Jurnal Mekanikal
June 2018, Vol 41, 59-68

Review of Driving Behavior Towards Fuel Consumption and Road Safety

Fatima Haque[1] and Mohd Azman Abas[1,2,*]

[1] Faculty of Mechanical Engineering
[2] UTM Centre for Low Carbon Transportation (LoCARtic)
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
Johor, Malaysia

ABSTRACT

One of the main concerns for automobile researchers is establish a driving method that is efficient to the engine and ensures road safety. Most studies categorized driver's behavior based on aggressiveness while driving. It was found that aggressive drivers tend to provoke fast start and quick acceleration, driving at high engine revolution, and causing sudden speed change that are prone to road accidents. On the other hand, eco-driving which consists of gentle acceleration, coast-down deceleration, maintaining a steady speed and avoidance of high speed is much safer than the aggressive driving. At the same time smooth, experienced pattern in the eco-driving consumes lesser fuel in a statistically significant way. Driver's aid system in modern cars have been invented to assist the driver into eco-driving were claimed to be effective. However, in the absence or failure of such system, drivers are suggested to drive by maintaining steady speed, avoiding sudden stop and harsh acceleration. Nevertheless, the suggestions varied between one another because there are no certain standards that could be referred to. This paper gathers the findings from available studies and highlights the recommended driving behavior in a passenger car that could be adapted in the effort to simultaneously improve the fuel economy and road safety.

Keywords: *Driving behavior, vehicle speed, acceleration, fuel consumption, road safety*

1.0 INTRODUCTION

From the time people started using automobiles to go from point A to point B, there has been a question of how to drive in a way that would be economical and safe. Since natural resources are not abundant, automotive researches are constantly being driven in finding ways to improve the fuel economy. As environmental concern is rising, fuel economic way of driving is becoming more relevant than ever. It has been known for decades that the way people drive strongly affects the fuel consumption of the vehicle and safety of the passengers. One should ask what the ideal driving behavior would be to achieve the best fuel economy and to ensure road safety. Therefore, this paper investigates the efficient way of driving by considering both the fuel consumption and road safety with regards to the passenger car speed and acceleration variables.

[*]Corresponding email: azman.abas@utm.my

When it comes to fuel consumption, several characteristics such as over-speeding, unnecessary revving and harsh stops are traditionally known to be more fuel consuming. Studies have been long conducted to correlate the driving behavior with the fuel consumption and road safety. Fuel consumption depends on many other variables such as time, distance travelled and stops [1]. On the other hand, when it comes to safety, smooth and skillfully cautious way of driving are safe. There are three components that influence fuel consumption and safety on road namely driver, vehicle and traffic. The most dominant element is the driver where the chosen direction profoundly impacts the fuel consumption and road safety. Given a certain vehicle and any traffic condition, the driver has the choice to drive in an efficient way. In addition, some modern cars are equipped with several modes of driving such as Sports and Eco mode. These different modes assist the driver to control the driving behavior to achieve better fuel consumption as what the manufacturers proclaim.

What differentiates drivers in terms of the aggressiveness is the characteristics of the driving patterns. Speed, acceleration and gear shifting technique are the key parameters to determine the safety threshold and any driver that goes out of the safe and efficient domain is considered as aggressive. In this paper, speed and acceleration are the main parameters discussed to evaluate the drivers' behavior since these are the most influential variables.

