Driver Perception-Reaction Times in Level 3 Automated Vehicles

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Basis for Scope of Research (1)

Research Topic	Results of Research
Difference between Connected Vehicles (CVs) and Automated Vehicles (AVs)	CVs: based on V2V, V2I, V2D, V2X and vice-versa. AVs: artificial intelligence which operates the AV using sensors and auxiliary devices.
Levels of AVs	Level 0-2: driver is the operator Level 3: driver is the supervisor and intervenes when required Level 4-5: driverless
Development of AVs	The levels of AV increase with an increase in the technological development of the vehicles. Deployment is estimated to be 2025 for Level 3 and 2030 for Levels 4-5.

Basis for Scope of Research(2)

Research Topic	Results of Research
Effect of alert strategy & type on driver distraction for sudden braking	Resulted that participants responded similarly to haptic and auditory alerts & alert strategy adopted was important.
Adaptation to vehicle automation	Research showed that trust increases with use but acceptance does not increase.
Tendency to take risks	Concluded that adaptation to automation depends on driver education, experience and personality.
Automation & secondary tasks	Concluded that increased automation results in an increase in secondary tasks.
Impact of secondary task on PRT	Examined the Perception-Reaction Time (PRT) of drivers to critical situations during manual and automated control.
Effect of reading as a 2nd task	Effect examined in relation to the driver reacting to a stationary vehicle during automated driving.
Re-engage in manual control under different conditions	#1: re-engage in manual driving at regular intervals. #2: re-engaged based on time period that driver was distracted.

Basis for Scope of Research(3)

Research Topic	Results of Research
Different studies result in different PRT and which variables influence PRT	Due to different definitions used for PRT and BRT. Resulted that age, alcohol consumption and whether the stimulus was expected or unexpected effected PRT.
Establish driver response times in actual driving scenarios without vehicle automation	Participants not aware of experiment. Concluded that RT depended on complexity of traffic scenario, level of urgency, speed of the vehicles when the hazard alert starts and PRT in normal vehicle expected to exceed 2.5s.
Design Guidelines for Different Countries	Refer to Table

Stopping Sight Distances for Level Roads adopted in different Countries

Country	Time (sec)	Design Speed (km/h)												
		20	30	40	50	60	70	80	90	100	110	120	130	140
		Stopping Sight Distance (m)												
Australia (all road types)	2.0	-	-	40	55	73	92	114	139	165	193	224	257	-
Austria	2.0	-	-	35	50	70	90	120	-	185	-	275	-	380
United Kingdom	2.0	-	-	-	70	90	120	-	-	215		295	-	-
Canada	2.5	-	-	45	65	85	110	140	170	200	220	240	-	-
France	2.0	15	25	35	50	65	85	105	130	160	-	-	-	-
Germany	2.0	-	-	-	-	65	85	110	140	170	210	255	-	-
Greece	2.0	-	-	-	-	65	85	110	140	170	205	245	-	-
South Africa	2.5	-	-	50	65	80	95	115	135	155	180	210	-	-
Sweden	2.0	-	35	-	70	-	165	-	-	-	-	-	-	-
United States	2.5	-	30	44	63	85	111	139	169	205	246	286	-	-

Research Questions

1. *Which type or combination of driver alert systems are most effective according to driver characteristics criteria?*
2. *Do driving experience, age, gender and disability affect response times?*
3. *Does the type of secondary tasks affect driver response times differently?*
4. *How will driver perception-response time affect standard design guidelines for Stopping Sight Distances?*

Main Hypothesis

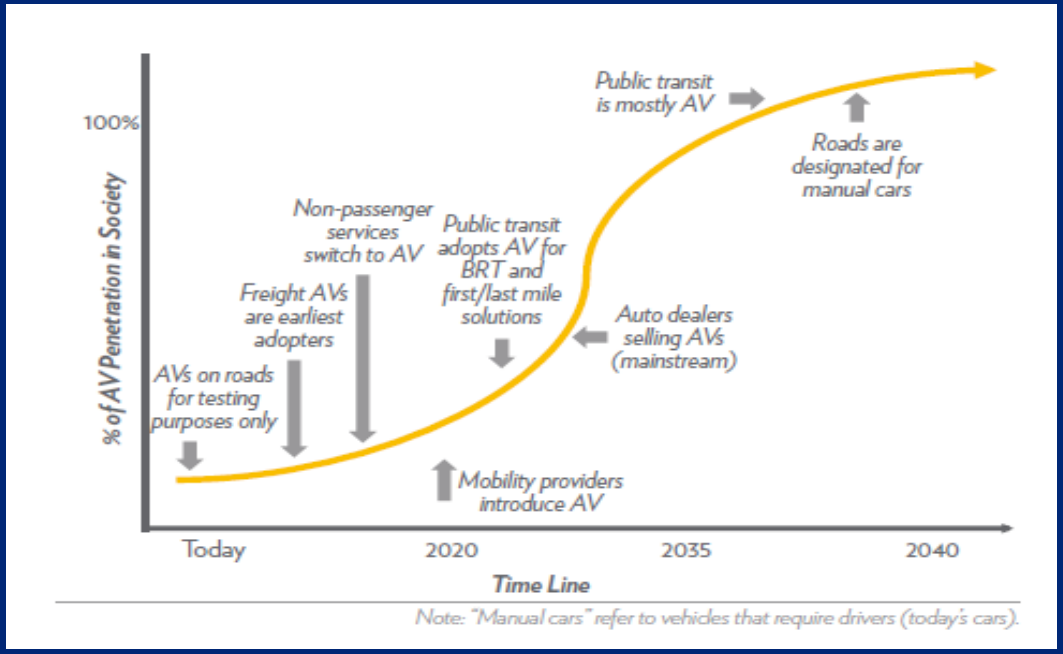
Driver Response Time in a Level 3 Automated Vehicle will necessitate updates of the existing design guidelines for Stopping Sight Distances

