Driving style for better fuel economy

Akena, Robert; Schmid, Felix; Burrow, Michael

DOI:
10.1680/jtran.15.00116

Transport

Driving Style for Better Fuel Economy

--Manuscript Draft--

Manuscript Number:	
Full Title:	Driving Style for Better Fuel Economy
Article Type:	Paper
Corresponding Author:	Robert Akena, BSc(Eng), MSc, PhD Amey Birmingham, UNITED KINGDOM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Amey
Corresponding Author's Secondary Institution:	
First Author:	Robert Akena, BSc(Eng), MSc, PhD
First Author Secondary Information:	
Order of Authors:	Robert Akena, BSc(Eng), MSc, PhD
	Felix Schmid, Dip. El. Ing. ETH, PhD
	Michael Burrow, MA (Cantab), PhD
Order of Authors Secondary Information:	
Abstract:	Driving style has emerged as an important determinant of fuel economy. There is now evidence that driving style can be influenced to improve fuel economy as well as other aspects such as safety. However, it is not clear which are the most appropriate and influential factors that affect an individual's, or a group's, driving style with respect to improving fuel economy. In this paper, such factors were identified from the literature and existing driver training programmes for fuel economy. The factors were then categorised under driver factors, operating the vehicle, vehicle dynamics and driver awareness. The influences of the factors on fuel economy were prioritised using a multi-criteria analysis (MCA) method called the analytical hierarchy process (AHP) using expert opinion to determine the relative importance of the identified factors. It was found that driver awareness, measured in terms of culture change and better management, was considered the most influential category. The second most influential category of factors concerned operating the vehicle or vehicle control where, acceleration and speed were found to have the highest influence on fuel economy in the category. These results can be used to improve interventions such as driver training for fuel economy by informing training modules.

Driving Style for Better Fuel Economy

Dr Robert Akena (BSc(Eng), MSc, PhD, CEng)
Network Asset Manager
Amey
Amey International Design Hub
Colmore Plaza
20 Colmore Circus
Birmingham
B4 6AT
E-mail: robert.akena@amey.co.uk

Professor Felix Schmid (Dip. El. Ing. ETH, PhD)
Centre for Railway Research and Education
Gisbett Kapp Building
University of Birmingham
Edgbaston
Birmingham
B15 2TT
UK
f.schmid@bham.ac.uk

Dr Michael Burrow (MA (Cantab), PhD)
Lecturer and Convenor of MSc Road Management and Engineering
School of Civil Engineering
University of Birmingham
Edgbaston
Birmingham
B15 2TT
UK
E-mail: burrowmp@adf.bham.ac.uk

Keywords
Roads & highways, Fossil Fuels, Driving Style

Number of words
About 3,867 excluding references

Abstract

Driving style has emerged as an important determinant of fuel economy. There is now evidence that driving style can be influenced to improve fuel economy as well as other aspects such as safety. However, it is not clear which are the most appropriate and influential factors that affect an individual's, or a group's, driving style that with respect to improving fuel economy. In this paper, such factors were identified from the literature and via driver training programmes for fuel economy. The factors were then categorised under driver factors, operating the vehicle, vehicle dynamics and driver awareness. The influences of the factors on fuel economy were prioritised using a multi-criteria analysis (MCA) method called the analytical hierarchy process (AHP) which utilized expert opinion to determine the relative importance of the identified factors. It was found that driver awareness, measured in terms of culture change and better management, was considered the most influential category. The second most influential category of factors concerned operating the vehicle or vehicle control where, acceleration and speed were found to have the highest influence on fuel economy in the category. The driver-related factors were considered to have the least influence on fuel economy. These results can be used to improve interventions such as driver training for fuel economy by developing specific training modules which emphasise the most influential driving factors.

Abbreviations

AFRCOM	ARRB Fuel Consumption Model
AHP	Analytical Hierarchy Process
ARRB	Australian Road Research Board
DfT	Department for Transport (UK)
FEDIC	Fuel Economy Driver Interface Concept
GPS	Global Positioning System
HGV	Heavy Goods Vehicle
ITS	Intelligent Transportation System
MCA	Multi-Criteria Analysis
MPG	Miles per Gallon
PTT	Postal and Telecommunications Services
SA	Sensitivity Analysis
SAFED	Safe and Fuel-Efficient Driver Training

Equations

Ai	is the weight assigned to the training attribute *i* based on the influence of the attribute *i* on fuel economy; and the sum of A_i is unity or 1
a_{ij}	is the element of row *i* and column *j* of the comparison matrix
CIx	the consistency index, a measure of the consistency of the respondents
CRa	the consistency ratio
F	is Boolean function
N	is the number of elements of each row of the hierarchy (comparison) matrix, that is, the number of selected criteria (factors).
NM_{ij}	is the normalised value of matrix cell described by row *i*, column *j*
Rix	is the random consistency index (RI); average value of CIx random matrices using the Saaty scale (1980) obtained by Forman (1990) (Table 7)
RW_{ij}	is the value of the hierarchy (or comparison) matrix cell described by row *i*, and column *j*
TS_i	is an importance factor that can be assigned to an attribute *i* in a traffic system or the driving environment
W_i	is the value of the column matrix cell described by row *i*
β_o	is the overall influence of the driving factors or attributes on vehicle fuel economy, and can independently be assumed as equal to the total influence of driver training on fuel economy
λmax	the principal Eigen value of the normalised matrix considered to be a measure of the degree of inconsistency
Φ	is the level of consistency needed as used by Alonso and Lamata (2006)

