

## Driving style for better fuel economy

Akena, Robert; Schmid, Felix; Burrow, Michael

DOI:

[10.1680/jtran.15.00116](https://doi.org/10.1680/jtran.15.00116)

License:

None: All rights reserved

*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Akena, R, Schmid, F & Burrow, M 2016, 'Driving style for better fuel economy', *Institution of Civil Engineers. Proceedings. Transport*. <https://doi.org/10.1680/jtran.15.00116>

[Link to publication on Research at Birmingham portal](#)

**Publisher Rights Statement:**

Final Version of Record available at: <http://dx.doi.org/10.1680/jtran.15.00116>

Checked for eligibility: 17/08/2016

**General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

**Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

# Transport

## Driving Style for Better Fuel Economy

--Manuscript Draft--

<b>Manuscript Number:</b>	
<b>Full Title:</b>	Driving Style for Better Fuel Economy
<b>Article Type:</b>	Paper
<b>Corresponding Author:</b>	Robert Akena, BSc(Eng), MSc, PhD Amey Birmingham, UNITED KINGDOM
<b>Corresponding Author Secondary Information:</b>	
<b>Corresponding Author's Institution:</b>	Amey
<b>Corresponding Author's Secondary Institution:</b>	
<b>First Author:</b>	Robert Akena, BSc(Eng), MSc, PhD
<b>First Author Secondary Information:</b>	
<b>Order of Authors:</b>	Robert Akena, BSc(Eng), MSc, PhD Felix Schmid, Dip. El. Ing. ETH, PhD Michael Burrow, MA (Cantab), PhD
<b>Order of Authors Secondary Information:</b>	
<b>Abstract:</b>	<p>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.</p>

# Driving Style for Better Fuel Economy

1  
2  
3  
4  
5  
6  
7 Dr Robert Akena (BSc(Eng), MSc, PhD, CEng)  
8 Network Asset Manager  
9 Amey  
10 Amey International Design Hub  
11 Colmore Plaza  
12 20 Colmore Circus  
13 Birmingham  
14 B4 6AT  
15 E-mail: robert.akena@amey.co.uk  
16  
17  
18

19  
20 Professor Felix Schmid (Dip. El. Ing. ETH, PhD)  
21 Centre for Railway Research and Education  
22 Gisbett Kapp Building  
23 University of Birmingham  
24 Edgbaston  
25 Birmingham  
26 B15 2TT  
27 UK  
28 f.schmid@bham.ac.uk  
29  
30  
31  
32

33 Dr Michael Burrow (MA (Cantab), PhD)  
34 Lecturer and Convenor of MSc Road Management and Engineering  
35 School of Civil Engineering  
36 University of Birmingham  
37 Edgbaston  
38 Birmingham  
39 B15 2TT  
40 UK  
41 E-mail: burrowmp@adf.bham.ac.uk  
42  
43  
44  
45  
46  
47  
48

## Keywords

49 Roads & highways, Fossil Fuels, Driving Style  
50  
51  
52

## Number of words

53 About 3,867 excluding references  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## Abstract

1  
2 Driving style has emerged as an important determinant of fuel economy. There is now  
3  
4 evidence that driving style can be influenced to improve fuel economy as well as other  
5  
6 aspects such as safety. However, it is not clear which are the most appropriate and influential  
7  
8 factors that affect an individual's, or a group's, driving style that with respect to improving  
9  
10 fuel economy. In this paper, such factors were identified from the literature and via driver  
11  
12 training programmes for fuel economy. The factors were then categorised under driver  
13  
14 factors, operating the vehicle, vehicle dynamics and driver awareness. The influences of the  
15  
16 factors on fuel economy were prioritised using a multi-criteria analysis (MCA) method called  
17  
18 the analytical hierarchy process (AHP) which utilized expert opinion to determine the relative  
19  
20 importance of the identified factors. It was found that driver awareness, measured in terms of  
21  
22 culture change and better management, was considered the most influential category. The  
23  
24 second most influential category of factors concerned operating the vehicle or vehicle control  
25  
26 where, acceleration and speed were found to have the highest influence on fuel economy in  
27  
28 the category. The driver-related factors were considered to have the least influence on fuel  
29  
30 economy by developing specific training modules which emphasise the most influential  
31  
32 driving factors.  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## Abbreviations

