THE ACCELERATION OF LIGHT VEHICLES

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ABSTRACT

The acceleration of light vehicles is often seen as an indicator of driver aggression. In automotive advertising the number of seconds it takes to reach a speed of 100 km/h can be a major selling point for certain types of vehicle. The development of representative and reliable speed profiles for vehicles accelerating from a stationary position, for vehicles overtaking slower vehicles from a reduced speed and for vehicles exiting a horizontal curve are important parameters for engineers involved with the design and/or appraisal of the safety of roads. Importantly, this paper only deals with vehicles accelerating from a stationary position to speeds of 60 and 100 km/h. Most drivers of light vehicles do not utilise the maximum power available to them when accelerating a vehicle. The purpose of a recent study (Grobler, 2012) was to determine the proportion of the maximum acceleration that drivers are using when accelerating their vehicle within an urban environment.

In this study a limited number of drivers and vehicles were used to determine their acceleration from a stationary position. Since acceleration is decreasing from a maximum value with an increase in speed up to a point where the maximum speed of the vehicle is reached (Papacostas et al, 2005), it was necessary to calibrate a model for each test. The results showed that drivers on average used about 55% of the maximum acceleration available to them. This average and the distribution can be used in speed profile calculation and programs that simulate the acceleration of vehicles. From the percentage of individual drivers it was also possible to categorise the drivers into three different groups, namely standard, gradual and hard accelerators, which may be an indicator of driver aggression.

1 INTRODUCTION

For the calculation of a speed profile of vehicles along a specific road alignment it is important to know the normal acceleration of the vehicles (Bester, 1981). When a vehicle is accelerating it is using the available power after provision has been made for:

- rolling resistance;
- air resistance; and
- gradient resistance.

Since all of these resistances increase with an increase in speed it is clear that the available power and therefore the acceleration of a vehicle will decrease with speed to the point when the maximum speed of the vehicle is reached (when acceleration becomes zero). In the case of a linear relationship between acceleration and speed (Papacostas et al, 2005) the formulation is as follows:

$a = A - Bv$ ……………………………………………(1)

Where:

a = acceleration (m/s^2)

v = speed (m/s)

A = maximum initial acceleration (m/s^2)

B = slope of the line, i.e. the rate at which the acceleration decreases.

From Equation 1 it can be determined that the maximum speed of the vehicle will be A/B (i.e. when a = 0). By integration the relationship between speed (v) and time (t) can be determined:

$v = A/B(1 – e^{-Bt}) + v_0e^{-Bt}$ ………………………………………………..(2)

Where:

v_0 = the initial speed (m/s)

v = speed after time (t).

From Equation 2 it is possible to calculate the values of A and B for maximum theoretical acceleration by using the vehicle specifications for acceleration. This is usually given in terms of the time it takes a vehicle to reach 100 km/h (27.78 m/s) and the maximum speed of the vehicle.

It is, however, known that drivers of light vehicles do not necessarily use the maximum available power when they accelerate the vehicle. The purpose of this paper is to describe a project in which the proportion of maximum acceleration that a sample of drivers utilises was determined. This will be described in terms of the methodology of an experiment, the results that were found and a discussion of the results.

2 METHODOLOGY

2.1 Test Procedures

Testing was performed in 2012 in Stellenbosch and surrounding areas. The tests that were done involved the acceleration of a vehicle from stationary to a speed of 60 km/h at a rate at which the driver would normally accelerate. This was repeated 10 times for the same driver and vehicle. Tests were performed in daytime and good weather conditions on relatively flat stretches of road in off peak hours as to avoid heavy traffic volumes that may disturb the normal acceleration of the vehicles. The goal was to simulate the typical acceleration profile that a typical, normal, unimpeded vehicle will adopt from a stop line. Twenty different drivers with their own vehicles were used for the analysis. The exact vehicle specifications were attained from the vehicle owners. The test vehicles were fitted with an accelerometer equipped with a GPS unit that collected data of acceleration, speed, time and distance travelled at a rate of 100 times per second. The accelerometer that was used is the DL1 Logger of Race Technology (Race Technology, 2012). The drivers were aware that they were being tested and were told to accelerate at their normal rate and pattern until the end of the testing section. Variability for the driver was dealt with by conducting 10 runs with every test driver. The results are presented later in this report.

2.2 Test drivers and vehicles

The test drivers were selected at random and consisted of students from Stellenbosch University, not necessarily representative of a normal driver population. Twenty drivers were identified to partake in this experiment. They comprised 12 men and 8 women. The drivers' ages ranged from 19 to 25. Over 50% of drivers are normally male and therefore 60% of the studied drivers for this experiment were male (Snare Mathew, 2002). Table 1 shows a breakdown of the drivers that were used and the vehicles in which they did the tests.