2.0 DIFFERENT DRIVING BEHAVIORS

Many studies have presented variation of driving patterns in terms of aggressiveness in relation to the fuel consumption and road safety. The definition of aggressiveness in driving behavior varies among the literatures. In one research, researchers classified four groups of drivers named as aggressive/unsteady, conservative, professional/smooth and experienced/fast driving [2]. Drivers' behavior has also been classified based on the vehicle speed with the vehicle acceleration intensity which was categorized into normal, mild and aggressive [3]. In the same year, a study compared driving behavior among categories of quiet, normal and aggressive [4]. These studies classify the driving patterns and treats aggressive driving from different aspects. While some researchers used personality and behavioral parameters to define aggressiveness, others used simple kinematic parameters such as speed and acceleration. A case study on driving risk factors revealed that the group with frequent hard brakes tends to drive faster with frequent hard acceleration and driving speed is different from other drivers which consequently creates traffic disturbances [6]. All of which indicates that aggressiveness in a driving behavior causes high driving risks. Others evaluated the risky driver behavior by combining accelerometer data and contextual variables [7]. They gave drivers risk scores, the risk scores are then completed to an individual level, and the ranking of customers then show clear distinctions between the good, average, and bad performers. Nevertheless, all of these studies used the vehicle speed and acceleration as the main parameters to assess the aggressiveness of a driving behavior. Therefore, driving behavior may be generally categorized as smooth/experienced and aggressive driving itself. Aggressive driving, or sometimes referred as 'dynamic driving', consists of high accelerations and decelerations, high maximum vehicle speeds and high engine speed operations that leads to the increase of fuel consumption.

According to all the studies mentioned above, aggressive driving behavior characteristics are related to the driver's behavior of fast/impatient reaction to changing driving situations, sudden harsh accelerations, sudden stops, continuous changes in lateral and longitudinal accelerations, high speed driving and non-consistent gear shifting. On the other hand, according to the website of Natural Resources of The Government of Canada smooth/experienced driving behavior consists of gentle accelerations, coast down decelerations, maintaining a steady-state speeds, avoidance of high speeds and earlier gear shifting [5]. A study by [3] analyzes three acceleration levels; aggressive, normal and mild produced by the driver as shown in Figure 1, representing different acceleration degrees in relation to speed. The figure illustrates the change of speed with respect to time for the vehicle to reach target speed 100 km/h and aggressive speed has the steepest slope [3].

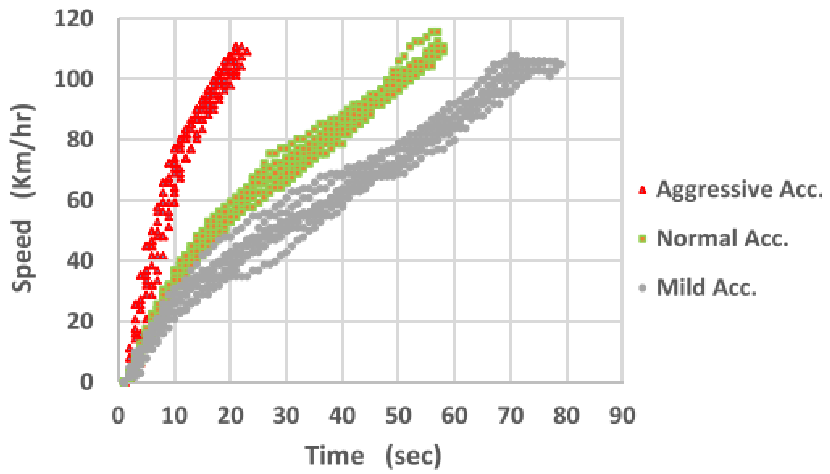

Figure 1: Instantaneous vehicle speed profiles at different acceleration levels [3]

To classify certain kinds of driving behavior as safe or unsafe requires certain standards [8]. Among the standards, vehicle speed limits imposed by the authority are one of the widely known gauges used to classify the driving as an aggressive. According to Motor Vehicle Speed Limits Rules 1989, the default national speed limit on Malaysian expressways are 110 km/h, but in certain areas, a lower speed limit (such as 90 or 80 km/h) are applied, especially in single carriageway expressway, large urban areas, crosswinds, heavy traffic and in dangerous mountainous routes [9]. U.S. Department of Transportation, Federal Highway Administration sets speed limits in the United States which vary depending on jurisdiction, with 120 to 130 km/h are common in the Western United States and 100 to 120 km/h are common in the Eastern United States [10]. According to European Commission website on mobility and transport, the general speed limit for motorways in EU Member States are mostly 120 or 130 km/h. While Germany does not have a general speed limit for motorways, instead recommends a maximum speed limit of 130 km/h. The general speed limit for rural roads in other EU member states is mostly 80 or 90 km/h and for urban roads, 50 km/h [11].

