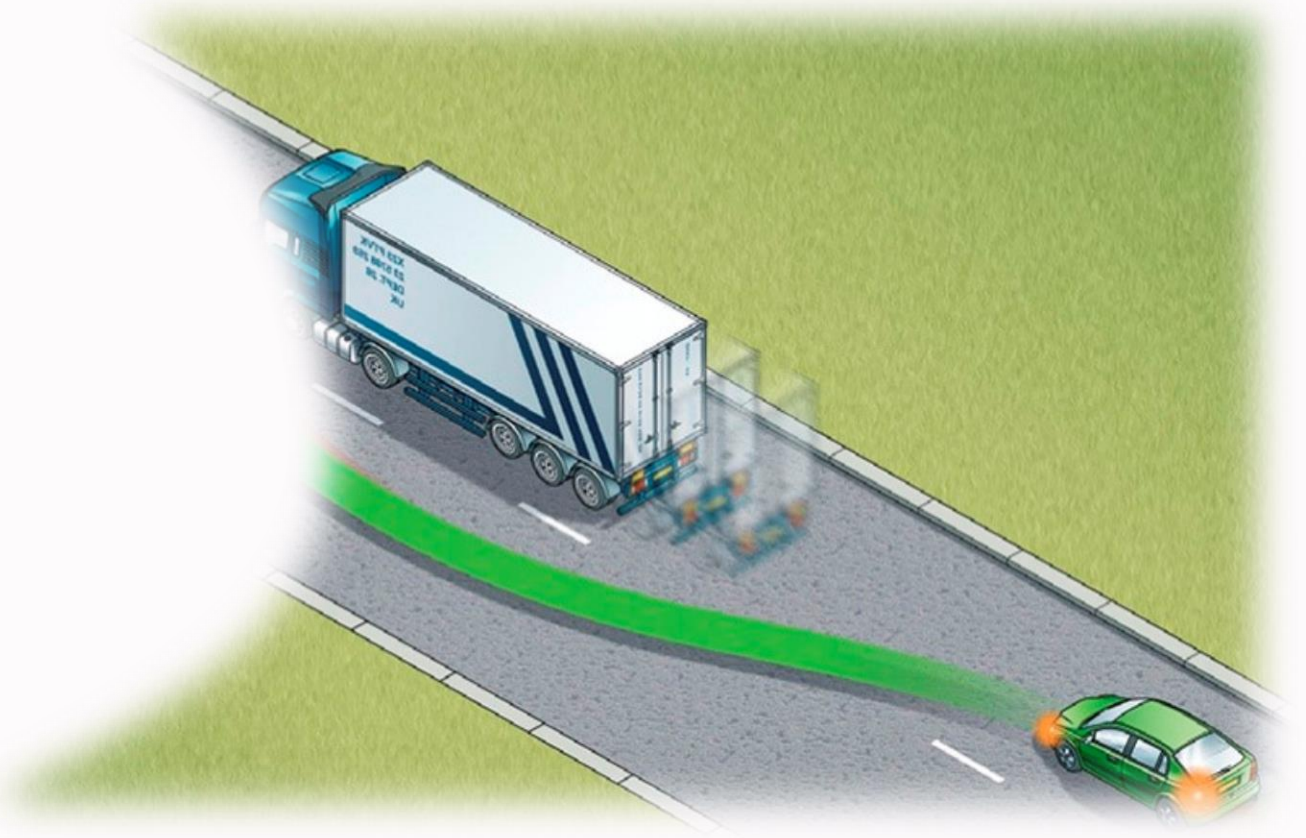
6th International Symposium on HIGHWAY GEOMETRIC DESIGN

Passing Sight Distance Regulations Vs Reality

Konstantinos Apostoleris, Phd Candidate, Civil Engineer
Stergios Mavromatis, Associate Professor
Vassilios Matragos, Phd Candidate, Civil Engineer
Basil Psarianos, Professor
Fotis Mertzanis, Phd, Civil Engineer
Kiriakos Amiridis, Phd, Rural and Surveing Engineer