In an attempt to verify the maximum acceleration specification given by the manufacturer, 0–100 km/h test runs at maximum acceleration were also performed. A graph of the relationship between acceleration and speed was plotted and measured against the theoretical graph based on the manufacturer specifications. It was anticipated that these test runs would fall below that of the manufacturer specifications, as it is very difficult to achieve the maximum acceleration of a vehicle. The data that was gathered from the accelerometer contains a certain amount of "noise" that was dealt with by using a lower frequency of output data.

Table 1: Drivers and their vehicles

Driver No.	Vehicle	Model	Age	Gender
1	Ford Fiesta 1.6 Ambient	2006	22	Male
2	VW Jetta 1.8 CLX	1990	22	Male
3	Opel Corsa 1.4	2005	24	Male
4	Honda Civic 1.7i	2001	25	Female
5	Opel Corsa Utility 1.4	2003	20	Male
6	Toyota Yaris 1.3	2006	23	Female
7	BMW 328i	2011	22	Male
8	BMW 325i	1993	21	Male
9	Ford Figo 1.4 Ambient	2011	19	Male
10	VW Polo Classic	2004	21	Male
11	Audi A3 2.0 TFSI	2006	23	Male
12	Isuzu KB 300 Club Cab	2009	19	Male
13	Mini Cooper	2007	22	Female
14	Toyota Hilux 2.7i	2001	22	Male
15	Chevrolet Spark	2011	22	Female
16	Renault Scenic 1.6	2000	23	Female
17	VW Polo 1.4	2010	24	Female
18	Renault Clio	2004	23	Female
19	Mazda 2 1.3	2010	20	Female
20	VW City Golf 1.4	2002	22	Male

For each run the acceleration versus speed was plotted and a trend line fitted to the curve. From this trend line it was possible to determine the values of A and B (from Equation 1) for each test run. The average of these values was then calculated for each driver.

3 RESULTS

3.1 Acceleration Patterns

From the analysis that was done the test drivers could be classified into three general groups of typical acceleration patterns. The three groups that were identified were standard accelerators, gradual accelerators and hard accelerators.

3.1.1 *Standard Accelerators*

The majority of the group of drivers that were observed fell into the category of standard accelerators. The defining characteristic of this group is that the acceleration behaviour is similar in nature to the pattern of maximum acceleration, only at a lower rate.. Figure 1 and Table 2 shows the plot of acceleration versus speed from which we can conclude that the standard accelerators have the same acceleration pattern as maximum acceleration, just reduced by a constant factor.

It can be seen that the slope of the line (B) is very similar for the theoretical and tested equation. The initial acceleration (A) is the only value that is reduced in the sample that was tested. This is because the drivers did not utilise the maximum acceleration capability of the vehicles. Ten men and six woman best fit this classification – representing 80% of the drivers tested.

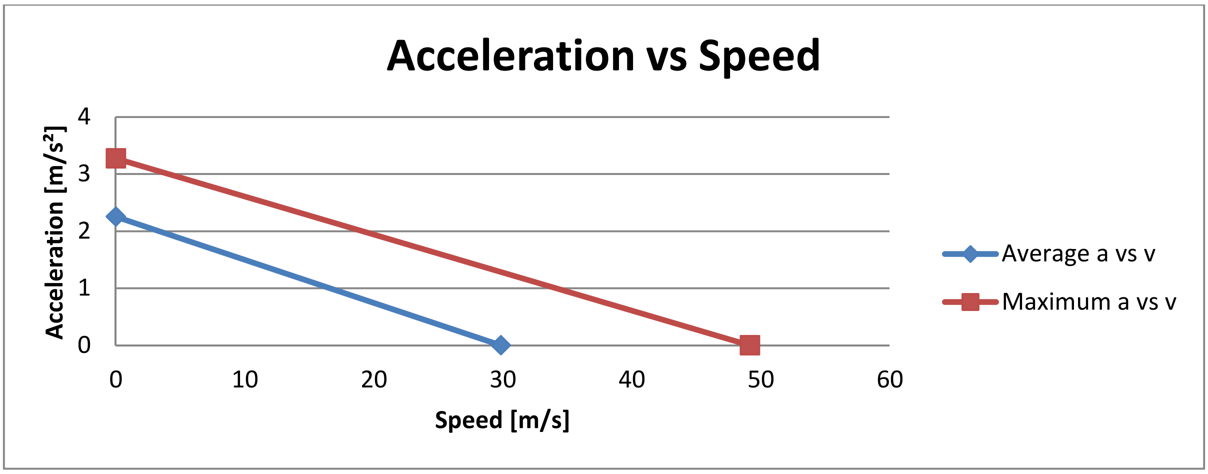

Figure 1: Acceleration vs speed for a standard accelerator (Vehicle 12)