3.0 OPTIMAL DRIVING BEHAVIOR

According to the World Health Organization (WHO), every year the lives of more than 1.25 million people are cut short because of road traffic crashes. In addition, between 20 to 50 million people suffers non-fatal injuries [12]. Several driving patterns or behaviors are directly associated to these road accidents. The behavioral pattern of driving that leads to road accidents is labeled as aggressive driving which consist of aggressive acceleration and sudden acceleration. An aggressive driver tends to drive with numerous and sudden changes of instantaneous speed resulting in sudden acceleration and deceleration. With variability of speed, other vehicles on the road are exposed to danger and forced into interactions.

The main cause of accident crashes by novice teenage drivers were speeding which strongly relates to rapid acceleration from aggressive driving behaviors [16]. A statistical analysis on accident involvement by young Saudi male drivers showed that accidents are highly influenced by the drivers' attitudes towards traffic safety and speeding [17]. Studies on the cause and prevention of road accidents from law enforcer have also highlighted that excessive speed is among the main causes of road accidents [18]. The results in Figure 2 also shows that younger drivers are more likely to be involved in accidents.

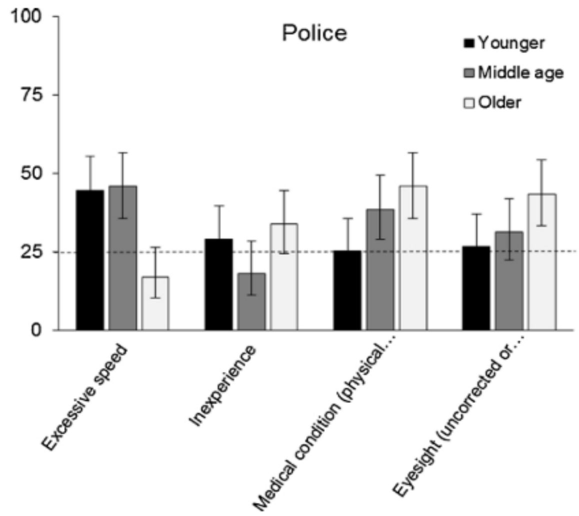

Figure 2: Percentage of correct recalls for each factor reported to have contributed to the road traffic collisions [18]

There are several models to estimate fuel consumption due to different acceleration levels. A model that provides a good estimation of the instantaneous fuel consumptions is a linear, relatively simple model because it uses few input variables [19]. Time has major effect on fuel consumption since time spent in acceleration phase determines fuel usage [2]. This study suggested that fuel consumption is less in case of aggressive acceleration by 8% than that of mild acceleration. In the case of aggressive acceleration, the time spent to reach maximum speed is lower which resulted in lower fuel consumption compared to the mild and normal accelerations.

A methodology to calculate fuel consumption in real-time to assist drivers in achieving better fuel economy was developed and different drivers' fuel consumption were observed [3]. Figure 4 compares the fuel consumption among quiet, normal and aggressive driving categories in the study. Fuel consumption obviously increases for aggressive driving with average differences of up to 1.5 L per 100 km. With the fuel consumption increase, the study stated that aggressive driving increases the fuel costs by more than 20% [3]. Fuel consumption for aggressive driving can substantially increase by 25% within urban areas [14]. This is due to the change of driving behavior by the traffic which leads to a higher fuel consumption.

A recent study concluded that experienced drivers with preference for faster speed had lower fuel consumption and emission compared to aggressive drivers [1]. Table 1 shows that aggressive driving labeled 1 which has lower cruise speed has longer headways consumes more fuel and produce more emission compared to the fast driving behavior labelled 4.