1		
2	AFRCOM	ARRB Fuel Consumption Model
3		
4	AHP	Analytical Hierarchy Process
5		
6	ARRB	Australian Road Research Board
7		
8	DfT	Department for Transport (UK)
9		
10	FEDIC	Fuel Economy Driver Interface Concept
11		
12	GPS	Global Positioning System
13		
14	HGV	Heavy Goods Vehicle
15		
16	ITS	Intelligent Transportation System
17		
18	MCA	Multi-Criteria Analysis
19		
20	MPG	Miles per Gallon
21		
22	PTT	Postal and Telecommunications Services
23		
24	SA	Sensitivity Analysis
25		
26	SAFED	Safe and Fuel-Efficient Driver Training
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
41		
42		
43		
44		
45		
46		
47		
48		
49		
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		
61		
62		
63		
64		
65		

## Equations

1		
2	$A_i$	is the weight assigned to the training attribute $i$ based on the influence of the
3		
4		attribute $i$ on fuel economy; and the sum of $A_i$ is unity or 1
5		
6	$a_{ij}$	is the element of row $i$ and column $j$ of the comparison matrix
7		
8	$CI_x$	the consistency index, a measure of the consistency of the respondents
9		
10	$CRA$	the consistency ratio
11		
12	$F$	is Boolean function
13		
14	$N$	is the number of elements of each row of the hierarchy (comparison) matrix,
15		that is, the number of selected criteria (factors).
16		
17	$NM_{ij}$	is the normalised value of matrix cell described by row $i$ , column $j$
18		
19	$Rix$	is the random consistency index (RI); average value of $CI_x$ random matrices
20		using the Saaty scale (1980) obtained by Forman (1990) (Table 7)
21		
22	$RW_{ij}$	is the value of the hierarchy (or comparison) matrix cell described by row $i$ ,
23		and column $j$
24		
25		
26	$TS_i$	is an importance factor that can be assigned to an attribute $i$ in a traffic system
27		or the driving environment
28		
29		
30	$W_i$	is the value of the column matrix cell described by row $i$
31		
32	$\beta_o$	is the overall influence of the driving factors or attributes on vehicle fuel
33		economy, and can independently be assumed as equal to the total influence of
34		driver training on fuel economy
35		
36		
37	$\lambda_{max}$	the principal Eigen value of the normalised matrix considered to be a measure
38		of the degree of inconsistency
39		
40	$\Phi$	is the level of consistency needed as used by Alonso and Lamata (2006)
41		
42		
43		
44		
45		
46		
47		
48		
49		
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		
61		
62		
63		
64		
65		

## 1 Introduction

1  
2 Driving style is known to affect many aspects of driver performance. For example, there  
3  
4 have been several studies relating driving style to safety (accidents), fuel consumption and  
5  
6 emissions, time saving, and vehicle wear and tear (af Wåhlberg, 2007; Turpin and Scott,  
7  
8 2010; French et al, 1993). Until recently studies regarding the influence of driving style on  
9  
10 road transportation have mainly been focussed on road safety where, real benefits have  
11  
12 been realised Cacciabue and Carsten (2010). Increasingly however, the potential benefits of  
13  
14 influencing driving style to improve fuel economy are being recognised (af Wåhlberg,  
15  
16 2007; Turpin and Scott, 2010; ecoDriver, 2013). Fuel consumption forms the biggest  
17  
18 component of total road transport energy requirement (that is, over 90% of the energy  
19  
20 requirement) based on the traditional fossil oils types for transport fuel (in particularly  
21  
22 diesel and petrol as ‘shale’ oil is still a much recent and not fully proven resource) (Odoki  
23  
24 and Akena, 2008).