Table 2: Maximum and tested acceleration vs speed equations

Driver #	Theoretical acceleration	Tested acceleration
1	a = 3.9537 - 0.07375v	a = 1.61355 - 0.07411v
2	a = 3.5704 - 0.07439v	a = 1.75715 - 0.07503v
3	a = 3.344 - 0.06959v	a = 2.12533 - 0.05946v
4	a = 3.536 - 0.06994v	a = 1.88209 - 0.08406v
5	a = 3.465 - 0.07797v	a = 1.70009 - 0.08406v
6	a = 3.322 - 0.06833v	a = 1.58736 - 0.11822v
7	a = 5.816 - 0.08375v	a = 2.76363 - 0.07305v
8	a = 4.867 - 0.07009v	a = 2.62874 - 0.06287v
11	a = 5.375 - 0.0774v	a = 1.87484 - 0.05023v
12	a = 3.102 - 0.0657v	a = 1.3975 - 0.0727v
13	a = 4.204 - 0.07456v	a = 1.39752 - 0.07271v
14	a = 2.951 - 0.06249v	a = 1.93956 - 0.08728v
17	a = 3.274 - 0.06659v	a = 1.64911 - 0.08731v
18	a = 3.866 - 0.07326v	a = 2.25177 - 0.09569v
19	a = 3.135 - 0.0624v	a = 1.62355 - 0.07108v
20	a = 3.318 - 0.06904v	a = 1.81826 - 0.07445v

From Table 2 it is clear that the slope (B) of the two equations are more or less equal at about 0.07 but that the major difference is in the value of A, the maximum acceleration. It is interesting to note that the average A-value for the tests was 1.876 m/s^2 which is very close to a value (1.85 m/s^2) proposed for South African light vehicles (Van As and Joubert, 1990).

3.1.2 *Gradual accelerators*

Only one of the tested drivers exhibited gradual acceleration behaviour. This driver tended to start out more slowly and accelerate at a lower initial rate. The acceleration can pick up and be higher than initial acceleration. This driver tended to have a flatter gradient (B) than the drivers that had adopted a standard acceleration pattern. The gradient of B can even become positive. This means that the value of B is generally larger than that of standard accelerators. In an extreme case of gradual acceleration the starting acceleration would be very low and the gradient is very close to becoming positive.

Test driver 15 exhibited this behaviour as can be seen in Figure 2. The slope of the plots between acceleration and speed is close to zero. This means that the value of B is very small. Initial acceleration, A, was 47% of the vehicle's capability. This was the most uncommon acceleration behaviour found during the tests.

3.1.3 *Hard accelerators*

Three of the test drivers exhibited hard acceleration behaviour. Two of the drivers that were observed were male and the other was female. This classification of driver shows very forceful initial acceleration. This is when the vehicle's acceleration capability is the greatest. When the target speed is reached, acceleration is rapidly decreased. Figure 3 shows the high initial acceleration rates that are exhibited by one of the hard accelerators. These drivers utilise an initial acceleration in excess of 70% of the vehicle's specified capability.

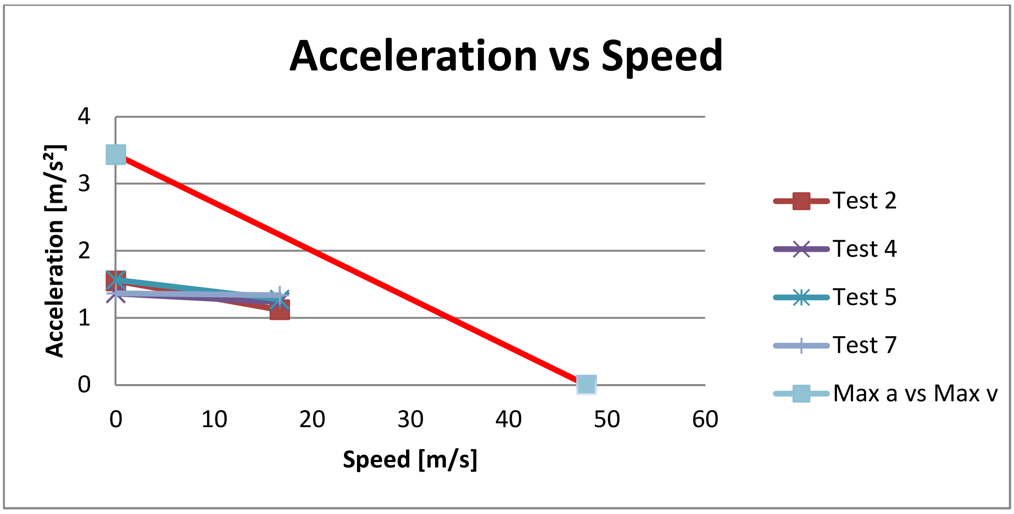

Figure 2: Acceleration vs speed for a gradual accelerator (Vehicle 15)