1 Introduction

Driving style is known to affect many aspects of driver performance. For example, there have been several studies relating driving style to safety (accidents), fuel consumption and emissions, time saving, and vehicle wear and tear (af Wåhlberg, 2007; Turpin and Scott, 2010; French et al, 1993). Until recently studies regarding the influence of driving style on road transportation have mainly been focussed on road safety where, real benefits have been realised Cacciabue and Carsten (2010). Increasingly however, the potential benefits of influencing driving style to improve fuel economy are being recognised (af Wåhlberg, 2007; Turpin and Scott, 2010; ecoDriver, 2013). Fuel consumption forms the biggest component of total road transport energy requirement (that is, over 90% of the energy requirement) based on the traditional fossil oils types for transport fuel (in particularly diesel and petrol as ‘shale’ oil is still a much recent and not fully proven resource) (Odoki and Akena, 2008).

However, there is still limited knowledge regarding the driving factors which have the most influence on fuel economy ecoDriver (2013). Such driving factors are those that a driver could influence to improve vehicle fuel economy during driving. There is also limited knowledge regarding the relative influences of these factors to meet the needs of different interventions aimed at improving the relevant performances of the transport services, for example, driver training for fuel economy. This means that such factors need to be identified using a robust criterion which provides scientific explanations regarding how they influence fuel economy. The relative influence, or the importance of such driving factors, can then be determined using appropriate methods. Thereafter, the interventions aimed at improving driver fuel economy such as driver training for fuel economy can then be improved by emphasising those driving factors which have the greatest influence on fuel economy.

This paper focusses on the determination of the relative importance of the driving factors which affects fuel economy. Thus, the factors which affect driving style for fuel economy were identified and categorised based on a review of the literature and an assessment of traditional driver training for fuel economy (that is, training that utilise intelligent driver-vehicle interface). The influences of the driving factors on fuel economy were then prioritised using a multi-criteria analysis (MCA) technique that combines both qualitative and quantitative methods called analytical hierarchy process (AHP) (Saaty, 1980).

2 Driving Style and Fuel Consumption

2.1 Driving Style

Driving style can be defined in terms of the way an individual chooses to drive or the driving habits that have become established over a period of time (years). The habits are related to speed, threshold for overtaking, headway, and the inclination to commit traffic violations. To facilitate an analysis of the driving styles of individuals or groups, French et al (1993) suggested the following six independent variables to classify driving style as summarised in Figure 1. Cacciabue and Carsten (2010) discuss the factors that influence driving style, also outlined in Figure 1.

Consequently, in order to improve or maximise the potential performance from a driver with regards to achieving certain goals like improvement in fuel economy and safer driving, some of the factors associated with the five categories above need to be changed or influenced to change. Clearly some of those parameters will be more difficult to change than others, but some can be influenced through, for example, various individual, group, community, company, national and international based initiatives summarised in Table 1. This study was focused on the driver feedback method and in particular driving factors associated with driver training.

2.2 Driver Training for Fuel Economy

The literature shows that driving styles have a strong influence on fuel economy, and that by training drivers to drive differently (i.e. by imparting specific driving skills), fuel economy can be improved (see for example, Siero et al, 1989; af Wåhlberg, 2007; Turpin and Scott, 2010). The initial work regarding the training of drivers in economical driving styles were primarily focussed on reducing the amount of vehicle fuel consumption (Siero et al, 1989) but more recently studies have addressed optimising training, for example, when the drivers return to their normal driving (af Wåhlberg, 2007). A summary of the most commonly used methods of driver training for fuel economy being practiced in the European Union, including documented improvement in fuel economy, is given in Table 2.

Most of the methods of training focus on four areas to improve performance, namely: (1) factors associated with the driver, (2) operating the vehicle, (3) vehicle dynamics and (4) awareness (af Wåhlberg, 2007; DfT, 2009). These areas can be further broken down as summarised in Table 3.

3 A Framework for Prioritising Driving Factors Affecting Fuel Economy

As discussed in the previous section, a comprehensive training system for driving for fuel economy may require a driver to be trained in a number of areas to improve performance (see Table 3). The influence of each of the driving attributes on vehicle fuel consumption is likely to vary by driver, vehicle, road type and the general driving environment or task. Even under similar driving conditions the influence of the attributes on fuel consumption can vary, therefore, by quantifying the relative influence of the attributes, driver training can be better informed so that appropriate focus can be given to the most influential factors. Furthermore, due to cost, time limitations and the skill sets or quality of the trainers, a system is required to identify and prioritise the most significant areas to focus any training for a particular driver or group of drivers for a given driving environment or task.

