INFLUENCING DRIVER BEHAVIOUR FOR ENVIRONMENTAL BENEFIT: THE ROLE OF ITS TECHNOLOGIES

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ABSTRACT

As vehicle technologies become ever more efficient and sophisticated, it is increasingly the case that the most inefficient and variable component in the modern passenger car is the driver. With the support of a case study, this paper investigates variability in driver behaviour, and seeks to both classify and quantify the effects. Statistical cluster analysis techniques are utilised to group different types of driver behaviour. The paper then goes on to investigate the relationships between these clusters of behaviour types, and metrics of environmental efficiency. Finally, a range of ITS technologies are discussed which have the potential to influence driver behaviour towards an environmental and resource optimum.

KEYWORDS: Driver behaviour, environment, ITS technologies, efficiency

INTRODUCTION

To date, terms such as 'aggressive' and 'passive' have often been utilised to characterise driver behaviour, for example when researching vehicle drive cycles [1]. However, such terms are inherently subjective and require qualification and definition before they become useful. The development of an alternative, more objective taxonomy which lends itself to measurement would be potentially more useful, but would require a better understanding of the defining characteristics of variability in driver behaviour.

Metrics which help to define driver 'competence' and 'efficiency' would be more useful when combined with a defined objective function. For example, a 'performance index' could be defined which incorporates (perhaps weighted) measures of fuel efficiency, CO_2 production, exhaust emissions, and journey time. Such an approach would then present the possibility of influencing driver behaviour to move towards optimisation of the 'performance index'. This paper begins to explore some of these issues, and suggests avenues for future research.

SOURCES OF VARIABILITY IN DRIVER BEHAVIOUR

It must be recognised that human beings are not machines, and cannot be expected to operate in a mechanistic manner. Indeed, if this were the objective, it would probably be better to replace the human driver with an automaton. Human beings display variability in driver behaviour for a range of reasons, some of which include:

- Intrinsic behavioural traits
- Adaptation of intrinsic traits in response to external stimuli
- ‘Taught’ or ‘learned’ behaviours (levels of training and experience)
- ‘Inherent’ ability (e.g. hand / eye coordination, response times, spatial awareness)

Such variability in driver behaviour is revealed in the use of primary vehicle controls such as accelerator, brakes, clutch, gears, and steering.

Large data sets exist in the commercial road haulage sector, where on-vehicle data acquisition is utilised to reduce operating costs by targeting variables such as fuel consumption. Schemes are in place in many companies to reward economical driving, supported by targeted training for poor performing professional drivers. However, relatively little data is available on the characteristics of, and variability within, the ‘amateur’ driver population (i.e. the general car owning public). However, ITS technologies are beginning to present new opportunities to gain a better understanding of these issues, and consequently to provide the opportunity to influence driver behaviour and operational efficiency.

DRIVER BEHAVIOUR VARIABILITY AND ENVIRONMENTAL EFFICIENCY – A CASE SUDY

To illustrate the point, a brief case study is presented which highlights the importance of gaining a better understanding of variability in driver behaviour. As part of the RETEMM (Real-world Traffic Emissions Monitoring and Modelling) project, funded by the UK Engineering and Physical Sciences Research Council, the behaviour of 40 drivers was investigated using an instrumented spark ignition passenger car with an engine capacity of 1.8 litres with manual transmission, over a fixed suburban test route of approximately 0.6km. Each driver performed ten repetitions of the route, giving a total of approximately 6km test distance per driver. The route was characterised by four short straights of between 140m and 160m, linked by left hand turns at priority junctions. Speeds were therefore generally low, with 2^{nd} and 3^{rd} gears being used most frequently. Driver behaviour and emissions data were collected at a frequency of 1Hz. The data collection and processing is discussed in more detail in earlier publications [2], [3].

Cluster analysis is a term used to describe a range of statistical methods for grouping cases with similar attributes or characteristics [4]. In this case, hierarchical cluster analysis was applied to the driver behaviour data to investigate how engine speed (rpm), throttle position (%), and vehicle acceleration (+ve or –ve m/s^2) could be used to group or ‘cluster’ drivers. The environmental efficiency of these clusters of drivers could then be investigated to provide an insight into the relationship between driver behaviour and environmental performance.