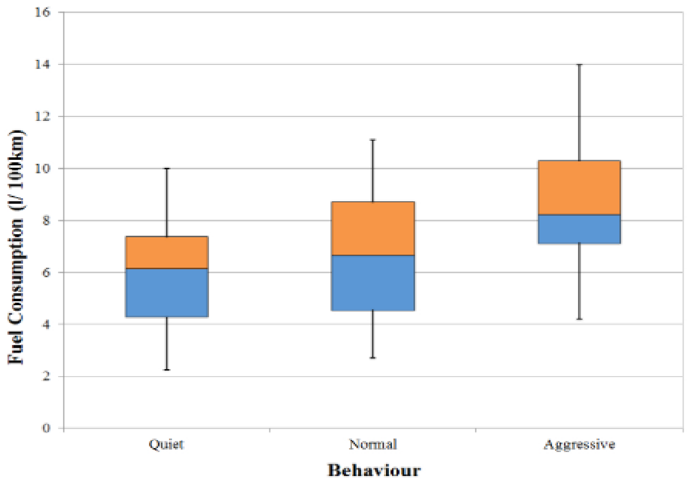

Figure 3: Fuel Consumption for different driving behaviors [4]

Table 1: Estimated fuel consumption per driver type per stop

Driver type	1	2	3	4
Fuel gram/stop	18.764	16.477	16.421	9.1075

Studies were also conducted to observe whether an acceleration advisory tool could reduce fuel consumption [13]. Acceleration advisory tool provides advices to the driver through the accelerator pedal resistance when there is an attempt for rapid acceleration. Nevertheless, according to a study, no statistically significant reduction in fuel consumption or emission was found when driving with the acceleration advisor [13]. The same study also states that decreasing the amount of strong acceleration alone does not necessarily lead to lower fuel consumption. Similarly, another study suggested that eco-driving or smooth driving behavior does not save fuel in a statistically significant way [30].

Some used dynamic programming to get optimal drive cycle which is efficient in terms of fuel consumption. The resulting optimal trajectory can be seen in Figure 4 in comparison with the original drive cycle [20]. They compared the original and the economic cycle and found that the optimal vehicle operation uses hard, short acceleration phases to attain the lowest, within the time constraint possible, cruising speed. In addition, a higher gear was chosen for eco-driving and the engine operation was pushed into the more efficient high torque and low speed region. The economic cycle reaches a certain cruise speed then maintains that speed for a while compared to original cycle where speed is constantly fluctuating. Testing the two cycles (economic and original) it was found that fuel consumption was reduced by 27.8% from 9.0 L/100 km for the original cycle to 6.5 L/100 km for the economic cycle [20]. Even though this economic cycle reduces fuel consumption, it is not very effective in terms of safety since it contains harsh acceleration which strongly contributes to high pollutant emission as well.

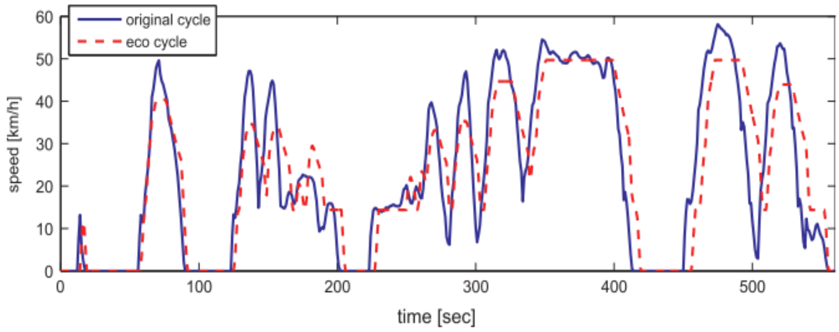

Figure 4: Original against economic drive cycles [20]

To establish a safety domain for vehicle both lateral-longitudinal acceleration and speed were used to establish a quadratic relationship between *V* and *a* [15]. In the (*V*, *a*) plane, a decreasing trend of *a* as a function of *V* speed and *g* value is 9.81 m/s^2 as shown in Figure 5. As the speed increases, vehicle acceleration is suggested to be reduced to stay in safety domain as shown in the figure. Any driving behavior outside the domain is considered as unsafe.