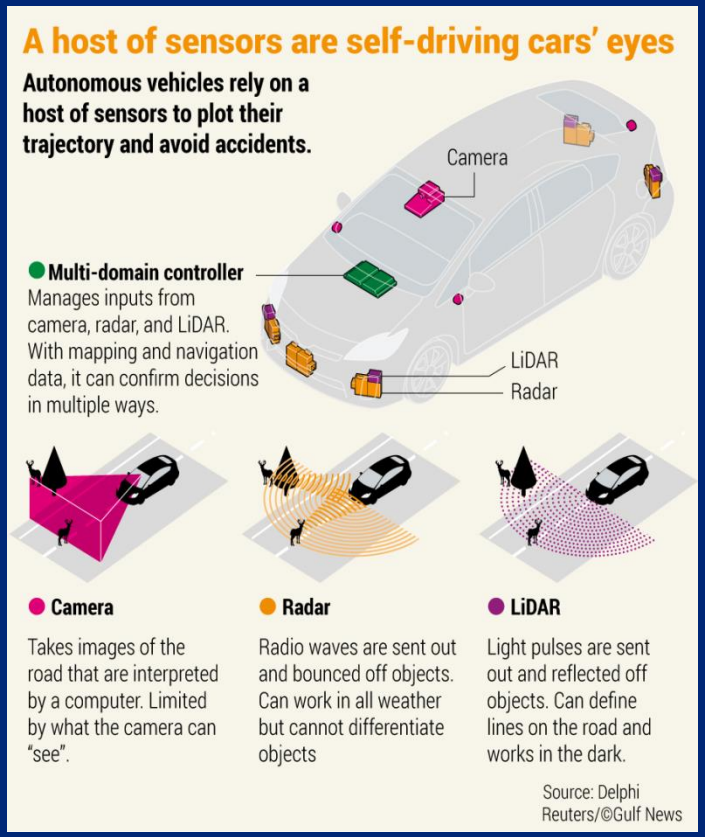
Research Goals

1. to examine the effectiveness of two different driver alert systems;
2. to establish the driver response times for drivers in relation to:
    - •different alert systems
    - •different age groups
    - •different driving experience
    - •different secondary tasks (distractions)
    - •disabilities which impair driver perception-reaction times;
3. to focus on the establishment of revised SSD values which determine the design guidelines for road design to safely accommodate Level 3 AVs on the road network in relation to the perception-response times obtained as part of this research.