The distributions of the behavioural data for each variable by driver were standardised by generating percentile values at 5 percentile intervals. These percentile values were then utilised in the cluster analysis. The average (between-group) linkage cluster method was adopted, with squared Euclidean distance being used as the measure of similarity. Separate cluster analyses were carried out for each variable, engine speed, throttle position, and acceleration respectively. Data from 37 of the 40 drivers were utilised in the analysis, 3 drivers being discarded due to instrumentation reliability issues. Hierarchical cluster analysis (unlike other methods such as k-means clustering) makes no prior assumptions about the number of clusters to be generated. The number of clusters is determined by the analyst using metrics from the analysis such as the measure of proximity between clusters. In this case, four clusters of drivers were identified for each variable respectively.

Table 1 – Clustering of drivers by variable

	Cluster (R1)	**Cluster (R2)**	**Cluster (R3)**	**Cluster (R4)**
(R) Engine speed	10, 15, 17, 36	7, 8, 9, 12, 13, 16, 18, 19, 20, 21, 22, 23, 26, 29, 30, 33, 34, 35, 37, 38, 40	1, 5, 6, 11, 24, 25, 31, 32	2, 14, 27, 28
	Cluster (T1)	**Cluster (T2)**	**Cluster (T3)**	**Cluster (T4)**
(T) Throttle Position	15*	20, 22, 24, 25, 27	2, 8, 10, 11, 14, 16, 17, 18, 19, 21, 23, 26, 28, 30, 33, 37	1, 5, 6, 7, 9, 12, 13, 29, 31, 32, 34, 35, 36, 38, 40
	Cluster (A1)	**Cluster (A2)**	**Cluster (A3)**	**Cluster (A4)**
(A) Vehicle acceleration	15, 20, 24	2, 10, 18, 21, 22, 23, 25, 27, 30, 33, 37	1, 7, 8, 11, 12, 14, 16, 17, 19, 26, 28, 29, 31, 32, 36, 40	5, 6, 9, 13, 34, 35, 38

*N.B. Driver 15 was an outlier for the Throttle Position variable, and was allocated to its own cluster.

Investigation of the clusters generated by the analysis determined that they could be characterised by the attributes in Table 2.

Table 2 – Behavioural attributes of clustered drivers by variable

		Cluster (R1)	**Cluster (R2)**	**Cluster (R3)**	**Cluster (R4)**
(R) Engine speed (RPM)	Mean 25th %tile	1561 rpm	1343 rpm	1184 rpm	825 rpm
	Mean 50th %tile	2094 rpm	1754 rpm	1493 rpm	1311 rpm
	Mean 75th %tile	2500 rpm	1970 rpm	1706 rpm	1573 rpm
	Mean 95th %tile	2896 rpm	2359 rpm	2021 rpm	1927 rpm
		Cluster (T1)	**Cluster (T2)**	**Cluster (T3)**	**Cluster (T4)**
(T) Throttle Position (%)	Mean 65th %tile	21%	19%	12%	6%
	Mean 75th %tile	35%	28%	20%	11%
	Mean 85th %tile	73%	36%	28%	15%
	Mean 95th %tile	98%	47%	38%	22%
		Cluster (A1)	**Cluster (A2)**	**Cluster (A3)**	**Cluster (A4)**
(A) Vehicle acceleration (m/s^2)	Mean 5th %tile	-1.97 m/s^2	-1.82 m/s^2	-1.45 m/s^2	-1.10 m/s^2
	Mean 25th %tile	-0.86 m/s^2	-0.66 m/s^2	-0.40 m/s^2	-0.30 m/s^2
	Mean 75th %tile	0.85 m/s^2	0.72 m/s^2	0.52 m/s^2	0.36 m/s^2
	Mean 95th %tile	1.60 m/s^2	1.34 m/s^2	1.09 m/s^2	0.92 m/s^2