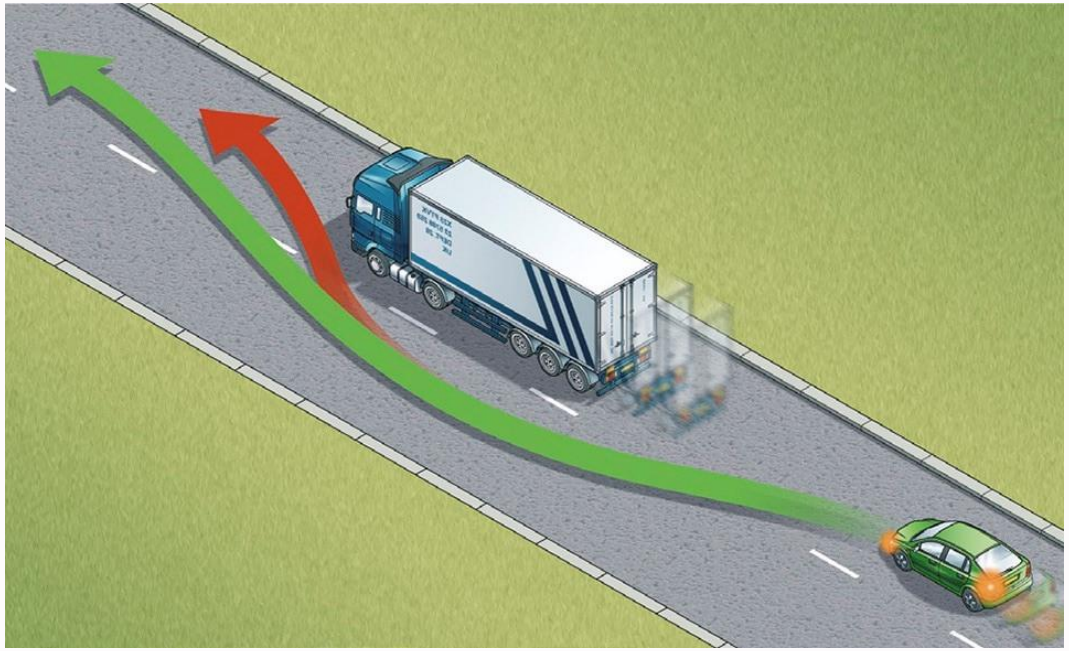
National Technical Univercity of Athens (NTUA)



Objective of the Study

The objective of the present study is to investigate the length required for a complete and safe overtaking procedure at various speeds and for different types of vehicles, taking also into account the influence of the road longitudinal slope.

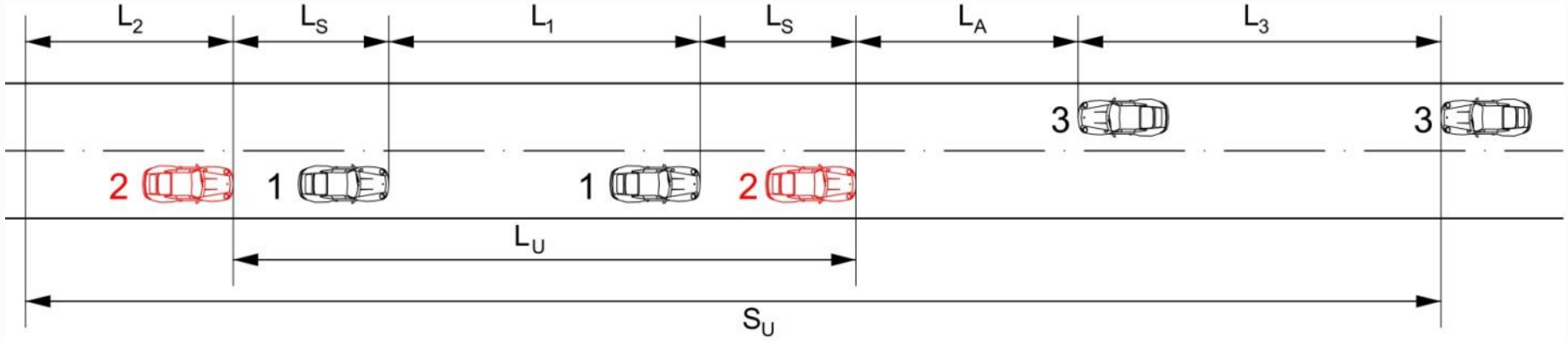
At the same time, measurements were carried out with appropriate equipment to determine the relationship between speed and acceleration of a newer technology vehicle in order to compare the results with the currently used regulations. The purpose of this analysis is to set the basis for the better determination of limiting PSD values in order to harmonize theory with practice.



Proposed Methodology

The overtaking process involves three vehicles with different characteristics:

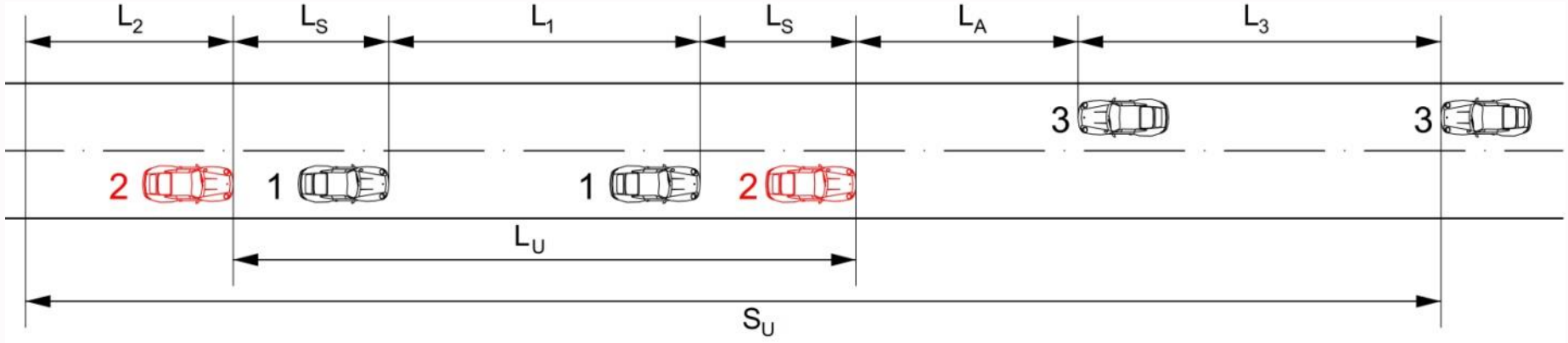
1. The passed vehicle 1, which may be considered moving at a constant speed, slightly below the speed limit of the road (e.g. 10~20km/h below the posted speed limit).
2. The passing vehicle 2, which may be considered moving at a constant speed until it decides to overtake. From the moment starting the overtaking process and until its completion, a smoothly accelerated motion is assumed; and
3. The vehicle 3 that is moving in the opposite direction, which may be considered in favor of safety as being driven at a constant speed equal to the V_{85} operating speed.



Proposed Methodology

The required overtaking length Su depends on the following factors:

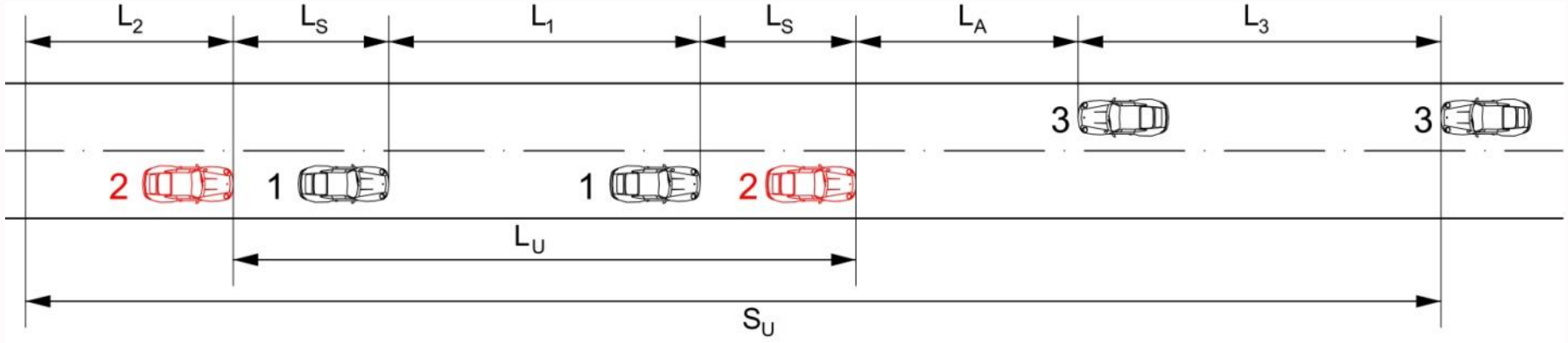
1. The decision time for the driver of vehicle 2 to proceed with the overtaking process. For this period of time, vehicle 2 is driven at a constant speed same with vehicle 1 speed.
2. The length Lu where the passing Vehicle 2 has travelled from the beginning of the overtaking process until completion. In this case, vehicle 2 achieves constant acceleration, which depends on the vehicle's technical characteristics and the longitudinal slope of the road.
3. The safety distance L_A between vehicles 2 and 3 when the overtaking process is completed.
4. The distance L_3 traveled by vehicle 3 during the overtaking process. At this time vehicle 3 is moving at a constant speed equal to V_{85} operating speed.



Assumptions

For the present research, the following assumptions were made:

1. Decision time $t_{dec.}$ was applied equal to 2 seconds.
2. Length Ls was set to 20 meters.
3. Speed V_1 of vehicle 1 was considered 20km/h lower than the design speed.
4. Operational speed V_{85} was considered 20km/h higher than the design speed.
5. Safety margin L_A applied as 50 meters.
6. Speed of the passing vehicle shall never exceed the operational speed V_{85} while the overtaking procedure is active (20km/h higher than the design speed).



Analysis and Relationship with current regulations

General analysis for many longitudinal slopes and several acceleration values has been completed and the results were primarily correlated with the limits proposed in the Greek Regulations OMOE-X and US Regulations (AASHTO), versions 2004 and 2018.