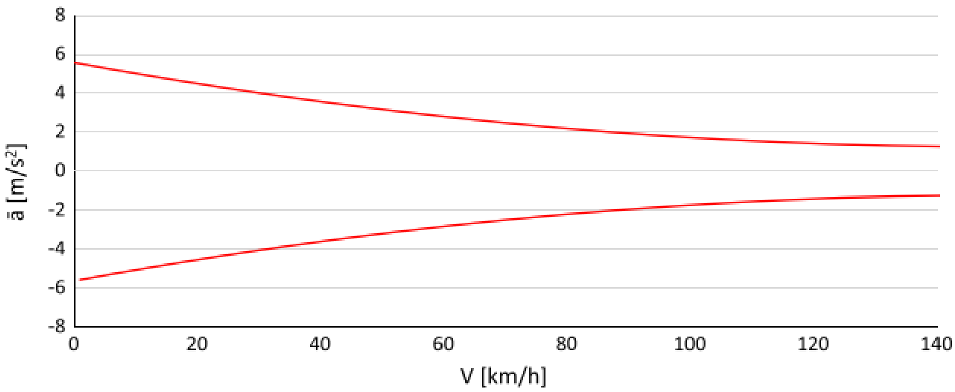

Figure 5: Borderline between safe and unsafe/aggressive driving condition [15]

Economical as well as ecological or less polluting behavior shows significant potential reductions in fuel consumption due to better choices of velocity and acceleration rates. The algorithm developed in a study was used to analyze both economic and ecologic pattern of driving and consequential fuel consumption. It was established that eco-driving consumes less fuel and produces less pollutants compared to original drive cycle [20]. This eco-driving consists of gentle accelerations, coast down decelerations, maintaining a steady speed, avoidance of high speeds and earlier gear shifting which is economical as well as ecological.

4.0 APPROACHES TO IMPROVE FUEL CONSUMPTION AND ROAD SAFETY

Studies are being conducted to combat harsh acceleration which leads to accidents and high level of fuel consumption. In this case it is important to study the general acceleration and deceleration behavior of different types of vehicles. Generally, the acceleration of a vehicle increases to a maximum value with increasing speed then acceleration rate decreases with further increase in speed [21].

Psychologically, main reason behind the aggressive, unsafe driving is due to the perception that they are better than other average drivers on the road [22]. The results of this study showed that the better-than-average effect was significantly positively associated with risky driving behavior, as well as with verbal and physical aggression and with the use of the vehicle to express their anger.

The most vulnerable group of drivers [23] get into car crashes as soon as they are out of training [22]. There are some existing technologies to assist these new drivers in terms of safety and fuel consumption. Some adaptive cruise control rules for advance driver assistance system and fundamentals for devising traffic accident solutions have been developed [24]. Another technology developed was the cooperative adaptive cruise control system which clearly showed improvements in string stability and has the potential to reduce disturbances and improve highway capacity and traffic flow stability [25]. Another model to ensure traffic safety is called CCC model which stabilizes vehicle platoons [26]. Variable speed limit (VSL) uses sensors along the roadway detect when congestion or weather conditions exceed specified thresholds and automatically reduce the speed limit (in 5 mph increments) to slow traffic and postpone the onset of congestion. Based on the simulation results, the VSL system was shown to result significantly improved performances in terms of mobility, safety and sustainability [28]. An improved car following model [29] and safety education might be helpful in order eliminate road accidents due to rapid acceleration. Although noticeable reduction in fuel consumption and acceleration behavior was found during training period, only 2% reduction was found in real life driving [22]. Some evaluated the effectiveness of behavior-based safety education methods for commercial vehicle drivers and concluded that Behavior-Based Safety (BBS) education was confirmed to be effective in safety-related event reduction [31].

On the other hand, 10% improvement in driving style in cars reduces 8.81% of fuel consumption [32]. Drivers' bounded rationality reduces fuel consumption as well [33]. While driving on hilly roads dynamic programming can be used to reduce fuel consumption. Between 6.89% to 24.78% fuel can be saved using the dynamic programming–based eco driving algorithm compared with using the cruise control algorithm [34]. Others suggested that using driving cycles results with an average fuel savings of 8– 12% compared to using average speed [35].