Literature Review

- Future of AVs
- Development of AVs
- Timelines
- The Driving Process





Literature Review: The Driving Process

Driving Process = Driving Strategy + Driving Tactics

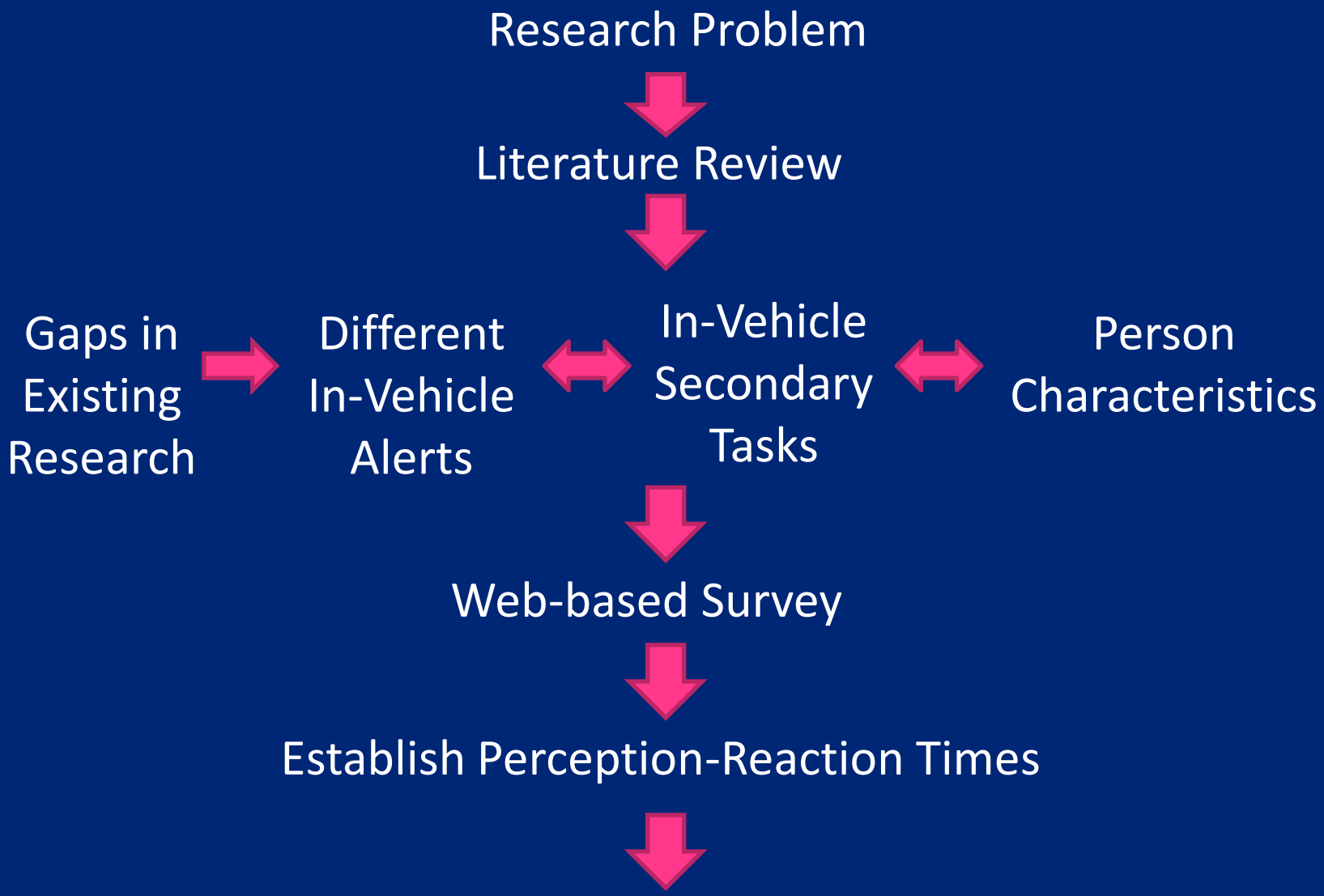
Perception-Reaction of Hazard

Manoeuvers to avoid Hazard

Criteria which affect Perception-Reaction Time for Levels 1 and 2 vehicles:

- Country of Origin: PRT affected by country of origin and driver awareness because it is related to the driver, the vehicle and the roadside scenario;
- Gender: Different research yielded different results;
- Age: PRT increases with age;
- Driving Experience: Correlation with PRT is unclear;
- Perception Delay/Psychological Refractory Period: In Level 3 vehicles this delay includes shifting from automated to driving mode;
- Driver distraction: Competes with driver attention and causes delays in recognition and processing of information. Can be visual, auditory, biomechanical, cognitive or a combination of these;
- Alerts: Haptic, auditory, visual or a combination of such. Auditory RT is less than visual RT. Multisensory RT less than unisensory RT;
- Hue: red alert button
- Disabilities: Musculoskeletal, Neurological and Cognitive/Sensory increase PRT because they affect perception, processing of information and reduced motor capabilities.

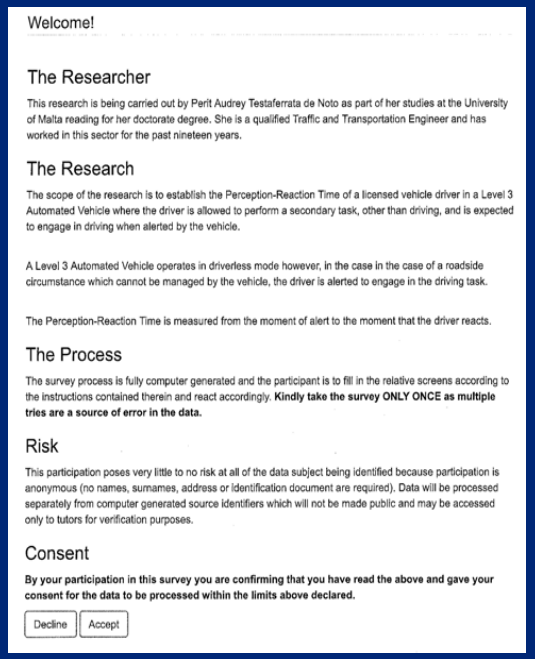
Research Design and Methodology: Schematic