Hard acceleration is difficult to classify as vehicle capability has a great effect as to what can be classified as hard acceleration. The BMW 328i has a much greater acceleration capability than that of the Volkswagen Polo Classic 1.4 the driver of which was classified as a hard accelerator. This is easily verifiable by looking at the manufacturer specification of the time it takes the vehicle to accelerate from 0-100km/h. The BMW reaches 100km/h in 6.1 seconds (BMW, 2012), whereas the Polo reaches it in 14.3 seconds. However, the driver of the Polo had an average A-value of 2.74 m/s^2 which is 95 % of the vehicle's specified capability while the driver of the BMW had an average A-value of 2.76 m/s^2 which is only 48% of its specified capability. It would have been interesting to see what would have happened if the two drivers were switched.

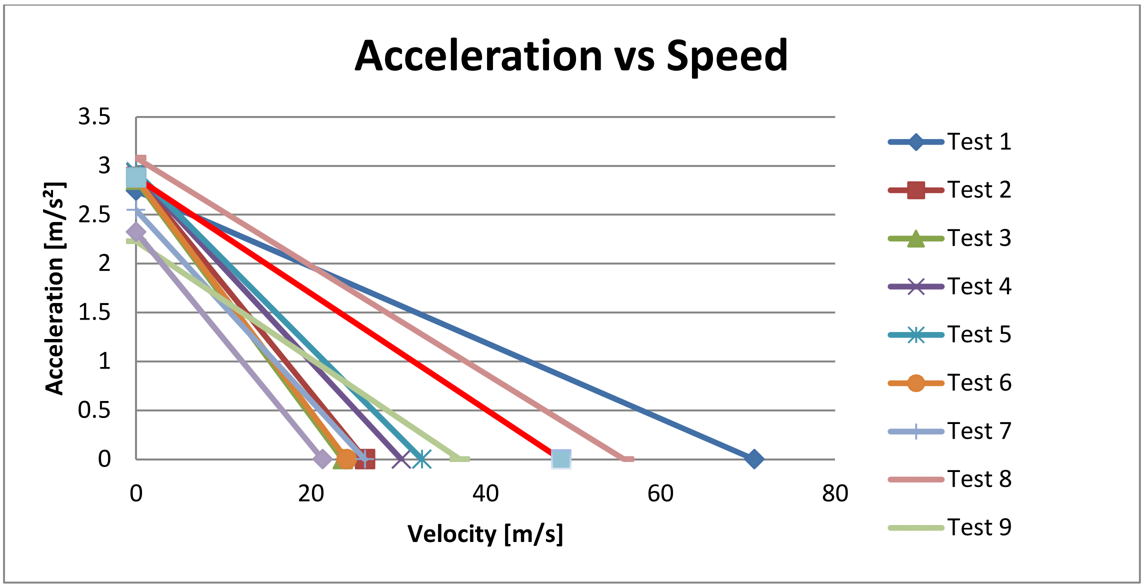

Figure 3: Acceleration vs speed for a hard accelerator

3.2 The driver factor

The driver factor can be defined as the average A-value achieved by the driver divided by the maximum theoretical initial specified A-value of the vehicle. This is then the proportion of the available power utilised by the driver. By using the driver factor one can derive some statistical conclusions regarding the acceleration trends of the various test drivers. The distribution of driver factors can be seen in Figure 4.