Prioritisation of the attributes required setting ranks or ratings of the importance in terms of fuel economy. Prioritisation exercises are usually challenging when there are conflicting and competing objectives and when there is lack of a consistent framework to measure the performance of the alternatives (or attributes) against the objectives (fuel economy) (Odoki et al, 2013). To address this, a framework has been developed (see Figure 2) which, utilizes, among other methods, expert knowledge, and consists of the elements described hereafter.

3.1 Description of the Framework

The proposed framework for prioritising the factors affecting fuel economy of drivers is divided into four components as described in the following sections.

3.1.1 Definition of the Driving Factors or Attributes

The influence of the driving factors or attributes on fuel economy for a particular driving environment or task can be defined using Equation 1.

Equation 1 $$\beta_0 = \sum_{i=1}^{N} (A \times TS)_i$$

Where, β_o is the overall influence of the driving factors or attributes on vehicle fuel economy, and can be independently assumed to be equal to the total influence of the driver training on fuel economy; A_i is the weight assigned to the driving attribute i based on its influence on fuel economy; and the sum of A_i is unity or 1; TS_i is an importance factor that can be associated to attribute i within the driving environment or task and N is the total number of the factors or attributes being considered.

3.1.2 Identification of the Factors

The factors can be identified from relevant literature and also through experimental tests where appropriate. In this study the driving factors were identified from existing literature and driver training specifications.

3.1.3 Algorithm

An algorithm can then be used to determine the influence of the factors on fuel economy. This can be achieved using expert knowledge, experimental tests or existing models which have been developed to predict the influence of the factors on fuel economy. Relevant methods like the multi-criteria analysis (MCA) and sensitivity analysis (SA) can be used to determine the relative influence of the factors on fuel economy.

3.1.4 Testing and Review

The prioritised list of the factors can then be applied to inform driver training for fuel economy. The results can be reviewed for potential improvement and similar needs.

3.2 Case Study

In order to demonstrate an application the proposed framework, a study was carried out based on expert knowledge (see method 1 in Figure 2) for reasons of costs and lack of existing models for predicting the influence of the driving factors on fuel economy. A multi-criteria analysis method called analytical hierarchy process (AHP) was used to determine the relative influence of the factors.

3.2.1 Analytical Hierarchy Process (AHP)

AHP is a multi-criteria analysis (MCA) technique that can combine qualitative and quantitative factors for prioritising, ranking and evaluating alternatives (Odoki et al, 2013). The method systematically transforms competing objectives to a series of simple “pairwise” comparisons (in this case driving factors or attributes) and uses these to generate the rankings (Saaty, 1980). Compared to similar MCA methods, the method does not require an explicit definition of trade-offs between the possible values of each attribute (that is, it is not necessary to build utility functions), and it allows users to understand the way in which outcomes are reached and how the weightings influence the outcomes (Odoki et al, 2013). AHP provides a framework for both qualitative and quantitative analysis which allow for the differences between attributes to be assessed. A certain degree of inconsistency is allowed in the method meaning that it does not allow for complete reliance on the decision maker's preference (Odoki et al, 2013).

3.2.2 Material Design and Procedure

The study consisted of sending 54 questionnaires to collect pair-wise comparisons information from driver trainers or instructors of the safe and fuel efficient driving (SAFED) programme in England. The questionnaire was developed using the principles of pair-wise comparisons (Saaty, 1980). The pair-wise comparisons were carried out for all the factors or attributes using the Saaty (1980) rating scale (1980) as shown in Table 4. Table 5 shows a typical pair-wise comparison using an optimised Saaty rating scale. This would mean that driving factor or attribute 1 (braking) is much more important than factor or attribute 2 (clutch control) in terms of fuel economy.

The experts (trainers) were identified through consultation with the Transport Research Laboratory (TRL) where the SAFED programme was developed (from 2003) and also where the initial training of trainers had been carried out. By 2009, several certified private training businesses were already established across England although many were facing economic difficulties due to the recession forcing several transportation businesses to close.

A total of 54 questionnaires were sent out to be completed by instructors working in 9 driver training offices identified in England in 2009. 36 completed questionnaires were received from the respondents.

The questionnaire asked the participants to rank the relative importance of the driving factors summarised in Table 3, in terms of their influence on fuel economy, using the Saaty (1980) rating scale. The collected data was used to produce a frequency table of pair-wise comparisons. The table was built from individual comparisons of the factors or attributes by each trainer or instructor based on the methodology described above.

3.3 Analysis and Results from Case Study

3.3.1 Matrix of Comparison

The rating value represented by the mode (or median where appropriate) for each of the attributes pair-wise comparisons represented the relative importance of each of the pair-wise comparisons in terms of fuel economy. A triangular matrix, illustrated by Figure 3, was generated using the following rules:

1. If the representative rating value was on the left side of the diagonal of the matrix containing 1s in Figure 3, the actual rating value was used; and,
2. If the representative rating value was on the right side of the diagonal of the matrix containing 1s in Figure 3, the reciprocal of the rating value was used.

The lower triangular matrix of comparison (C) was completed using the reciprocal values of the upper diagonal, that is, if a_{ij} is the element of row *i* and column *j* of the matrix, then the lower diagonal is completed using Equation 2.