In principle, the production of 4 clusters of drivers for each of the 3 variables produces 4^3 (64) potential cluster combinations ($R_{1 \text{ to } 4}$ x $T_{1 \text{ to } 4}$ x $A_{1 \text{ to } 4}$). However, with a relatively small sample of 37 drivers, the three dimensional cluster matrix could not be fully populated. In addition, some combinations of driver behaviour clusters may have a greater probability than others, and others may not be feasible in practice. It transpired that when the clusters of drivers by variable are cross-tabulated, 18 of the possible 64 matrix cells are populated, 11 of these by individual drivers.

The environmental 'performance' of these 18 cluster cells is presented in Table 3 in terms of CO_2 emissions, fuel consumption, and pollutant emissions HC, CO, and NO_x.

Table 3 – Environmental performance of clustered drivers

	Carbon dioxide		**Fuel Consumption**		**Hydrocarbons**		**Carbon monoxide**		**Oxides of nitrogen***	
Cluster cell	Mean rate (g/sec)	Mean rate (g/km)	Mean rate (g/sec)	Mean rate (g/km)	Mean rate (g/sec)	Mean rate (g/km)	Mean rate (g/sec)	Mean rate (g/km)	Mean rate (g/sec)	Mean rate (g/km)
R1_T1_A1 *(n=1)*	3.67	385	1.10	115	0.00411	0.43	0.1219	12.77	0.1217	1.27
R1_T3_A2 *(n=1)*	2.72	344	0.83	106	0.00261	0.33	0.0277	3.51	0.0059	0.75
R1_T3_A3 *(n=1)*	3.02	365	0.87	105	0.00020	0.02	0.0056	0.67	0.0020	0.25
R1_T4_A3 *(n=1)*	2.41	340	0.72	102	0.00077	0.11	0.0033	0.46	0.0014	0.20
R2_T2_A1 *(n=1)*	3.11	346	0.91	101	0.00049	0.05	0.0126	1.40	0.0026	0.30
R2_T2_A2 *(n=1)*	2.87	346	0.84	101	0.00026	0.03	0.0083	1.01	0.0023	0.28
R2_T3_A2 *(n=6)*	2.79	348	0.83	104	0.00114	0.14	0.0104	1.29	0.0030	0.38
R2_T3_A3 *(n=4)*	2.60	349	0.76	102	0.00133	0.18	0.0114	1.54	0.0030	0.41
R2_T4_A3 *(n=4)*	2.22	325	0.66	97	0.00131	0.19	0.0049	0.72	0.0025	0.37
R2_T4_A4 *(n=5)*	2.14	330	0.63	98	0.00094	0.14	0.0024	0.38	0.0017	0.26
R3_T2_A1 *(n=1)*	3.21	369	0.99	113	0.00069	0.08	0.0233	2.68	0.0041	0.47
R3_T2_A2 *(n=1)*	3.22	375	0.98	115	0.00079	0.09	0.0131	1.53	0.0035	0.41
R3_T3_A3 *(n=1)*	2.51	328	0.75	98	0.00161	0.21	0.0107	1.40	0.0033	0.44
R3_T4_A3 *(n=3)*	2.11	312	0.63	93	0.00088	0.13	0.0047	0.70	0.0027	0.41
R3_T4_A4 *(n=2)*	1.93	307	0.58	93	0.00110	0.18	0.0032	0.51	0.0030	0.48
R4_T2_A2 *(n=1)*	2.89	343	0.93	111	0.00184	0.22	0.0219	2.61	0.0043	0.51
R4_T3_A2 *(n=1)*	2.77	350	0.84	106	0.00038	0.05	0.0112	1.41	0.0041	0.52
R4_T3_A3 *(n=2)*	2.34	358	0.72	110	0.00154	0.24	0.0133	2.02	0.0036	0.56

*N.B. The NO_x emissions values should be interpreted with caution. It has been demonstrated that the sensor utilised in the experiment is cross-sensitive to ammonia (NH_3), rendering measurements sometimes unreliable, especially under rich engine operating conditions [5].