25  
26 However, there is still limited knowledge regarding the driving factors which have the most  
27  
28 influence on fuel economy ecoDriver (2013). Such driving factors are those that a driver  
29  
30 could influence to improve vehicle fuel economy during driving. There is also limited  
31  
32 knowledge regarding the relative influences of these factors to meet the needs of different  
33  
34 interventions aimed at improving the relevant performances of the transport services, for  
35  
36 example, driver training for fuel economy. This means that such factors need to be  
37  
38 identified using a robust criterion which provides scientific explanations regarding how  
39  
40 they influence fuel economy. The relative influence, or the importance of such driving  
41  
42 factors, can then be determined using appropriate methods. Thereafter, the interventions  
43  
44 aimed at improving driver fuel economy such as driver training for fuel economy can then  
45  
46 be improved by emphasising those driving factors which have the greatest influence on fuel  
47  
48 economy.

49  
50 This paper focusses on the determination of the relative importance of the driving factors  
51  
52 which affects fuel economy. Thus, the factors which affect driving style for fuel economy  
53  
54 were identified and categorised based on a review of the literature and an assessment of  
55  
56 traditional driver training for fuel economy (that is, training that utilise intelligent driver-  
57  
58 vehicle interface). The influences of the driving factors on fuel economy were then  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

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.



1 Most of the methods of training focus on four areas to improve performance, namely: (1)  
2 factors associated with the driver, (2) operating the vehicle, (3) vehicle dynamics and (4)  
3 awareness (af Wählberg, 2007; DfT, 2009). These areas can be further broken down as  
4 summarised in Table 3.  
5  
6  
7

### 8 **3 A Framework for Prioritising Driving Factors Affecting Fuel** 9 **Economy**

10 As discussed in the previous section, a comprehensive training system for driving for fuel  
11 economy may require a driver to be trained in a number of areas to improve performance  
12 (see Table 3). The influence of each of the driving attributes on vehicle fuel consumption is  
13 likely to vary by driver, vehicle, road type and the general driving environment or task.  
14 Even under similar driving conditions the influence of the attributes on fuel consumption  
15 can vary, therefore, by quantifying the relative influence of the attributes, driver training  
16 can be better informed so that appropriate focus can be given to the most influential factors.  
17 Furthermore, due to cost, time limitations and the skill sets or quality of the trainers, a  
18 system is required to identify and prioritise the most significant areas to focus any training  
19 for a particular driver or group of drivers for a given driving environment or task.  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31

32  
33  
34 Prioritisation of the attributes required setting ranks or ratings of the importance in terms of  
35 fuel economy. Prioritisation exercises are usually challenging when there are conflicting  
36 and competing objectives and when there is lack of a consistent framework to measure the  
37 performance of the alternatives (or attributes) against the objectives (fuel economy) (Odoki  
38 et al, 2013). To address this, a framework has been developed (see Figure 2) which,  
39 utilizes, among other methods, expert knowledge, and consists of the elements described  
40 hereafter.  
41  
42  
43  
44  
45  
46  
47  
48

#### 49 **3.1 Description of the Framework**

50  
51  
52 The proposed framework for prioritising the factors affecting fuel economy of drivers is  
53 divided into four components as described in the following sections.  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

### 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,  $\beta_0$  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

1 existing models for predicting the influence of the driving factors on fuel economy. A  
2 multi-criteria analysis method called analytical hierarchy process (AHP) was used to  
3 determine the relative influence of the factors.  
4  
5

### 6 7 *3.2.1 Analytical Hierarchy Process (AHP)* 8

9 AHP is a multi-criteria analysis (MCA) technique that can combine qualitative and  
10 quantitative factors for prioritising, ranking and evaluating alternatives (Odoki et al, 2013).  
11 The method systematically transforms competing objectives to a series of simple  
12 “pairwise” comparisons (in this case driving factors or attributes) and uses these to generate  
13 the rankings (Saaty, 1980). Compared to similar MCA methods, the method does not  
14 require an explicit definition of trade-offs between the possible values of each attribute  
15 (that is, it is not necessary to build utility functions), and it allows users to understand the  
16 way in which outcomes are reached and how the weightings influence the outcomes (Odoki  
17 et al, 2013). AHP provides a framework for both qualitative and quantitative analysis  
18 which allow for the differences between attributes to be assessed. A certain degree of  
19 inconsistency is allowed in the method meaning that it does not allow for complete reliance  
20 on the decision maker's preference (Odoki et al, 2013).  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31