Equation 2 $$a_{ji} = \frac{1}{a_{ij}}$$

The comparison matrix (C) was then used to model the relative influence of the driving factors or attributes which influence fuel economy as discussed below.

3.3.2 Priority Matrix

The matrix of comparison was used to produce the priority matrix (or vector of priorities). The priority vector was obtained by applying Equation 3 and Equation 4 (Saaty, 1980) which produces an approximation of an Eigen vector (and Eigen value) of a reciprocal matrix.

Equation 3 $$\mathrm{NM_{ij}} = \frac{\mathrm{RW_{ij}}}{\sum_{\mathrm{i=1}}^{\mathrm{N}}(\mathrm{RW})_{\mathrm{ij}}}$$

Where NM_{ij} is the normalised value of a matrix cell described by row *i*, and column *j*, RW_{ij} is the value of the hierarchy (or comparison) matrix cell described by row *i*, and column *j*, *N* is the number of elements of each row of the hierarchy (comparison) matrix (C), that is, the number of selected criteria (in this case the number of the factors).

Equation 4 $$\mathrm{W_i} = \frac{\sum_{\mathrm{j=1}}^{\mathrm{N}}(\mathrm{NM})_{\mathrm{ij}}}{\mathrm{N}}$$

Where, W_i is the value of the column or priority matrix cell described by row *i*; this is the vector of priorities summarised as Table 6.

The vectors of priorities represent the relative importance of the driving attributes in terms of their influence on fuel economy, that is, *Ai*, given in Equation 1. Therefore, the results show that acceleration (and speed) is judged by the experts consulted to have the highest influence on fuel economy and it is followed by culture change and management aspects while driver fatigue has the least influence.

3.3.3 Model Consistency

It is strongly recommended that consistency checks are carried out in AHP applications. According to Coyle (2004), if *N* elements are considered for comparison, C_1 … C_N and the relative 'weight' (or priority or significance) of *Ci* with respect to *Cj* is denoted by *aij* and form a square matrix $A = (a_{ij})$ of order *N* with the constraints that $a_{ij} = 1/a_{ji}$, for $i \neq j$, and $a_{ii} = 1$, for all *i*; such a matrix is said to be a reciprocal matrix. Although many authors (Saaty, 1980; Coyle, 2004) recommend *N*, the number of elements considered for comparison to be 7±2 for better consistency regarding the expert pair-wise choice, studies where values of *N* exceeded 10 have been documented. In such cases, the related eigenvector of the resulting matrix of comparison yields a measure for inconsistency. The degree of inconsistency is measured by the principal Eigen value, λmax of the matrix. Furthermore, if C is a pair-wise comparison matrix of size N, it is known that $\lambda max \geq N$ and C is consistent if and only if $\lambda max = N$. The quantity (λmax - N) gives the consistency. Normalizing by the size of the matrix, the consistency index (CIx) is defined by Equation 5.

Equation 5 $$\mathrm{CIx} = \frac{\lambda_{\mathrm{max}} - \mathrm{N}}{\mathrm{N} - 1}$$

Saaty (1980) showed that if the respondent or expert consistent then $CIx = 0$, however, if the referee is not absolutely consistent then $\lambda max > N$, and thus the need to measure the related level of inconsistency. For this purpose, Saaty (1980) defined the consistency ratio (CRa) shown by Equation 6.

Equation 6 $$\mathrm{CRa} = \frac{\mathrm{CIx}}{\mathrm{RIx}}$$

Where, *Rix* is the random consistency index (RI) average value of CIx random matrices using the Saaty scale (1980) obtained by Forman (1990) (Table 7).

Alonso and Lamata (2006) discuss the problem of accepting/rejecting matrices and in particular the relationship between the consistency and the scale used to represent the decision maker's judgements to which they developed an adaptable and simpler criterion of matrix acceptance. Their criterion is shown as Boolean function (F) given by Equation 7.

Equation 7 $$\mathrm{F} = (\lambda_{\mathrm{max}}, \phi)$$

Where, λmax is the measure of CI; ϕ is the level of consistency needed, and $0 < \phi \leq 1$. This level provides adaptability to different scopes (applications) as shown in Table 8 where $\phi = 0.10$ would represent Saaty's limit for acceptance.

For this study, λmax was computed as 19.41 and by using Table 8, with $N = 15$, the level of consistency of the model was evaluated as 0.20. Saaty (1980) recommends the revision of the hierarchy matrix (or matrices) used to compute the CIx of the model if the consistency is greater than 0.1, which would be the case in this analysis, say by possibly repeating the survey. However, Alonso and Lamata (2006) argue that the responses are usually taken from a wide range of persons (characteristics and knowledge) and therefore the specification of the level of the consistency needed to support various applications of the model is more important (see Equation 7 and Table 8). The latter view was taken for the model utilisation presented here in because of two main reasons, first, much literature regarding driver training for fuel economy shows that the it is still difficult to clearly assign the influence change in fuel consumption to a specific element or parameter related to driver behaviour (see for example, Siero et al, 1989; af Wåhlberg, 2007; Turpin and Scott, 2010), therefore, some level of variability should still be accommodated until when fine coarse data and models can predict these occurrences. Secondly, resource limitation, for example time and money needed to produce high quality results are usually limited.