TABLE 3: Required PSD in Respect to the Longitudinal Slope, for Acceleration values equal to 2.0 m/s^2

Constant vehicle acceleration during overtaking procedure equal to α=2.0 m/s^2														
Ve (km/h)	Road Longitudinal Slope / (+) Upgrade, (-) Downgrade											OMOE	AASHTO	
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%		2004	2018
40	362	346	334	325	318	312	307	304	300	297	295	425	270	140
50	423	403	388	377	368	361	356	351	347	343	340	475	345	160
60	483	459	442	429	419	411	404	398	394	390	386	500	410	180
70	544	516	496	481	470	460	452	446	440	436	432	525	485	210
80	604	573	551	534	520	509	501	493	487	482	477	575	540	245
90	665	630	605	586	571	559	549	541	534	528	523	625	615	280

300	Required length less than the one provided for Greek and AASHTO (2004) regulations
400	Required length less than the one provided for Greek and greater than AASHTO (2004) regulations
500	Required length greater than the one provided for in Greek and AASHTO (2004) regulations
600	Grades allowed by exception for the specific design speed

Analysis and Relationship with current regulations

From the general analysis some conclusions were exported:

- A realistic conservative acceleration value of α=1.5 m/s^2 can be achieved with a vehicle of 100 hp, while for this acceleration value the required passing sight distance is significantly shorter in many cases than the minimum value presented in Greek regulations.
- AASHTO regulations (2018) has lower limits, and **the required PSD in all cases is significantly higher from the calculated values**.
- Previous version of AASHTO Regulations (2004) has more realistic thresholds, especially on lower design speed roads (lower than 60km/h).
- For higher design speed roads, AASHTO limit values (2004) converge to Greek regulation limits.
- Vehicles with higher horsepower, which are presently widely used on the National and Rural Road network, achieve a safe overtaking procedure much shorter than required by the Greek and previous AASHTO regulations (2004), but are not sufficient according to the recent AASHTO limits (2018).
- In the German RAL-2012 design guidelines, the required PSD is set to 600m, which is adequate for almost all vehicles to complete a safe overtaking procedure for any speed less than 90km/h.

Investigation for different types of vehicles

As a second step, alternative scenarios for vehicles weighting 1000 ~ 1500kg, with a horsepower of 80 to 300 HP were considered in relation to the value of the acceleration (α) that vehicle 2 may achieve.

TABLE 1: Acceleration Values (m/s^2), for Vehicles Weighing 1000kg in Respect to the Horsepower.

Range of Velocity	Box Gear	Horsepower (HP)					
		80	100	120	140	180	210
40-80	2nd	1,70	2,00	2,20	2,50	3,20	3,60
60-100	3rd	1,20	1,40	1,60	1,80	2,20	2,50
80-120	4th	0,90	1,05	1,20	1,40	1,70	1,90

TABLE 2: Acceleration Values (m/s^2), for Vehicles Weighing 1500kg in Respect to the Horsepower.

Range of Velocity	Box Gear	Horsepower (HP)						
		80	100	120	140	180	210	300
40-80	2nd	1,30	1,50	1,70	1,90	2,40	2,80	4,50
60-100	3rd	0,90	1,05	1,20	1,40	1,70	2,00	3,20
80-120	4th	0,70	0,80	0,90	1,05	1,30	1,50	2,50

Investigation for different types of vehicles

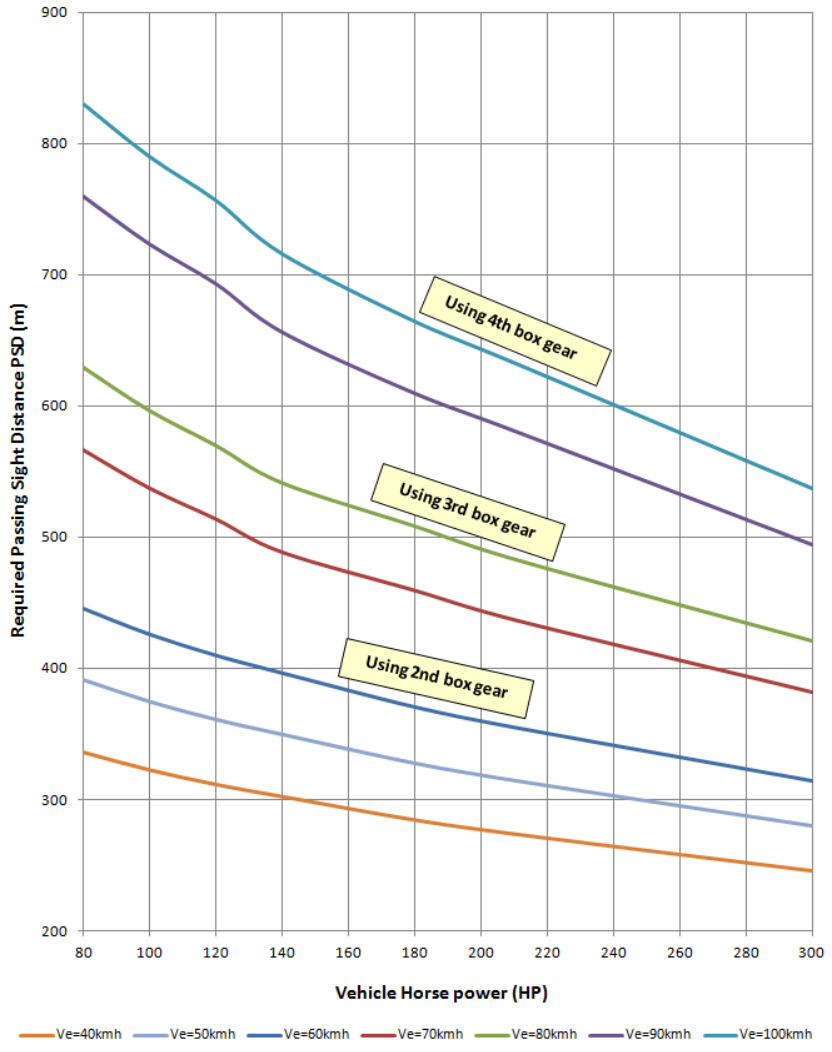
The technical characteristics of the vehicles, and therefore the acceleration they can develop at the time of the overtaking procedure, is greatly influence the required PSD. In the present study, an analysis was performed by considering the average acceleration values presented above.