### 32 33 *3.2.2 Material Design and Procedure* 34

35 The study consisted of sending 54 questionnaires to collect pair-wise comparisons  
36 information from driver trainers or instructors of the safe and fuel efficient driving  
37 (SAFED) programme in England. The questionnaire was developed using the principles of  
38 pair-wise comparisons (Saaty, 1980). The pair-wise comparisons were carried out for all  
39 the factors or attributes using the Saaty (1980) rating scale (1980) as shown in Table 4.  
40 Table 5 shows a typical pair-wise comparison using an optimised Saaty rating scale. This  
41 would mean that driving factor or attribute 1 (braking) is much more important than factor  
42 or attribute 2 (clutch control) in terms of fuel economy.  
43  
44  
45  
46  
47  
48  
49  
50

51 The experts (trainers) were identified through consultation with the Transport Research  
52 Laboratory (TRL) where the SAFED programme was developed (from 2003) and also  
53 where the initial training of trainers had been carried out. By 2009, several certified private  
54 training businesses were already established across England although many were facing  
55 economic difficulties due to the recession forcing several transportation businesses to close.  
56  
57  
58  
59  
60  
61

1 A total of 54 questionnaires were sent out to be completed by instructors working in 9  
2 driver training offices identified in England in 2009. 36 completed questionnaires were  
3 received from the respondents.  
4

5  
6  
7 The questionnaire asked the participants to rank the relative importance of the driving  
8 factors summarised in Table 3, in terms of their influence on fuel economy, using the Saaty  
9 (1980) rating scale. The collected data was used to produce a frequency table of pair-wise  
10 comparisons. The table was built from individual comparisons of the factors or attributes  
11 by each trainer or instructor based on the methodology described above.  
12  
13  
14  
15  
16

### 17 3.3 Analysis and Results from Case Study

#### 18 3.3.1 Matrix of Comparison

19  
20  
21 The rating value represented by the mode (or median where appropriate) for each of the  
22 attributes pair-wise comparisons represented the relative importance of each of the pair-  
23 wise comparisons in terms of fuel economy. A triangular matrix, illustrated by Figure 3,  
24 was generated using the following rules:  
25  
26  
27  
28  
29  
30

- 31 1. If the representative rating value was on the left side of the diagonal of the matrix  
32 containing 1s in Figure 3, the actual rating value was used; and,  
33
- 34 2. If the representative rating value was on the right side of the diagonal of the matrix  
35 containing 1s in Figure 3, the reciprocal of the rating value was used.  
36  
37  
38  
39

40 The lower triangular matrix of comparison (C) was completed using the reciprocal values  
41 of the upper diagonal, that is, if  $a_{ij}$  is the element of row  $i$  and column  $j$  of the matrix, then  
42 the lower diagonal is completed using Equation 2.  
43  
44  
45  
46

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

48  
49  
50  
51 The comparison matrix (C) was then used to model the relative influence of the driving  
52 factors or attributes which influence fuel economy as discussed below.  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

### 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.

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

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).

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

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,  $A_i$ , 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,  $C_1 \dots C_N$  and the relative 'weight' (or priority or significance) of  $C_i$  with respect to  $C_j$  is denoted by  $a_{ij}$  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  $7 \pm 2$  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,  $\lambda_{max}$  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  $(\lambda_{max} - N)$  gives the consistency. Normalizing by the size of the matrix, the consistency index (CIx) is defined by Equation 5.

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

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.

$$\text{Equation 6} \quad \text{CRa} = \frac{\text{CIx}}{\text{RIx}}$$

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.