3.4 Discussion

The results of the prioritisation study carried out show that the participants think that creating awareness regarding fuel economy would have the highest influence towards improving the driver MPG or fuel economy performance. In this case awareness indicated by culture change towards recognising the importance of better fuel economy and better management in a business or organisation. According to DfT (2008) the majority of driver development is about changing driver attitudes and behaviour which, in many instances, cannot be done by compulsion. The benefits of the driver development interventions have to be sold to the drivers. The second most influential category of the factors is the operation of the vehicle or vehicle control where, acceleration (and speed), as a driving factor or attribute, is considered by the experts to have the highest influence on fuel economy. High and long accelerations (both positive and negative) and high speeds have been reported to have high influence in increasing vehicle fuel consumption (Odoki and Akena, 2008). The literature instead suggests that effective use of accelerations can be transformed into useful torque with appropriate gear selections with better fuel economy results. The results also revealed that the driver-related factors (e.g. driver attitude and driver fatigue) were considered by the experts to have the least influence on driver fuel economy.

The influence of the driving factors or attributes on fuel economy could also be explained by the use of well-established mechanistic models for estimating fuel consumption, for example, the Australian Road Research Board (ARRB) Road Fuel Consumption Model (ARFCOM) for fuel consumption (Bennett and Greenwood, 2003). The principle is that fuel is consumed to overcome resistances to motion including aerodynamic drag, rolling, gradient, curvature and inertial resistances, while taking into consideration the influence of congestion and vehicle power/efficiency. Consequently, any driver action can be considered to influence these forces and, in the long run, fuel economy.

The literature shows that specific and comprehensive intelligent transport systems (ITS), involving improved driver-vehicle interface, is emerging as a way of improving driving goals like safety and fuel economy (see Manser et al 2010; ecoDriver, 2012; Cacciabue and Carsten, 2010) and much of the literature demonstrates the potential of the systems with regards to the goals. For example, a report by Manser et al (2010) regarding the use of fuel economy driver interface concept (FEDIC), a device that drivers could use to change driving behaviours to improve fuel economy, suggests that such interfaces could improve fuel economy by as much as 11%. Such systems could provide continuous driver feedback exceeding the effectiveness and efficiency of the traditional driver training like the SAFED.

3.5 Limitations and Further Work

The prioritisation study reported in this paper has limitations as follows: first, the size of the sample or participants is relatively small; this could be improved by increasing number of the participants. Secondly, the results of the prioritisation need to be validated. The validation could be carried out in driving simulators equipped with robust models of the driving or traffic environment or by training drivers to concentrate on particular factors or attributes at a time. The results of the prioritisation study reported in this paper have been used to develop a unique approach to driver training and have been tested with 94 drivers. The main aims of the study were to validate the results of the prioritisation exercise and to improve the effectiveness and efficiency of driver training for fuel economy for drivers involved in road network maintenance and operation. The result of the training has been reported separately from this paper by the same authors. In summary, the results show improvement in fuel economy (in terms of MPG) of about 6% for the heavy goods vehicle drivers, 7% for the medium duty vehicle drivers and 3% for the light duty vehicle drivers during the first month after the training.

4 Conclusion

There are several driving factors or attributes that affect fuel driver economy and the influences of these factors can vary among individual drivers or groups of drivers. In this research, a number of driving factors which affect fuel economy were identified based on existing literature and then prioritised using a multi-criteria analysis method called analytical hierarchy process (AHP) which utilized expert knowledge. For the case study considered herein, the key factors which have the highest influence on drivers' fuel economy were found to be creating awareness and operating the vehicle. By quantifying the relative influence of the factors on driver fuel economy using approaches such as that advocated herein, driver training for fuel economy can be improved by focusing the training on the most influential factors.

5 Acknowledgement

The authors express their gratitude for the support from the Royal Commission for the Exhibition of 1851 who, through its Industrial Fellowships programme, funded this research. The contribution of the School of Civil Engineering at the University of Birmingham is also acknowledged with gratitude. Many other individuals and organisations have supported the research, in particular colleagues at Amey Plc.

6 References

af Wåhlberg AE (2007). Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behavior and technical feedback. International Journal of Industrial Ergonomics, Vol. 37(4), pp. 333-343.

Alonso J and Lamata T (2006). Consistency in the analytic hierarchy process: a new approach. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 14, pp. 445-459.

Bennett CR and Greenwood ID (2003). Modelling road user and environmental effects. Highway Development and Management.HDM-4 Series of Publications. Vol. 7. World Bank, Washington DC, and PIARC, Paris, France.

Cacciabue PC and Carsten O (2010). A simple model of driver behaviour to sustain design and safety assessment of automated systems in automotive environments. Applied Ergonomics, Vol. 41(2), pp. 187-197.

Coyle G (2004). Practical strategy: structured tools and techniques. Pearson Education, England.