Research Design and Methodology: Main Points

a. Based on gaps in existing research and scope of research
b. Identified secondary tasks – use of mobile phone and watching a video
c. Stratified sampling technique used – random sampling which divides population into strata – drivers/non-drivers. Disproportional sampling to applied to strata and subgroups. Used statistical Hypothesis Testing to determine level of significance of sample data.
d. Survey using C# and Java and designed in two parts – 1st part collection of demographic data, 2nd part interactive survey. Survey link: http://survey.horizon2000computers.com/

Research Design and Methodology: Web-Based Survey (1)



Welcome!

The Researcher

This research is being carried out by Perit Audrey Testaferrata de Noto as part of her studies at the University of Malta reading for her doctorate degree. She is a qualified Traffic and Transportation Engineer and has worked in this sector for the past nineteen years.

The Research

The scope of the research is to establish the Perception-Reaction Time of a licensed vehicle driver in a Level 3 Automated Vehicle where the driver is allowed to perform a secondary task, other than driving, and is expected to engage in driving when alerted by the vehicle.

A Level 3 Automated Vehicle operates in driverless mode however, in the case in the case of a roadside circumstance which cannot be managed by the vehicle, the driver is alerted to engage in the driving task.

The Perception-Reaction Time is measured from the moment of alert to the moment that the driver reacts.

The Process

The survey process is fully computer generated and the participant is to fill in the relative screens according to the instructions contained therein and react accordingly. **Kindly take the survey ONLY ONCE as multiple tries are a source of error in the data.**

Risk

This participation poses very little to no risk at all of the data subject being identified because participation is anonymous (no names, surnames, address or identification document are required). Data will be processed separately from computer generated source identifiers which will not be made public and may be accessed only to tutors for verification purposes.

Consent

By your participation in this survey you are confirming that you have read the above and gave your consent for the data to be processed within the limits above declared.

Decline | Accept

Part 1: Demographic Information

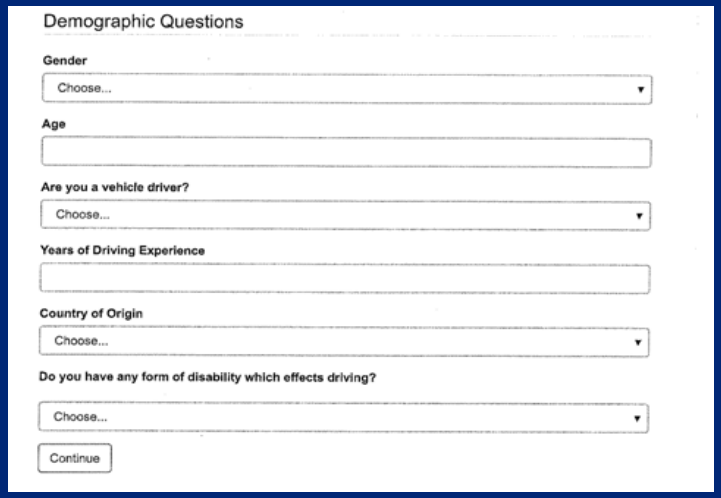
Instructions

Part 1 of the survey collects demographic information regarding the participant. Such information is important because it will show how participant-specific characteristics effect Perception-Reaction Times.

For questions regarding AGE OF DRIVER and YEARS OF DRIVING EXPERIENCE kindly reply by **entering the number** related to yourself as the participant.

For all other questions kindly reply using the **drop-down menu**.

Next



Demographic Questions

Gender

Choose...

Age

Are you a vehicle driver?

Choose...

Years of Driving Experience

Country of Origin

Choose...

Do you have any form of disability which effects driving?

Choose...

Continue

Part 2: DRIVING SIMULATION

Instructions

Part 2 of this survey is a **simulation** of a driver in a Level 3 Automated Vehicle.

The first scenario is a case where the **driver is not engaged** in a secondary task.