In a nutshell experienced, smooth driving is good for both fuel consumption and safety. Eco-driving in other words is optimal here in terms of fuel consumption and safety. This driving techniques includes gentle accelerations, coast down decelerations, maintaining a steady speed and avoidance of high speeds. But training people in eco driving didn't result in significant improvement of the situation. So, in my opinion Intelligent driving assistance system might be the solution. In case of vehicle to vehicle safety CACC and CCC are reliable new technologies to avoid accidents in a vehicle platoon. The results demonstrated that CCC also enhances vehicle fuel economy by 3.3 percent on average relative to manual driving [26].

Based on the aforementioned studies discussed, Figure 6 shows the plot that summarizes the vehicle speed and acceleration variables in which this study has highlighted regions as a recommendation for future studies. As it can be seen from the figure, few regions are concluded based on studies by [3, 15, 20, 21] which defines road safety, fuel economy and normal driving behaviors. Regions of driving behavior were labeled in the figure to recommend the optimal driving to achieve fuel economy and road safety. Based on these regions, driving within the road safety region does not necessarily brings benefit to the fuel economy, but driving within the fuel economy brings along the road safety benefit as well. Therefore, this study suggests that optimal driving behavior within the fuel economy region simultaneously improve the fuel economy and road safety.

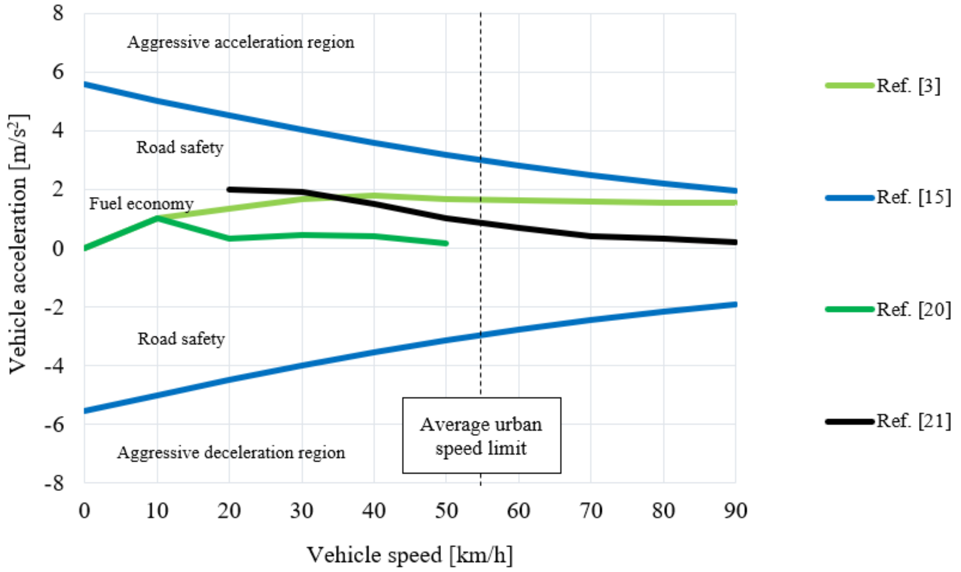

Figure 6: Acceleration with respect to vehicle speed regions

5.0 CONCLUSION

This paper highlighted different driving behaviors and their influence on fuel consumption and road safety by identifying a suitable driving based on available literatures. Most studies have categorized drivers based on their aggressiveness while driving. Thresholds for acceleration for different speed are presented with consideration on the fuel consumption and road safety. The established regions show the most suitable and conservative way of driving to reduce fuel consumption without compromising safety. In terms of road safety, it was found that aggressive drivers tend to behave with high accelerations, high engine speeds, and sudden speed changes are prone to accident involvement. While eco-driving which consist of gentle accelerations, coasting down, steady speeds and avoidance of extreme speeds is much safer than the aggressive driving. Results have shown attitude toward road safety and safety awareness can ensure safer travel. On the contrary of the road safety, studies have shown that trained drivers do not necessarily resulted on lower fuel consumption. Instead, smoothness from experienced driving pattern has a significant impact to lower the fuel consumption. Therefore, some technologies have been invented to intervene with the driver's behavior to achieve lower fuel consumption through eco-driving. However, with the absence of these technology in a passenger car, drivers should practice driving within the recommended fuel economy region to simultaneously improve the road safety as well.

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