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

Where,  $\lambda_{max}$  is the measure of CI;  $\phi$  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,  $\lambda_{max}$  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

1 is greater than 0.1, which would be the case in this analysis, say by possibly repeating the  
2 survey. However, Alonso and Lamata (2006) argue that the responses are usually taken  
3 from a wide range of persons (characteristics and knowledge) and therefore the  
4 specification of the level of the consistency needed to support various applications of the  
5 model is more important (see Equation 7 and Table 8). The latter view was taken for the  
6 model utilisation presented here in because of two main reasons, first, much literature  
7 regarding driver training for fuel economy shows that it is still difficult to clearly assign  
8 the influence change in fuel consumption to a specific element or parameter related to  
9 driver behaviour (see for example, Siero et al, 1989; af Wählberg, 2007; Turpin and Scott,  
10 2010), therefore, some level of variability should still be accommodated until when fine  
11 coarse data and models can predict these occurrences. Secondly, resource limitation, for  
12 example time and money needed to produce high quality results are usually limited.  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

### 24 3.4 Discussion

25  
26  
27 The results of the prioritisation study carried out show that the participants think that  
28 creating awareness regarding fuel economy would have the highest influence towards  
29 improving the driver MPG or fuel economy performance. In this case awareness indicated  
30 by culture change towards recognising the importance of better fuel economy and better  
31 management in a business or organisation. According to DfT (2008) the majority of driver  
32 development is about changing driver attitudes and behaviour which, in many instances,  
33 cannot be done by compulsion. The benefits of the driver development interventions have  
34 to be sold to the drivers. The second most influential category of the factors is the operation  
35 of the vehicle or vehicle control where, acceleration (and speed), as a driving factor or  
36 attribute, is considered by the experts to have the highest influence on fuel economy. High  
37 and long accelerations (both positive and negative) and high speeds have been reported to  
38 have high influence in increasing vehicle fuel consumption (Odoki and Akena, 2008). The  
39 literature instead suggests that effective use of accelerations can be transformed into useful  
40 torque with appropriate gear selections with better fuel economy results. The results also  
41 revealed that the driver-related factors (e.g. driver attitude and driver fatigue) were  
42 considered by the experts to have the least influence on driver fuel economy.  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57

58 The influence of the driving factors or attributes on fuel economy could also be explained  
59 by the use of well-established mechanistic models for estimating fuel consumption, for  
60  
61  
62  
63  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

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

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

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

- 1  
2 af Wählberg AE (2007). Long-term effects of training in economical driving: Fuel  
3 consumption, accidents, driver acceleration behavior and technical feedback. *International*  
4 *Journal of Industrial Ergonomics*, Vol. 37(4), pp. 333-343.  
5  
6 Alonso J and Lamata T (2006). Consistency in the analytic hierarchy process: a new  
7 approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*,  
8 14, pp. 445-459.  
9  
10 Bennett CR and Greenwood ID (2003). Modelling road user and environmental effects.  
11 *Highway Development and Management.HDM-4 Series of Publications*. Vol. 7. World  
12 Bank, Washington DC, and PIARC, Paris, France.  
13  
14 Cacciabue PC and Carsten O (2010). A simple model of driver behaviour to sustain design  
15 and safety assessment of automated systems in automotive environments. *Applied*  
16 *Ergonomics*, Vol. 41(2), pp. 187-197.  
17  
18 Coyle G (2004). *Practical strategy: structured tools and techniques*. Pearson Education,  
19 England.  
20  
21 Department for Transport (DfT) (2008). *Saving fuel through people: successful change*  
22 *management in road freight operations*. Freight Best Practice Guide. HMSO.  
23  
24 Department for Transport (DfT) (2009). *SAFED for HGVs: a guide to safe and fuel*  
25 *efficient driving for HGVs*. Freight Best Practice Guide. HMSO.  
26  
27 EcoDriver (2012). *EcoDriver project fact sheet*. 7th EU Framework Programme:  
28 [www.ecodriver-project.eu](http://www.ecodriver-project.eu)  
29  
30 Forman EH (1990). Random indices for incomplete pairwise comparison matrices.  
31 *European Journal of Operational Research*, Vol. 48, pp. 153-155.  
32  
33 French DJ, West RJ, Elander J and Wilding JM (1993). Decision-making style, driving  
34 style, and self-reported involvement in road traffic accidents. *Ergonomics*, Vol. 36, pp.  
35 627-644.  
36  
37 Manser MP, Rakauskas M, Graving J & Jenness JW (2010). *Fuel economy driver*  
38 *interfaces: develop interface recommendation*. Report on Task 3. National Highway Traffic  
39 *Safety: Technical Report (DOT HS 811 319)*.  
40  
41 Odoki JB and Akena R (2008). *Energy balance framework for appraising road projects*.  
42 *ICE Transport*, Vol. 161(1), pp. 23-35.  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 Odoki JB, Di Graziano A and Akena R (2013). A multi-criteria methodology for  
2 optimising road investments. The Proceedings of the ICE - Transport (Online): DOI:  
3 <http://dx.doi.org/10.1680/tran.12.00045>, pp. 1- 12.  
4