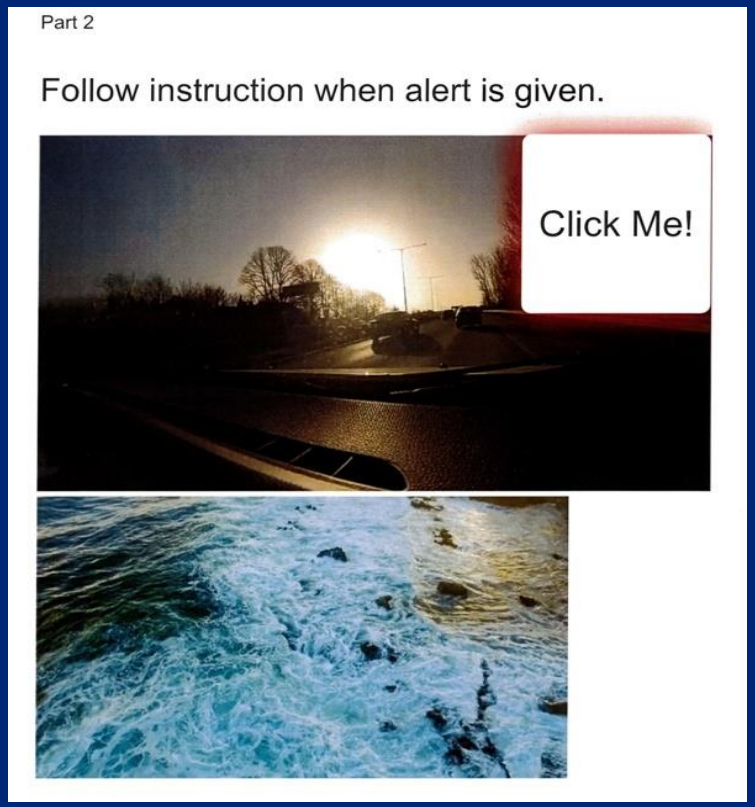
The second scenario is a case where the **driver is watching a video** as a secondary task in the vehicle.

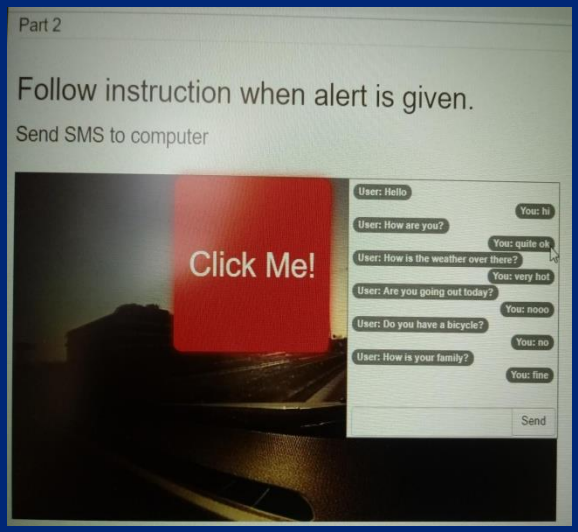
The third scenario is a case where the **driver is replying to an SMS** as a secondary task. The participant is kindly requested to interact with the survey by replying to the SMS. Replies to the SMS are to be **typed the text box** found at the bottom of the SMS pop-up box.

For each of these scenarios the participant is to click on the **RED BOX** which appears on the screen and which simulates an alert in a Level 3 Automated Vehicle for the driver to engage in the driving task.