TABLE 4: Required PSD for 0% Grade and Acceleration Values Depending on Horsepower and Vehicle Weight

Vehicle Weight 1500kgr										
Ve (km/h)	Vehicle Horsepower (HP)							OMOE	AASHTO	
	80	100	120	140	180	210	300		2004	2018
40	336	323	311	302	284	274	245	425	270	140
50	391	374	361	349	328	314	280	475	345	160
60	446	426	410	397	371	355	314	500	410	180
70	566	537	514	488	459	437	382	525	485	210
80	630	597	570	541	508	483	421	575	540	245
90	760	723	693	656	610	581	494	625	615	280
100	830	790	757	716	664	633	537	675	670	320

300	Required length less than the one provided for Greek and AASHTO (2004) regulations
400	Required length less than the one provided for Greek and greater than AASHTO (2004) regulations
500	Required length greater than the one provided for in Greek and AASHTO (2004) regulations

Investigation for different types of vehicles



From the above analysis some more conclusions were exported:

- For an average vehicle with a power of 140 hp, the length required for overtaking is usually shorter in respect to the Greek Regulations OMOE-X and German Regulations RAL-2012, especially on roads where the design speed is less than 80km/h.
- On the other hand, for the same vehicle, the values provided in the previous AASHTO Regulations (2004) appear to approach the values derived from the present analysis for an average vehicle.
- The required PSD is always higher than the one suggested in the new AASHTO guidelines (2018).

Figure 3 - Required PSD as related to vehicle horsepower (1500kg weight) and design speed for longitudinal slope equal to 0%

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

Figure 4 – VERICOM VC4000DAQ accelerometer

In order to further investigate literature results, measurements were made in the field with appropriate equipment and actual speed and acceleration data were recorded with a modern standard vehicle.

- A common large vehicle TOYOTA-CHR Hybrid 1800cc with 122 hp and manufacture year 2019 was used.
- Measurements were made using the VERICOM VC4000 accelerometer, which accurately records vehicle speed every 0.1 sec, as well as the longitudinal acceleration of the vehicle with a step of 0.01 sec.
- The measurements were carried out on a freeway road section with a very low curvature rate, without traffic in order to allow the vehicle to make the acceleration process unobstructed up to the vehicle speed limit.
- The average longitudinal slope of the motorway was approximately 1%, which was taken into account in the final results.
- The measurements were made on a dry, clean pavement and with high tire grip between tires and pavement.