5 Saaty TL (1980). The analytic hierarchy process. Mc Graw-Hill, New York.  
6

7 Siero S, Boon M, Kok G and Siero F (1989). Modification of driving behavior in a large  
8 transport organization: a field experiment. Journal of Applied Psychology, Vol. 74(3), pp.  
9 417-23.  
10

11 Turpin M and Scott H (2010). Longevity of SAFED benefits study. Final Analysis Report,  
12 AECOM Limited, Cheshire, UK.  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## List of Tables

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

Method	Example
Public education	<ul style="list-style-type: none"> <li>• Media</li> <li>• Institutions</li> </ul>
Driver feedback	<ul style="list-style-type: none"> <li>• General advice to a driver</li> <li>• Driver training for fuel economy</li> <li>• Conventional dashboards</li> <li>• Comprehensive driver-vehicles interface</li> <li>• Global Positioning System (GPS)</li> <li>• Smart phone applications</li> <li>• Offline fleet feedback systems</li> </ul>
Regulatory measure	<ul style="list-style-type: none"> <li>• Law including fuel economy or efficiency in driver or public education</li> </ul>
Economic measure	<ul style="list-style-type: none"> <li>• Demand</li> <li>• Supply</li> <li>• Prices</li> </ul>
Social measure	<ul style="list-style-type: none"> <li>• Campaigns</li> </ul>
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	<p>Cover the following driving factors or attributes:</p> <ul style="list-style-type: none"> <li>• Driver factor</li> <li>• Operating the vehicle</li> <li>• Vehicle dynamics</li> <li>• Awareness</li> </ul> <p>Developed by the Department for Transport (DfT), UK</p>	<p>Theory and practical sessions.</p> <p>4% to 8% for vans and about 2% for large vehicles over 6 months by Turpin and Scott (2010).</p>
Ecodriving	<p>Cover the following driving factors or attributes:</p> <ul style="list-style-type: none"> <li>• Acceleration;</li> <li>• Gear change;</li> <li>• Forward planning;</li> <li>• Braking;</li> <li>• Speeding and overtaking;</li> <li>• Awareness.</li> </ul> <p>Advised driving actions:</p> <ol style="list-style-type: none"> <li>1. Anticipate traffic flow</li> <li>2. Maintain a steady speed at low revolution per minute (RPM)</li> <li>3. Shift up early</li> <li>4. Check tyre pressures frequently at least once a month and before driving at high speed</li> <li>5. Consider any extra energy required costs fuel and money</li> </ol> <p>Developed and run at national and international levels in Europe</p>	<p>Theory and practical sessions.</p> <p>7% for vans over 12 months by Siero et al (1989). 2% for buses over 12 months by af Wählberg (2007).</p>