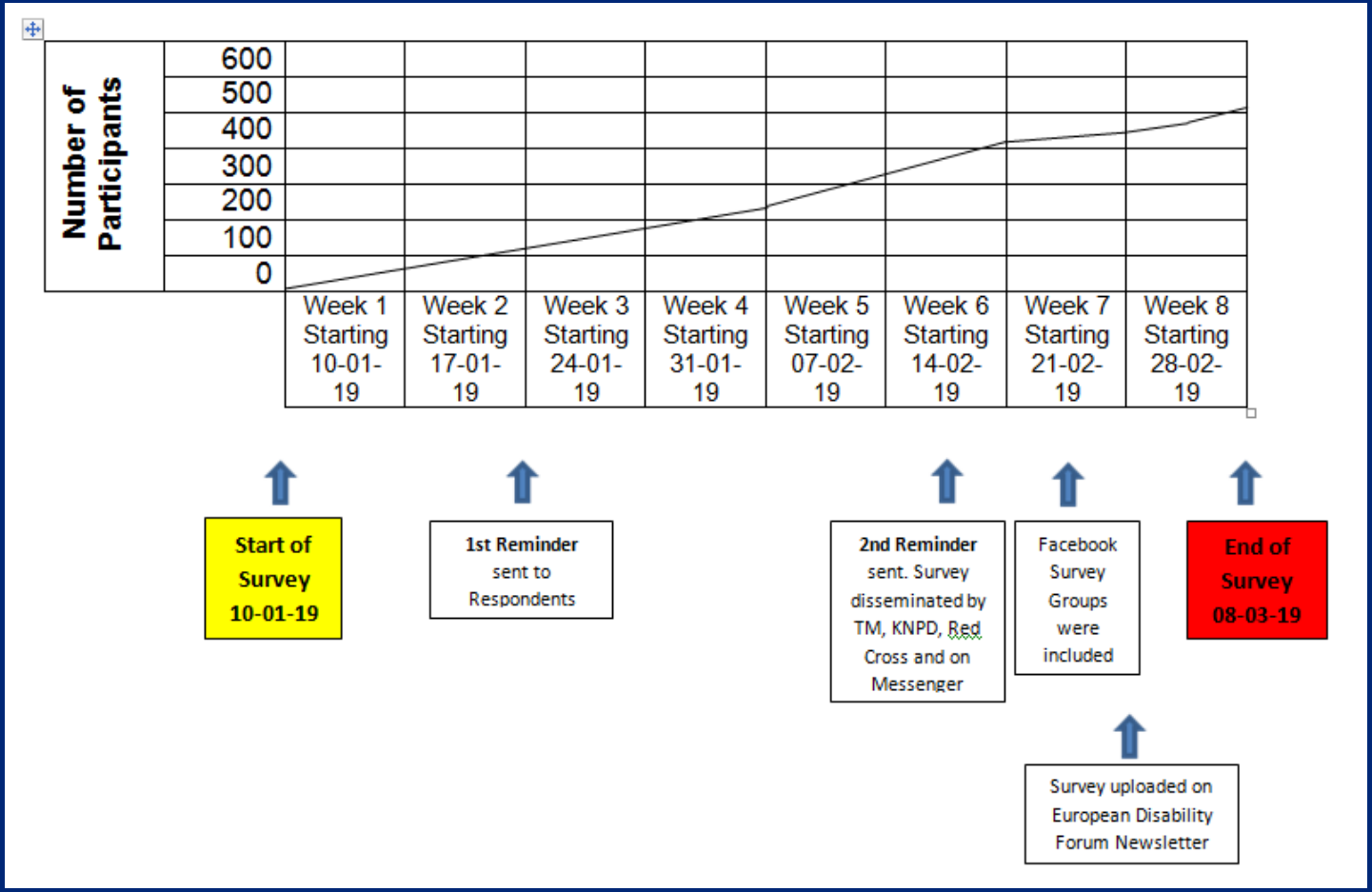
Next

Research Design and Methodology: Web-Based Survey (2)





Research Design and Methodology: Web-Based Survey (3)



Graph of Number of Survey Respondents against Time

Research Design and Methodology: Analysis

a. SPSS software was used to analyse the data;

b. Statistical tests used: Binomial, Null Hypothesis, p-Value, Alternative Hypothesis, One-Way ANOVA Test, Parsimonious Regression Model and Backward Procedure;

c. The results of the survey gave the Anticipated PRT and these values were multiplied by the 1.35 Correction Factor to give the Unexpected PRT. The 85^{tho}% value of the Perception-reaction time was subsequently calculated for each sub-group using z-score;

d. The PRT suggested by this research was taken as the average PRT values obtained in the worst case scenario P7 and established at 4.23 seconds;

e. SSD (distance travelled during the perception-reaction time period) was calculated for different design speeds using:

SSD = Perception-Reaction Distance + Braking Distance

$$SSD = 0.278\,Vt + \frac{V^2}{254\,f}$$

where:

SSD	= required stopping sight distance in m
V	= speed in Km/h
t	= perception-reaction time in seconds
f	= coefficient of friction, for a poor, wet pavement

Results and Discussion

1a. Results of the Demographic Data obtained:

	Gender	Sample size	Mean	Std. Dev.	P-value
P2Duration	Male	234	3.04	1.105	0.879
	Female	216	3.06	1.097	
P3Duration	Male	248	2.61	0.872	0.043
	Female	237	2.78	0.935	
P4Duration	Male	243	2.57	1.000	0.012
	Female	237	2.80	0.946	
P5Duration	Male	255	2.41	0.915	0.101
	Female	238	2.55	0.957	
P6Duration	Male	240	2.81	1.153	0.623
	Female	219	2.87	1.198	
P7Duration	Male	247	3.11	1.156	0.901
	Female	226	3.12	1.319	

	Country of origin	Sample size	Mean	Std. Dev.	P-value
P2Duration	Maltese	349	3.12	1.146	0.012
	Other EU resident	101	2.81	0.889	
P3Duration	Maltese	365	2.74	0.911	0.034
	Other EU resident	120	2.54	0.878	
P4Duration	Maltese	362	2.72	0.989	0.124
	Other EU resident	118	2.56	0.940	
P5Duration	Maltese	371	2.50	0.910	0.352
	Other EU resident	122	2.41	1.015	
P6Duration	Maltese	344	2.83	1.180	0.783
	Other EU resident	115	2.86	1.161	
P7Duration	Maltese	351	3.05	1.138	0.035
	Other EU resident	122	3.32	1.464	