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

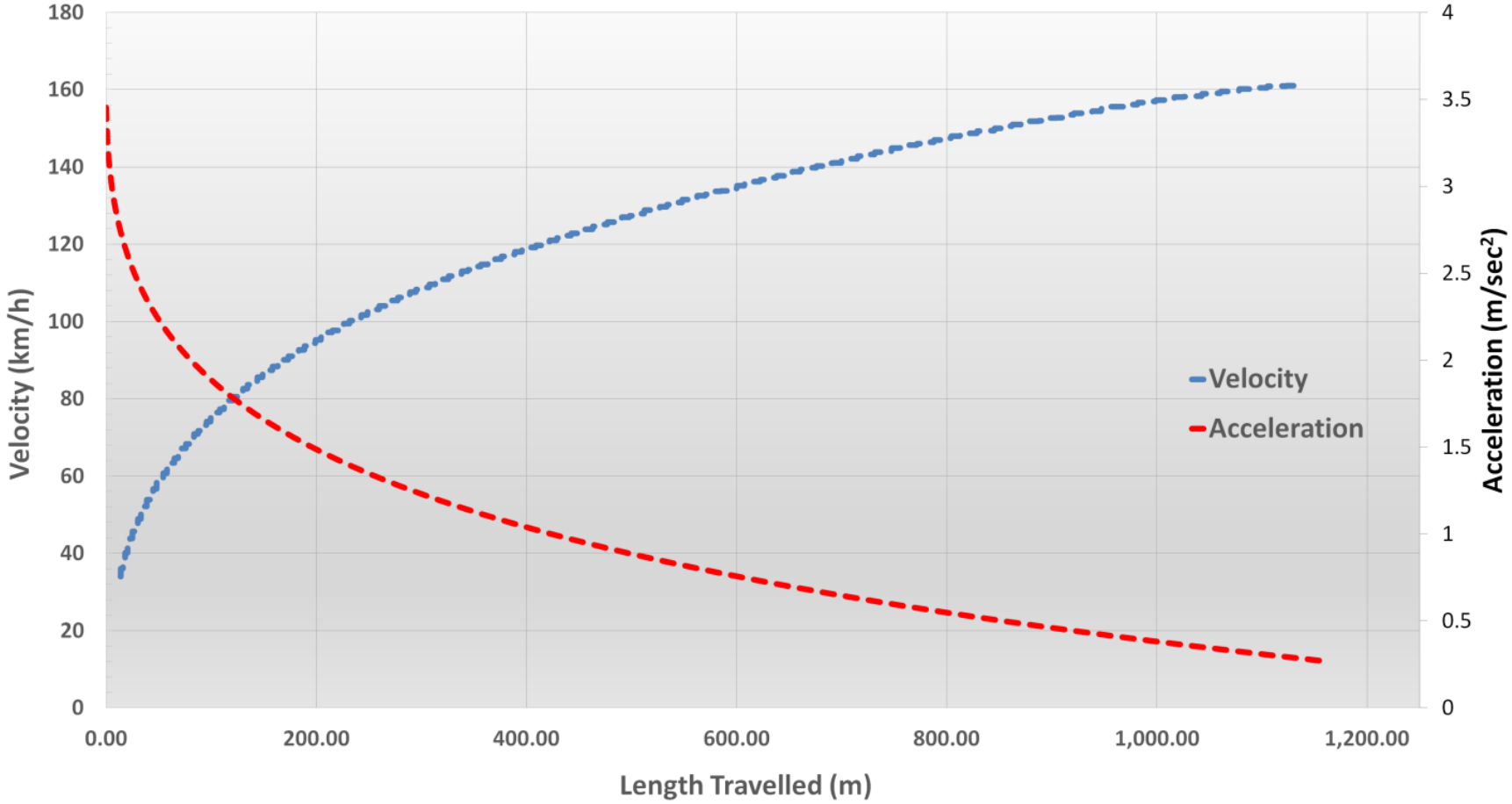


Figure 5 – For Toyota CHR (122hp)

Measurements of vehicle speed and acceleration in respect to the distance covered were completed.

Based on the measurements, a mathematical relationship for the acceleration of the CHR Hybrid vehicle in respect to the instant vehicle speed was developed.

$$\alpha = -0.0695*V+3.32-s*g \quad (3)$$

V (m/sec) = the instant vehicle speed of CHR Hybrid (122HP)

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

According to Equation 3 and the mathematical equations of accelerating movement (α=dV/dt and V=dS/dt), the following equations were determined for the **instant vehicle speed** for CHR Hybrid and the **distance travelled** in respect to vehicle's running time.

$$V = \frac{V_o - \frac{3.32 - s*g}{0.0695}}{1 + 0.0695 * t} + \frac{3.32 - s*g}{0.0695} \quad (4)$$

$$S = \frac{V_o - \frac{3.32 - s*g}{0.0695}}{0.0695} * ln(1 + 0.0695 * t) + \frac{3.32 - s*g}{0.0695} * t \quad (5)$$

where:
- V (m/sec) = the instant vehicle speed of CHR Hybrid (122HP)
- S (m) = the travelled distance by CHR Hybrid (122HP)
- V_o (m/sec) = the initial vehicle speed of CHR Hybrid (122HP)
- s (-) = the longitudinal grade of the road (+) for uphill and (-) for downhill.
- g (m/sec^2) = the gravity acceleration, equal to 9,81m/sec^2.
- t (sec) = the travel time of the vehicle CHR Hybrid (122HP)

Above equations **refers only to TOYOTA-CHR Hybrid (1800cc, 122HP, 2019)** that were used in the present study.