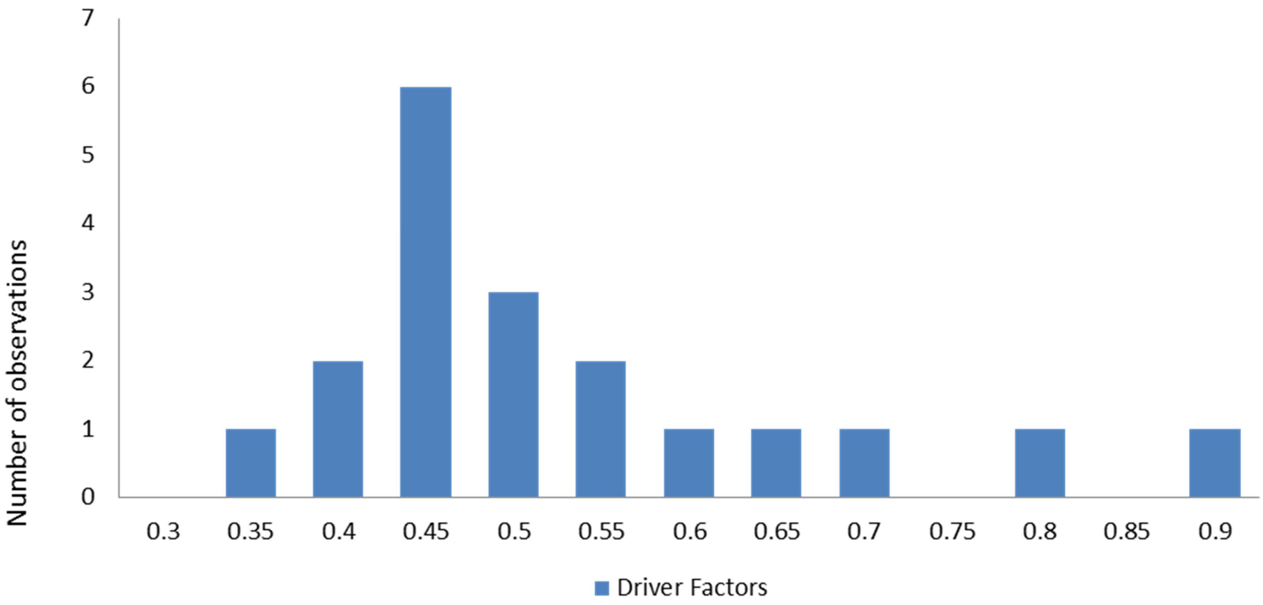

Figure 4: Distribution of driver factors

From the actual field data an average driver factor of 0.5545 was determined with a standard deviation of 0.147. This means that on average 55.45% of initial acceleration capability of the test vehicles was utilised.

3.3 Vehicle categories

From the data gathered from the 0-100 test it was clear that the maximum acceleration of the vehicles that were tested was lower than the specified values of the manufacturer. This can be due to age of the vehicle, modifications that were done on the vehicle and driver capability. On average the time it took to accelerate to a speed of 100 km/h was 1.57 seconds more than specified by the manufacturer. This means that drivers can on average only reach 88% of a vehicle's maximum acceleration capability.

The vehicles that were tested could be placed in categories according to their acceleration capabilities (time to reach 100 km/h) and three groups were identified. In the first group (6-9 s) were the two BMW's and the Audi, in the second group (9-12 s) were the Ford Fiesta, the VW Jetta, the Honda Civic, the Mini Cooper and the Renault Clio, with the rest in the third group (12-15 s).

Table 3 shows the groups that were defined and their characteristics. It is interesting to note that all the gradual and hard accelerators were from the third group.

Table 3: Acceleration behaviour in vehicle categories.

Category	Number	Time (s) to 100km/h	Accelerators			Percentage A utilised
			Standard	Gradual	Hard	
1	3	6 – 9	3	0	0	45.5
2	5	9 – 12	5	0	0	46.7
3	12	12 - 15	8	1	3	61.2

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3.4 Gender effects

When comparing the driver factors for the males and females it was found that the average for males was 0.559 and for females 0.545, a difference that is not statistically significant for the small sample size.

4 CONCLUSIONS

From the paper the following conclusions were drawn:

- The actual acceleration of vehicles is necessary for the determination of speed profiles. This can be measured and modelled by the procedures described in this paper.
- The results have shown that it may not be necessary to adjust the procedures for calculating speed profiles for light vehicles in South Africa.
- The acceleration of a vehicle at different speeds can be approximated by means of a linearly decreasing relationship.
- From the 20 participants in the experiment it was possible to identify three acceleration patterns namely standard, gradual and hard. The majority (80%) followed the standard pattern.
- Drivers utilise about 55% of the acceleration capability of the vehicle when accelerating to a speed of 60 km/h.
- Drivers of high performance vehicles utilise a lower percentage of the acceleration capability of their vehicles.
- No statistically significant difference was found between the acceleration characteristics of males and females.

5 RECOMMENDATIONS

It is recommended that further tests with a larger and more representative sample of participants and vehicles be conducted. It is also important that such tests be repeated with higher final speeds (100 and 120 km/h).

6 ACKNOWLEDGEMENT

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