	Driving License	Sample size	Mean	Std. Dev.	P-value
P2Duration	Yes	436	3.03	1.075	0.014
	No	14	3.76	1.604	
P3Duration	Yes	463	2.70	.917	0.768
	No	22	2.64	.656	
P4Duration	Yes	458	2.65	.969	0.002
	No	22	3.31	.997	
P5Duration	Yes	470	2.48	.943	0.595
	No	23	2.58	.805	
P6Duration	Yes	444	2.84	1.178	0.872
	No	15	2.79	1.078	
P7Duration	Yes	450	3.14	1.247	0.033
	No	23	2.58	.805	

	Disability	Sample size	Mean	Std. Dev.	P-value
P2Duration	Yes	5	4.05	1.909	0.040
	No	445	3.04	1.086	
P3Duration	Yes	6	2.93	1.016	0.531
	No	479	2.69	.905	
P4Duration	Yes	5	3.51	1.207	0.058
	No	475	2.67	.974	
P5Duration	Yes	6	2.93	1.016	0.243
	No	487	2.48	.936	
P6Duration	Yes	6	2.70	.854	0.772
	No	453	2.84	1.178	
P7Duration	Yes	6	3.60	1.635	0.335
	No	467	3.11	1.230	

Results and Discussion

1b. Results of the Demographic Data obtained:

	Driving experience	Sample size	Mean	Std. Dev.	P-value
P2Duration	0-10 years	126	2.76	.917	0.000
	11-20 years	102	2.87	.944	
	21-30 years	112	3.00	.901	
	31-40 years	63	3.30	1.231	
	41 years or more	36	3.98	1.441	
P3Duration	0-10 years	135	2.51	1.019	0.000
	11-20 years	110	2.66	.867	
	21-30 years	119	2.67	.713	
	31-40 years	71	2.89	1.002	
	41 years or more	38	3.20	.795	
P4Duration	0-10 years	132	2.50	1.008	0.024
	11-20 years	110	2.61	1.006	
	21-30 years	122	2.80	.953	
	31-40 years	65	2.82	.884	
	41 years or more	38	2.91	.916	
P5Duration	0-10 years	136	2.29	1.004	0.010
	11-20 years	108	2.46	.956	
	21-30 years	125	2.57	.864	
	31-40 years	75	2.74	.914	
	41 years or more	36	2.40	.919	
P6Duration	0-10 years	129	2.53	.955	0.001
	11-20 years	107	2.78	1.079	
	21-30 years	114	3.01	1.2450	
	31-40 years	65	3.01	1.302	
	41 years or more	33	3.44	1.475	
P7Duration	0-10 years	132	3.23	1.471	0.016
	11-20 years	106	2.85	1.059	
	21-30 years	115	3.08	1.020	
	31-40 years	74	3.25	1.243	
	41 years or more	33	3.48	1.393	

	Age	Sample size	Mean	Std. Dev.	P-value
P2Duration	18-30 years	123	2.75	.953	0.000
	31-40 years	102	2.82	.852	
	41-50 years	116	3.08	1.020	
	51-60 years	76	3.41	1.237	
	61 years or more	33	3.89	1.538	
P3Duration	18-30 years	133	2.51	.985	0.000
	31-40 years	106	2.55	.860	
	41-50 years	128	2.71	.748	
	51-60 years	84	2.94	.893	
	61 years or more	34	3.22	.998	
P4Duration	18-30 years	131	2.40	.937	0.001
	31-40 years	109	2.69	1.047	
	41-50 years	130	2.88	1.041	
	51-60 years	81	2.75	.811	
	61 years or more	29	2.89	.784	
P5Duration	18-30 years	135	2.28	.996	0.009
	31-40 years	107	2.40	.914	
	41-50 years	133	2.60	.889	
	51-60 years	85	2.64	.881	
	61 years or more	33	2.70	.955	
P6Duration	18-30 years	130	2.51	1.046	0.000
	31-40 years	105	2.74	.963	
	41-50 years	120	2.95	1.212	
	51-60 years	73	3.00	1.258	
	61 years or more	31	3.75	1.425	
P7Duration	18-30 years	131	3.16	1.399	0.172
	31-40 years	107	2.96	1.194	
	41-50 years	124	3.04	1.013	
	51-60 years	80	3.39	1.425	
	61 years or more	31	3.05	.777	

Results and Discussion

2. Results of the PRT obtained for the different scenarios are as follows:

Driving Scenario	85th Percentile Unexpected Perception-Reaction Time	Type of Alert	Type of Distraction
P2	4.19	Visual	No distraction. Control
P3	3.63	Visual & Auditory	
P4	3.69	Visual	Watching a video. Cognitive, visual & auditory.
P5	3.45	Visual & Auditory	
P6	4.06	Visual	Typing & Reading a Text Message. Cognitive, visual & biomechanical.
P7	4.40	Visual & Auditory	