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

Required PSD for vehicle TOYOTA CHR-Hybrid (122HP, 1800cc, 2019)														
Ve (km/h)	**Road Longitudinal Slope / (+) Upgrade, (-) Downgrade**											**OMOE**	**AASHTO**	
	10%	**8%**	**6%**	**4%**	**2%**	**0%**	**-2%**	**-4%**	**-6%**	**-8%**	**-10%**		**2004**	**2018**
40	299	290	282	276	270	266	262	259	256	253	251	**425**	**270**	**140**
50	363	350	340	330	322	315	310	305	301	297	294	**475**	**345**	**160**
60	436	418	402	389	378	368	360	353	348	343	338	**500**	**410**	**180**
70	519	493	472	454	439	426	415	405	397	390	385	**525**	**485**	**210**
80	618	580	550	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	433	**575**	**540**	**245**
90	738	683	641	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	485	**625**	**615**	**280**
Constant [illegible] **2.0 m/s²**														
Ve (km/h)	**Road L** [illegible]											**OMOE**	**AASHTO**	
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%		2004	2018
40	362	346	334	325	318	312	307	304	300	297	295	425	270	140
50	423	403	388	377	368	361	356	351	347	343	340	475	345	160
60	483	459	442	429	419	411	404	398	394	390	386	500	410	180
70	544	516	496	481	470	460	452	446	440	436	432	525	485	210
80	604	573	551	534	520	509	501	493	487	482	477	575	540	245
90	665	630	605	586	571	559	549	541	534	528	523	625	615	280

Less PSD needed (**25m ~ 63m**) for the overtaking procedure of Toyota CHR in respect to the constant acceleration of 2,0m/sec^2

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

Required PSD for vehicle TOYOTA CHR-Hybrid (122HP, 1800cc, 2019)														
Ve (km/h)	**Road Longitudinal Slope / (+) Upgrade, (-) Downgrade**											**OMOE**	**AASHTO**	
	10%	**8%**	**6%**	**4%**	**2%**	**0%**	**-2%**	**-4%**	**-6%**	**-8%**	**-10%**		**2004**	**2018**
40	299	290	282	276	270	266	262	259	256	253	251	**425**	**270**	**140**
50	363	350	340	330	322	315	310	305	301	297	294	**475**	**345**	**160**
60	436	418	402	389	378	368	360	353	348	343	338	**500**	**410**	**180**
70	519	493	472	454	439	426	415	405	397	390	385	**525**	**485**	**210**
80	618	580	550	526	506	489	474	461	450	441	433	**575**	**540**	**245**
90	738	683	641	607	580	557	538	522	507	495	485	**625**	**615**	**280**

Constant vehicle acceleration during overtaking procedure equal to α=2.0 m/s²

V	al Slope / (+) Upgrade, (-) Downgrade											OMOE	AASHTO	
					%	0%	-2%	-4%	-6%	-8%	-10%		2004	2018
					18	312	307	304	300	297	295	425	270	140
					68	361	356	351	347	343	340	475	345	160
					19	411	404	398	394	390	386	500	410	180
70	544	516	496	481	470	460	452	446	440	436	432	525	485	210
80	604	573	551	534	520	509	501	493	487	482	477	575	540	245
90	665	630	605	586	571	559	549	541	534	528	523	625	615	280

Required length for the overtaking procedure is higher **only in higher speed cases (80 ~ 90km/h) with higher longitudinal slope (+6% ~ +10%).**

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

Required PSD for vehicle TOYOTA CHR-Hybrid (122HP, 1800cc, 2019)														
Ve (km/h)	Road Longitudinal Slope / (+) Upgrade, (-) Downgrade											OMOE	AASHTO	
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%		2004	2018
40	299	290	282	276	270	266	262	259	256	253	251	425	270	140
50	363	350	340	330	322	315	310	305	301	297	294	475	345	160
60	436	418	402	389	378	368	360	353	348	343	338	500	410	180
70	519	493	472	454	439	426	415	405	397	390	385	525	485	210
80	618	580	550	526	506	489	474	461	450	441	433	575	540	245
90	738	683	641	607	580	557	538	522	507	495	485	625	615	280
Overall time for the overtaking procedure (sec) - Driver decision time, taken as 2.0sec, is not included														
Ve (km/h)	Road Longitudinal Slope / (+) Upgrade, (-) Downgrade											Comments		
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%			
40	7.38	6.99	6.66	6.36	6.12	5.91	5.73	5.58	5.45	5.34	5.24	The influence of the longitudinal slope is particularly important and should be taken into account in determining the required PSD.		
50	7.83	7.38	6.99						5.58	5.45	5.34			
60	8.37	7.83	7.37						5.73	5.58	5.45			
70	9.04	8.36	7.82						5.90	5.73	5.58			
80	9.87	9.02	8.36	7.81	7.36	6.97	6.64	6.35	6.10	5.90	5.72			
90	10.97	9.86	9.01	8.35	7.80	7.35	6.96	6.63	6.34	6.10	5.89			

Additional 1,2 sec ~ 2,7sec needed for the overtaking procedure in case of +6% Vs -6% slope

Application for specific vehicle Toyota CHR Hybrid (1800cc, 122HP - Year 2019)