Department for Transport (DfT) (2008). Saving fuel through people: successful change management in road freight operations. Freight Best Practice Guide. HMSO.

Department for Transport (DfT) (2009). SAFED for HGVs: a guide to safe and fuel efficient driving for HGVs. Freight Best Practice Guide. HMSO.

EcoDriver (2012). EcoDriver project fact sheet. 7th EU Framework Programme: www.ecodriver-project.eu

Forman EH (1990). Random indices for incomplete pairwise comparison matrices. European Journal of Operational Research, Vol. 48, pp. 153-155.

French DJ, West RJ, Elander J and Wilding JM (1993). Decision-making style, driving style, and self-reported involvement in road traffic accidents. Ergonomics, Vol. 36, pp. 627-644.

Manser MP, Rakauskas M, Graving J & Jenness JW (2010). Fuel economy driver interfaces: develop interface recommendation. Report on Task 3. National Highway Traffic Safety: Technical Report (DOT HS 811 319).

Odoki JB and Akena R (2008). Energy balance framework for appraising road projects. ICE Transport, Vol. 161(1), pp. 23-35.

Odoki JB, Di Graziano A and Akena R (2013). A multi-criteria methodology for optimising road investments. The Proceedings of the ICE - Transport (Online): DOI: http://dx.doi.org/10.1680/tran.12.00045, pp. 1- 12.

Saaty TL (1980). The analytic hierarchy process. Mc Graw-Hill, New York.

Siero S, Boon M, Kok G and Siero F (1989). Modification of driving behavior in a large transport organization: a field experiment. Journal of Applied Psychology, Vol. 74(3), pp. 417-23.

Turpin M and Scott H (2010). Longevity of SAFED benefits study. Final Analysis Report, AECOM Limited, Cheshire, UK.

List of Tables

Table 1: Summary of methods of influencing driving style to improve fuel economy

Method	Example
Public education	• Media • Institutions
Driver feedback	• General advice to a driver • Driver training for fuel economy • Convention dashboards • Comprehensive driver-vehicles interface • Global Positioning System (GPS) • Smart phone applications • Offline fleet feedback systems
Regulatory measure	• Law including fuel economy or efficiency in driver or public education
Economic measure	• Demand • Supply • Prices
Social measure	• Campaigns
Combination of approaches	-

Table 2: Selected driver training for fuel economy in the European zone including the UK

Training	Principle	Method and Benefit
Driver certificate of professional competency (CPC)	The implementation of EU Directive 2003/59 requires all professional bus, coach and lorry drivers to hold a Driver CPC, in addition to their vocational driving licence (EU, 2003). An optional part of the driver CPC regard fuel economy which is similar in contents to the trainings below (SAFED and ecodriving)	Theory and practical sessions
Safe and fuel efficient driver (SAFED) training	Cover the following driving factors or attributes: • Driver factor • Operating the vehicle • Vehicle dynamics • Awareness Developed by the Department for Transport (DfT), UK	Theory and practical sessions. 4% to 8% for vans and about 2% for large vehicles over 6 months by Turpin and Scott (2010).
Ecodriving	Cover the following driving factors or attributes: • Acceleration; • Gear change; • Forward planning; • Braking; • Speeding and overtaking; • Awareness. Advised driving actions: 1. Anticipate traffic flow 2. Maintain a steady speed at low revolution per minute (RPM 3. Shift up early 4. Check tyre pressures frequently at least once a month and before driving at high speed 5. Consider any extra energy required costs fuel and money Developed and run at national and international levels in Europe	Theory and practical sessions. 7% for vans over 12 months by Siero et al (1989). 2% for buses over 12 months by af Wåhlberg (2007).

Table 3: Categorisation of driving factors or attributes linked to SAFED

Item	Category	Driving Attribute
1	Driver factors	Hazard awareness
		Driver attitude
		Driver fatigue
2	Operating the vehicle	Initial checks
		Acceleration and speed
		Braking
		Gear changes /selection
		Clutch control
		Forward planning
		Vehicle idling
3	Vehicle dynamics	Route planning
		Loads and loading pattern
		Adjustable aerodynamics and windows
4	Awareness	Culture change
		Management commitment

Table 4: Pair-wise rating scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other
5	Much more important	Experience and judgement strongly favour one over the other
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

Table 5: Pair-wise comparison of factors or attributes 1 and 2

	9	7	5	3	1	3	5	7	9	
Factor or attribute 1 (e.g braking)			X							Factor or attribute 2 (e.g clutch control)

Table 6: Vector of priorities or the relative importance of the attributes

Vector of Priorities		Attribute	Vector of Priorities	Relative Importance (%)
Item	Category			
1	Driver Factor	Hazard	0.035	3.5
		Driver Behaviour	0.050	5.0
		Driver Fatigue	0.014	1.4
2	Operating the Vehicle	Initial Checks	0.048	4.8
		Acceleration and Speed	0.149	14.9
		Braking	0.084	8.4
		Gear Changes /Selection	0.102	10.2
		Clutch Control	0.030	3.0
		Forward Planning	0.045	4.5
		Vehicle Idling	0.052	5.2
3	Vehicle Dynamics	Route Planning	0.052	5.2
		Loads and Loading Pattern	0.040	4.0
		Adjustable Aerodynamics and windows	0.027	2.7
4	Awareness	Culture Change	0.135	13.5
		Management	0.136	13.6
Total			1.00	100.0