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

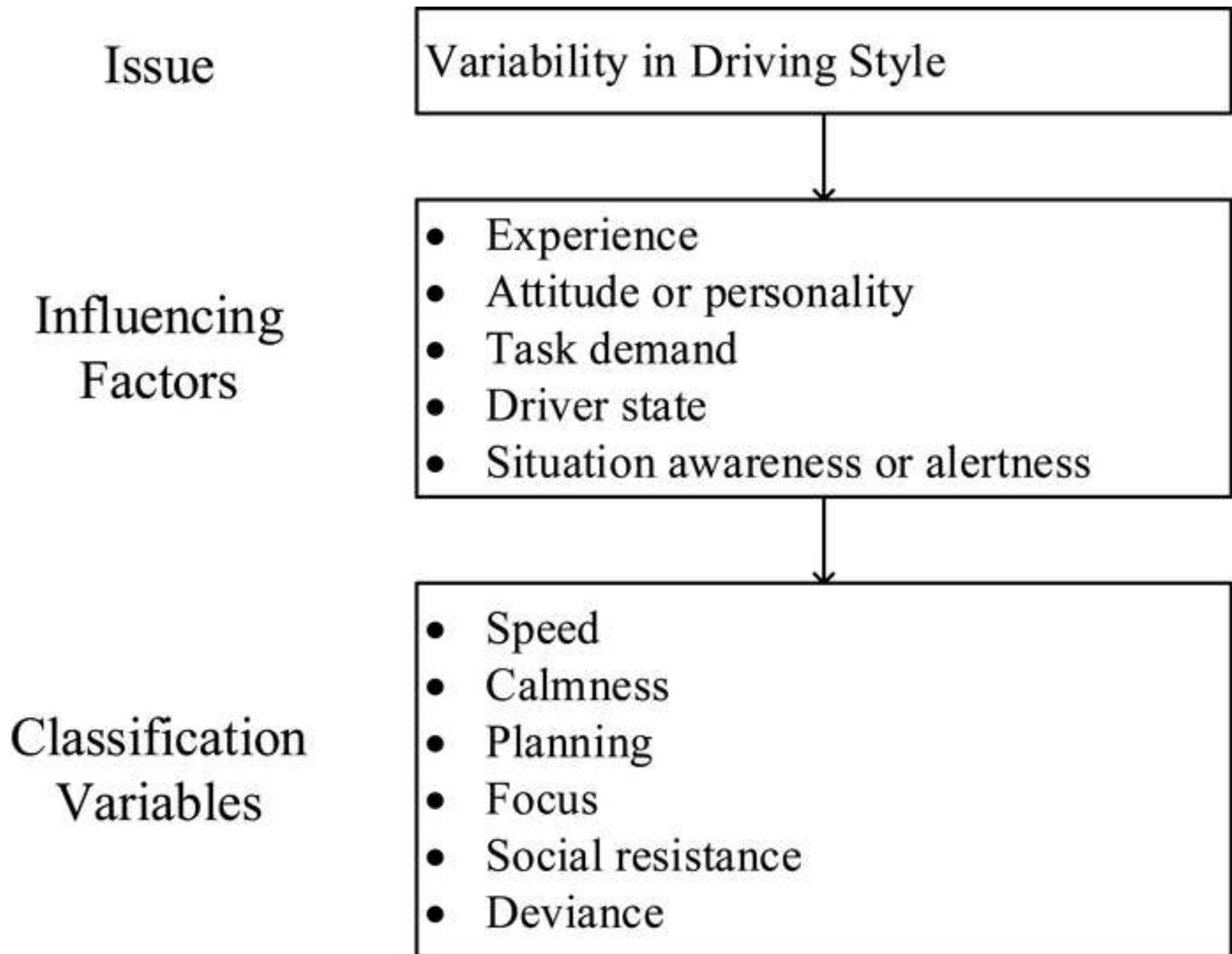
Table 7: Random consistency index (RIx) (Forman, 1990)