PRT suggested by this research is the average of the P6 and P7 scenarios being **4.23 seconds.**

Results and Discussion

3. PRT obtained for the predictors collectively (Parsimonius Regression Model) were as follows:

Scenario	Predictors for Average Perception-Reaction Time				
	Age	Gender	Driving License	Driving Experience	Country of residence
P2	Not significant	Not significant	Not significant	<10yrs PRT < 41+yrs	Maltese PRT > other EU
P3	<30yrs PRT < 61+yrs	Males PRT < females	Not significant	Not significant	Not significant
P4	<30yrs PRT <61+yrs	Males PRT < females	Licensed PRT < non-licensed	Not significant	Not significant
P5	Not significant	Males PRT < females	Not significant	<10yrs PRT < 41+yrs	Not significant
P6	<30yrs PRT <61+yrs	Not significant	Not significant	Not significant	Not significant
P7	Not significant	Not significant	Licensed PRT > non-licensed	<10yrs PRT < 41+yrs	Maltese PRT < other EU

Results and Discussion

4. The summary of the comparison of the PRT and SSD values obtained from this research with values of CEDR, AASHTO, DMRB, AUSTROADS and RAA are as follows:

Criteria	This research	CEDR[1,6]	AASHTO[2]	NCHRP[2]	DMRB[3]	Austroads[4]	RAA[5]
PARAMETERS							
Coefficient of Friction	0.377	0.377	from 0.4 for 30km/h to 0.28 for 120km/h	-	0.25	0.36	from 0.35 for 60km/h to 0.15 for 120km/h
Deceleration Rate(m/s^2)	-	-	-	3.4	-	-	
Perception-Reaction Time(sec)	4.23	2.0	2.5	2.5	2.0	2.0	2.0
DESIGN SPEED	Stopping Sight Distance						
30	45	26	29.6	31.0	31	27	-
40	64	39	44.4	45.9	47	40	-
50	85	54	62.8	63.1	70	55	-
60	108	71	84.6	82.5	90	73	65
70	134	90	110.8	104.2	120	92	85
80	161	111	139.4	128.2	145	114	110
90	191	135	168.7	154.4	178	139	140
100	222	160	205.0	182.9	215	165	170
110	256	188	246.4	213.7	252	193	210
120	291	217	285.6	246.7	295	224	255

Sources: Weber et al. (2016)[1], Design Manual for Roads and Bridges (2002)[3], Fambro et al (1997)[2], Fanning et al (2016)[4], Harwood et al (1998)[5], Petegem et al (2014)[6].

The Results and the Research Questions

1. *Which type or combination of **driver alert systems** are most effective according to driver characteristics criteria?*

   Multi-sensory driver alert systems are the most effective and reduce gender difference.

2. *Do **driving experience, age, gender and disability** affect response times?*

   Driving Experience and Age complement each other and either one or the other is a significant predictor in each scenario. Younger age group have shorter PRT.

3. *Does the **type of secondary tasks** affect driver response times differently?*

   When the nature of the secondary task exceeds the cognitive capacity of the driver, the PRT is greatly impaired – reading and writing an sms.

4. *How will driver perception-response time affect **standard design guidelines for Stopping Sight Distances**?*

   The PRT from this research exceeds the 2 and 2.5 seconds established by different specifications worldwide and thus resulting in longer SSDs.

Limitations of the Research

1. Due to limitations of software, the raw data comprised of discrete values;
2. Use of web-based survey which simulated the driving scenario but survey was not carried out on the road;
3. Limit on the duration of the web-based survey;
4. Differences in the devices used by participants – touch pad, mouse or smartphone;
5. Restricted type of alert;
6. Survey was unsupervised so it was not possible to ascertain the secondary task being carried out;
7. Results were for an EXPECTED alert and not for a SURPRISE alert;
8. Limited literature available on AVs.

Recommended Further Research

1. Evaluation of PRT using field studies rather than a web-based survey or driving simulator in a controlled environment;
2. Examine PRT using haptic alerts and a combination of different alerts;
3. Examine SSDs for vertical curves and offsets through horizontal curves;
4. Examine PRT in relation of automated heavy vehicles and their braking efficiency;
5. Examine the effect of the proposed revised SSDs on road reconstruction projects due to possible need for re-alignment or design exceptions resulting in additional costs and extended work programmes;
6. Examine the issue of the 40 second Comfortable Transition Time;
7. Issues related to quality, consistency and standardisation of road signage and line markings which are necessary for reliable operation of AVs which rely on cameras, sensors, radars and laser-mapping by utilising pavement markings to understand the roadside scenario.