Table 7: Random consistency index (RIx) (Forman, 1990)

N	1	2	3	4	5
RIx	0	0	0.58	0.9	1.12
N	6	7	8	9	10
RIx	1.24	1.32	1.41	1.45	1.49

Table 8: AHP model consistency parameter, λmax (Alonso and Lamata, 2006)

ϕ \ N	3	5	10	15	20	50	100	500
0.01	3.0096	5.0450	10.1335	15.2220	20.3104	50.8414	101.7264	508.8060
0.05	3.0478	5.2248	10.6673	16.1098	21.5523	54.2071	108.6319	544.0299
0.08	3.0765	5.3597	11.0677	16.7756	22.4836	56.7314	113.8110	570.4478
0.10	3.0957	5.4497	11.3346	17.2196	23.1045	58.4142	117.2637	588.0597
0.20	3.1913	5.8993	12.6692	19.4391	26.2090	66.8284	134.5274	676.1194
0.50	3.4784	7.2483	16.6730	26.0978	35.5225	92.0710	186.3185	940.2985

Figure 1 Click here to download Figure Figure-1-Variability.tif

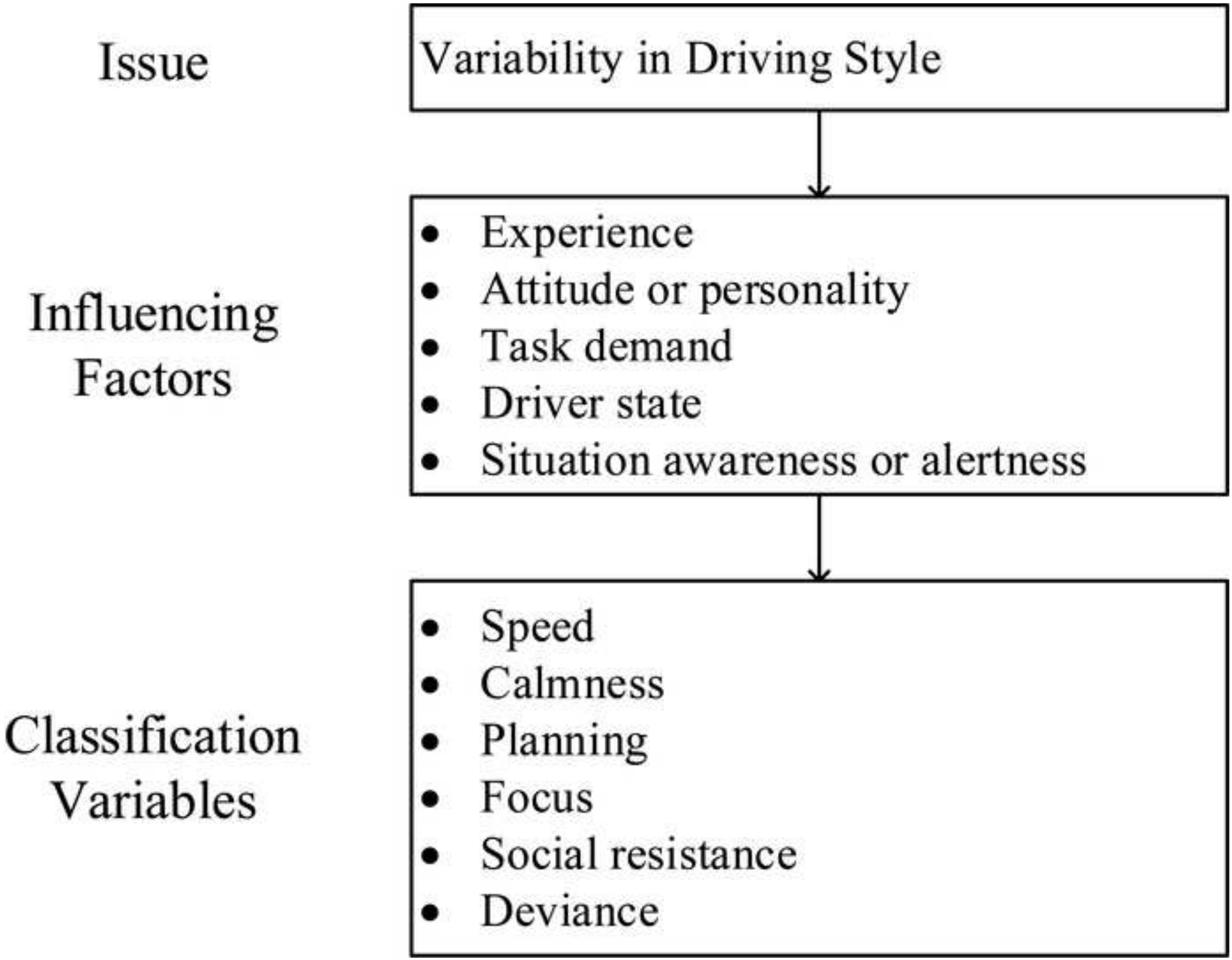