When interpreting the data, it should be remembered that the context of the measurements was a low speed suburban route with short links connected by left-hand turns at priority junctions. Drivers were generally either accelerating or decelerating between corners with no opportunity to 'cruise'. Gear selection was dominated by 2nd and 3rd gears. Hence, measured CO_2 emissions and fuel consumption would be expected to be significantly higher than 'typical' rates for mixed driving conditions. The main objective of the analysis is to assess the degree of variability displayed by drivers when presented with these constrained driving conditions, the vehicle and the highway geometry being held constant (ambient traffic conditions were extremely light with very little interaction with other traffic).

It is clear that the throttle application behaviour of Driver 15 was extreme relative to the other drivers. This behaviour tended to result in very high levels of fuel consumption and emissions for all pollutants. Generally, lower rates of fuel consumption and CO_2 emissions are associated with lighter throttle applications and lower rates of acceleration (a degree of symmetry was observed between positive (+ve) and negative (–ve) acceleration; the drivers who accelerated heavily also tended to brake heavily). However, it was observed that very low engine speeds (for example, associated with the R4 cluster) are not always desirable, perhaps because they are associated with engine 'labouring'. The engine appeared to operate more efficiently in the R2 and R3 clusters when combined with light throttle application and low levels of acceleration, although some of the lowest emissions results for HC, CO, and NO_x were associated with the R1 cluster when combined with light throttle application (T3, T4) and low levels of acceleration (A3). It should also be noted that there is sometimes a trade-off between the rate of emissions in g/sec and the rate of emissions in g/km, where average speed is a factor. Total emissions for a journey can be high, even with a low rate g/sec, if average speed is very low. This implies that over-cautious, hesitant driving can increase emissions in g/km for a total journey, relative to a more competent driver who maintains a reasonable g/sec emissions rate, and completes the journey expeditiously, resulting in a lower g/km.

Clearly, such a small sample of drivers is not necessarily representative of the whole driver population, but it is a subset of the UK driver population. The highway network used for the measurements is also only a subset of the total network, and only one vehicle was utilised in the measurements. Nevertheless, the research has provided an insight into the nature and potential scale of driver behaviour variability in the population, and can be used to inform future experimental design.

ITS SOLUTIONS FOR ENVIRONMENTAL BENEFIT

The case study has demonstrated that significant variability can exist in driver behaviour, even when drivers are presented with near identical driving conditions, and that this variability has a significant influence on environmental performance. This raises the question, 'What interventions can be considered to improve environmental performance?' In recent years, a range of solutions have been implemented with varying degrees of cost and potential efficacy. Such systems are not necessarily mutually exclusive, and may be adopted in a complementary fashion depending on context. In the following sections, different interventions and technologies which aim to control and regulate driving cycles/styles using on-vehicle technologies, intelligent system integration, and driver training are described.

Driver training

If the most significant positive and negative behavioural traits can be determined from the experimental data, driver training can be informed and adapted to incorporate such information. Directive 2006/126/EC of the European Parliament and of the Council (Annex II, section 9.3.2) states that "The driving examiner will .... assess whether the applicant is: Driving economically and in an environmentally friendly way, taking into account the revolutions per minute, changing gears, braking and accelerating" [6]. Such behavioural characteristics are potentially quantifiable in the light of developing research.

Recent research carried out in Belgium evaluated the long-term impact of an eco-driving training course. Average fuel consumption four months after the course fell by 5.8%. Most drivers showed an immediate improvement in fuel consumption that was stable over time, but some tended to fall back into their original driving habits [7]. Results from commercial initiatives such as the Ford Eco-driving Challenge 2008 have reported overall decreases in fuel consumption of 22.5% [8]. Commercial companies such as Renault have developed driving simulators, either focused on the issue of eco-driving, or with the capability to be utilised for eco-driving training [9].

