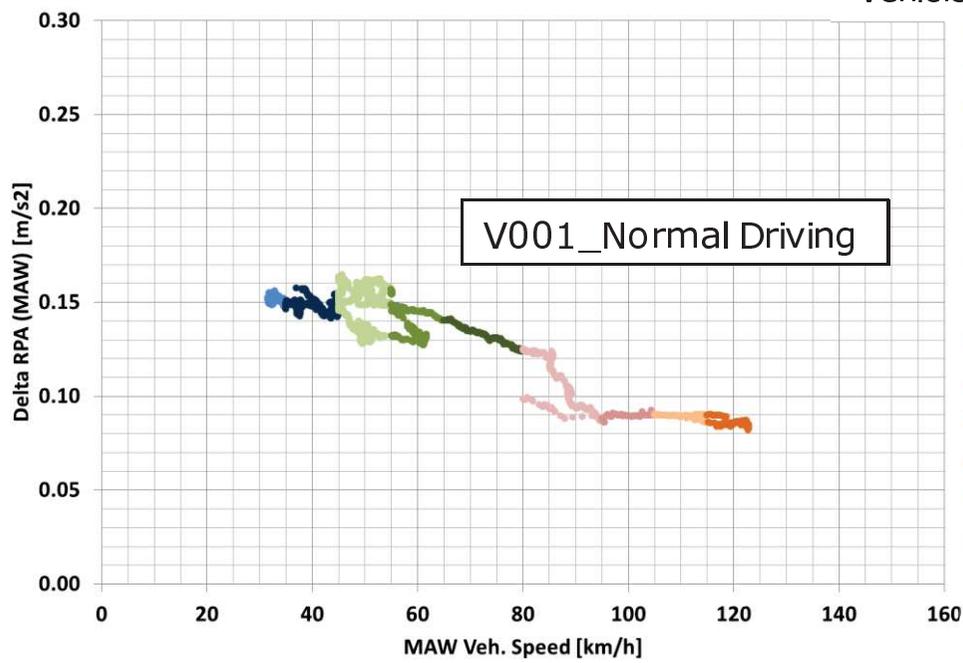
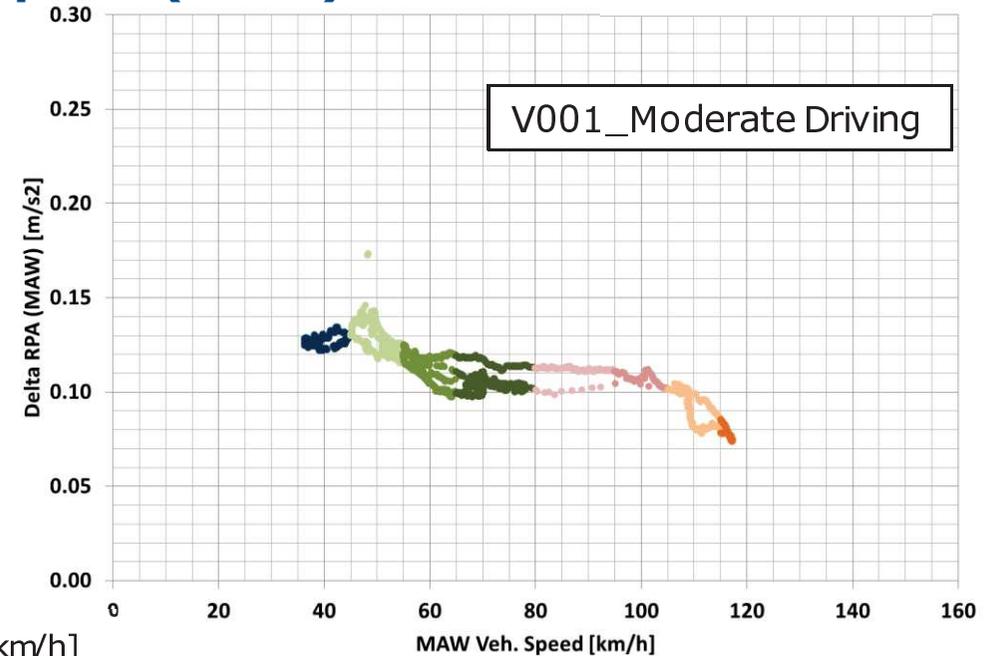
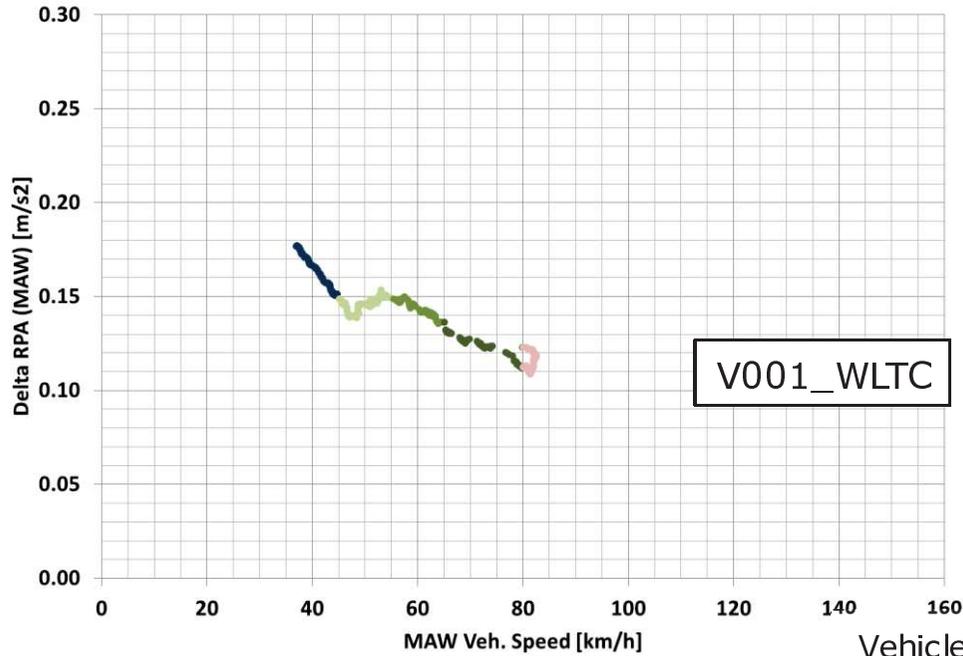
## Vehicle 005 – Acc. Indicator2 vs. Veh. Speed (MAW)



# V001 – Comparison of Driving Styles (3/3)



## ➤ Vehicle 001 – Acc. Indicator2 vs Veh. Speed (MAW)



- 0-15
- 15-25
- 25-35
- 35-45
- 45-55
- 45-55
- 55-65
- 65-80
- 80-95
- 95-105
- 105-115
- 115-125
- 125-135
- 135-145
- 145-155