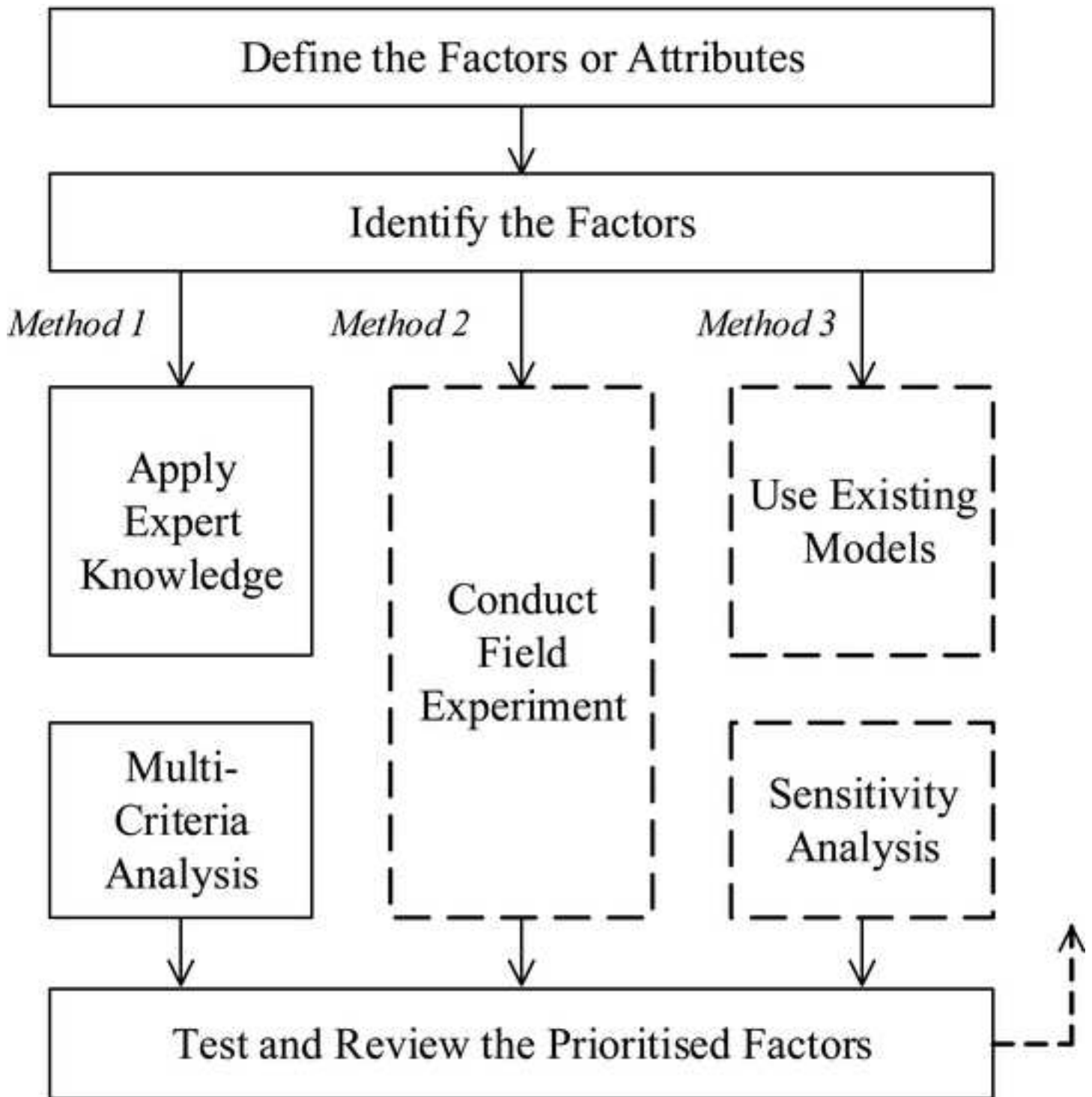
N	1	2	3	4	5
RIx	0	0	0.58	0.9	1.12
N	6	7	8	9	10
RIx	1.24	1.32	1.41	1.45	1.49

Table 8: AHP model consistency parameter,  $\lambda_{\max}$  (Alonso and Lamata, 2006)

$\phi \backslash N$	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







	Hazard	Driver Behaviour	Driver Fatigue	Initial Checks	...
Hazard	1	1/3	3	1/2	...
Driver Behaviour		1	5	3	...
Driver Fatigue			1	1/3	...
Initial Checks				1	...
...					1