Public information campaigns

Public information initiatives, such as the UK Government 'Act on CO_2' campaign [10], highlight simple generic messages for carbon footprint reduction. The UK Energy Saving Trust [11] issues guidance on changing gear / limiting engine speed to 2000 rpm for diesel car engines, and 2500 rpm for petrol car engines. Such adverts are often displayed on the back of buses, with the potential for also influencing modal choice. Clearly, such public information campaigns have the advantage of simplicity of a generic message, but the disadvantage of not being tailored to a particular vehicle type / make / model or situation.

In-vehicle (delayed feedback) intelligent transport systems

Some vehicle manufacturers have introduced technology which allows the driver to download historic data on vehicle operation (vehicle speed, gear selection, engine speed, acceleration, braking) from the vehicle onto a personal computer for analysis. An example is the Fiat Eco-Drive system [12]. Over time, such a system has the potential to allow the driver to quantify the benefits of eco-driving techniques, in terms of reduced fuel consumption and carbon emissions. A potential development of such systems would be to include positional data from satellite navigation (GPS) to facilitate detailed analysis of driver behaviour in a geographic context. However, access to such data by researchers for non-professional drivers may encounter privacy issues, and the time resolution of such data may not be ideal.

In-vehicle (real-time feedback) intelligent transport systems

In the commercial vehicle sector, econometers using vacuum gauge technology have been used for many years to help professional drivers reduce fuel consumption. In the passenger car market, instrumentation focused on efficient and economical driving has only recently become a marketing imperative for the vehicle manufacturers. Recent European legislation on CO_2 emissions of new vehicles has helped to encourage such changes. Most vehicle manufacturers now offer 'eco' versions of their products, with technology such as low rolling resistance tyres, improved aerodynamics, and instrumentation to aid driver efficiency (such as gear change indicators, fuel consumption meters etc.). It is envisaged that such technology will become ubiquitous in new vehicles in the coming years, driven both by legislation and customer demand.

Integrated systems for control / moderation of vehicle operation

In recent years, the potential of modern ITS technology has been exploited by the development of systems such as intelligent speed adaptation (ISA), which is promoted in the UK primarily for speed limit enforcement and road safety. The technological feasibility of such systems has been substantially proven, and trials are being carried out in the UK to assess acceptance and effectiveness [13].

However, from a purely technological point of view, the precedent set by systems such as ISA could lead to the development of ITS solutions which are focused on improving the environmental and resource efficiency of the vehicle, either at the level of the individual vehicle, or at a system wide level. Such a system could form a logical component of a next generation urban traffic management and control (UTMC) system, for example, linked to environmental monitoring systems, to meet air quality objectives. The Sentience project [14, 15] uses the concept of an 'electronic horizon' to improve vehicle fuel efficiency. Electronic horizon data includes variables such as traffic conditions, location, road topography (vertical and horizontal), and predicted speed. An Enhanced Acceleration/Deceleration System (EADS) has been implemented on an hybrid demonstration vehicle which, using route information, calculates and implements an optimal driving strategy via an advanced form of cruise control. This can be over-ridden by the driver at any time, but the system has demonstrated fuel savings of between 5% and 24% in track tests.

FUTURE RESEARCH

As new data sources become available, facilitated by new developments in ITS, there will be an opportunity to gain a greater understanding of the factors which influence driver behaviour, and the consequent impact on vehicle operation and environmental efficiency. Clearly, new vehicle propulsion technologies such as fuel cells and lithium-ion batteries have the potential to change the environmental performance of vehicles (at the local level) significantly. However, such technologies are still some way from wide scale market adoption, and until that time, operating the internal combustion engine in the most efficient manner possible will be a logical and socially responsible objective. If the individual driver is to remain in control of the passenger car, a better understanding of variation in driver behaviour, its consequences, and how to influence it for environmental benefit, will be useful in informing future vehicle and system design. A number of potential avenues present themselves; adaptation of driver behaviour; developments in vehicle design and information systems; and developments in integrated systems for driver-vehicle-infrastructure optimisation. These are not mutually exclusive, and developments in all three areas will continue in the coming years, influenced by public acceptance.

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