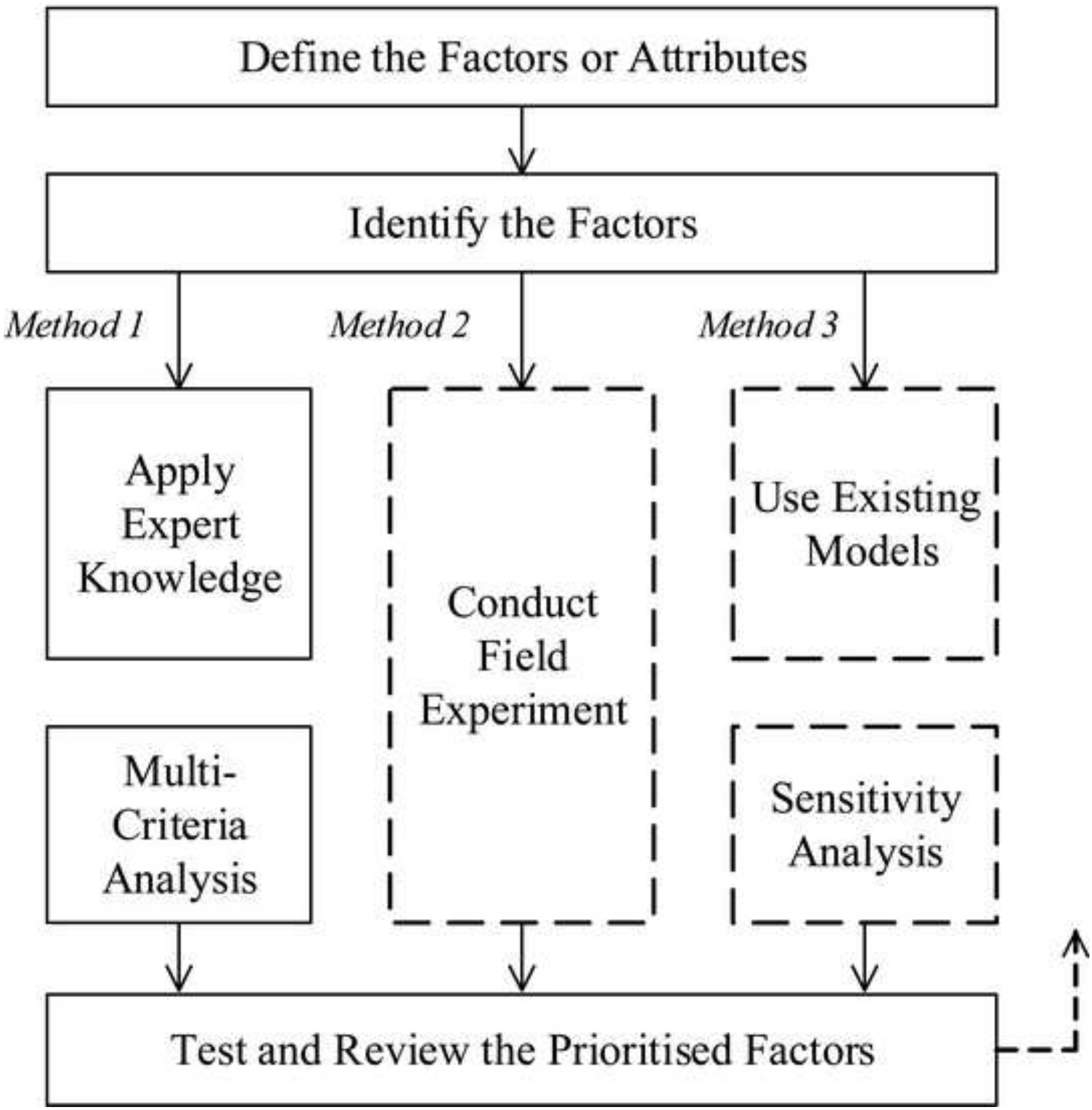


Figure 2


Define the Factors or Attributes
Identify the Factors
Method 1
Method 2
Method 3
Apply Expert Knowledge
Conduct Field Experiment
Use Existing Models
Multi-Criteria Analysis
Sensitivity Analysis
Test and Review the Prioritised Factors

$$\begin{array}{cc}
 & \begin{array}{ccccc} \text{Hazard} & \text{Driver Behaviour} & \text{Driver Fatigue} & \text{Initial Checks} & \vdots \end{array} \\
\begin{array}{c} \text{Hazard} \\ \text{Driver Behaviour} \\ \text{Driver Fatigue} \\ \text{Initial Checks} \\ \cdots \end{array} &
\begin{bmatrix}
1 & 1/3 & 3 & 1/2 & \cdots \\
 & 1 & 5 & 3 & \cdots \\
 & & 1 & 1/3 & \cdots \\
 & & & 1 & \cdots \\
 & & & & 1
\end{bmatrix}
\end{array}$$