Speed range achieved from the passing vehicle (km/h)												
Ve (km/h)	Road Longitudinal Slope / (+) Upgrade, (-) Downgrade											Comments
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%	
40	20 ~ 54	20 ~ 56	20 ~ 58	20 ~ 60	20 ~ 60	20 ~ 60	20 ~ 60	20 ~ 60	20 ~ 60	20 ~ 60	20 ~ 60	The passing vehicle starts the overtaking procedure with a speed 20km/h lower than the design speed, while the maximum speed does not exceed the design speed plus 20 km/h
50	30 ~ 62	30 ~ 64	30 ~ 66	30 ~ 68	30 ~ 70	30 ~ 70	30 ~ 70	30 ~ 70	30 ~ 70	30 ~ 70	30 ~ 70	
60	40 ~ 70	40 ~ 72	40 ~ 74	40 ~ 76	40 ~ 78	40 ~ 80	40 ~ 80	40 ~ 80	40 ~ 80	40 ~ 80	40 ~ 80	
70	50 ~ 77	50 ~ 80	50 ~ 82	50 ~ 84	50 ~ 87	50 ~ 89	50 ~ 90	50 ~ 90	50 ~ 90	50 ~ 90	50 ~ 90	
80	60 ~ 85	60 ~ 87	60 ~ 90	60 ~ 92	60 ~ 94	60 ~ 97	60 ~ 99	60 ~ 100	60 ~ 100	60 ~ 100	60 ~ 100	
90	70 ~ 92	70 ~ 95	70 ~ 98	70 ~ 100	70 ~ 102	70 ~ 104	70 ~ 107	70 ~ 109	70 ~ 110	70 ~ 110	70 ~ 110	

Acceleration range achieved from the passing vehicle (m/s^2) - The influence of the longitudinal slope is included												
Ve (km/h)	Road Longitudinal Slope / (+) Upgrade, (-) Downgrade											Comments
	10%	8%	6%	4%	2%	0%	-2%	-4%	-6%	-8%	-10%	
40	1.95 ~ 1.29	2.15 ~ 1.45	2.35 ~ 1.60	2.54 ~ 1.77	2.74 ~ 1.97	2.93 ~ 2.16	3.13 ~ 2.36	3.33 ~ 2.55	3.52 ~ 2.75	3.72 ~ 2.95	3.91 ~ 3.14	The acceleration that can be achieved during the overtaking procedure varies significantly depending on the speed and the longitudinal slope of the road section, affecting the required PSD
50	1.76 ~ 1.14	1.96 ~ 1.29	2.15 ~ 1.45	2.3				36	3.33 ~ 2.56	3.53 ~ 2.75	3.72 ~ 2.95	
60	1.57 ~ 0.99	1.76 ~ 1.14	1.96 ~ 1.30	2.1				17	3.14 ~ 2.36	3.33 ~ 2.56	3.53 ~ 2.76	
70	1.37 ~ 0.84	1.57 ~ 0.99	1.77 ~ 1.14	1.9				97	2.94 ~ 2.17	3.14 ~ 2.37	3.34 ~ 2.56	
80	1.18 ~ 0.70	1.38 ~ 0.85	1.57 ~ 1.00	1.77 ~ 1.15	1.97 ~ 1.30	2.16 ~ 1.46	2.36 ~ 1.61	2.55 ~ 1.78	2.75 ~ 1.98	2.95 ~ 2.17	3.14 ~ 2.37	
90	0.99 ~ 0.56	1.18 ~ 0.70	1.38 ~ 0.85	1.58 ~ 1.00	1.77 ~ 1.15	1.97 ~ 1.30	2.16 ~ 1.46	2.36 ~ 1.62	2.56 ~ 1.78	2.75 ~ 1.98	2.95 ~ 2.18	

50% ~ 105% higher acceleration on -6% in respect to +6%

Conclusions

- PSD provided by the Greek Regulations is significantly higher than the required. On the other hand, the AASHTO regulations, as they apply today (7th edition 2018), seem to provide very low values for the required overtaking length. Values in the 5th Edition (2004) of AASHTO appear to be more realistic, while 600m proposed by the German RAL-2012 guidelines seems to meet the requirements of a typical passenger car for the recommended speed of 90km/h applied in design class EKL3.
- The longitudinal slope of the road **has a significant influence** on the desired visibility threshold for overtaking and **should be considered in determining the acceptable PSD limits in regulations**.
- Increased acceleration even for small vehicles should lead to reconsider the conservative assumptions made in regulations currently used in several countries. From the preceding analysis it becomes apparent that even for a vehicle with 100hp horsepower, the required overtaking length is significantly lower in many cases than the minimum value provided by the Greek, US and German Regulations.
- Vehicles with higher horsepower can safely complete the overtaking procedure of a slow-moving vehicle in a shorter length. Nevertheless, the present analysis shows that the reduction is relatively small, especially on roads with a low design speed (less than 60km/h).

6th International Symposium on
HIGHWAY GEOMETRIC DESIGN

Thank You for your attention!