FUEL SAVING INTERVENTIONS: FACTS AND FICTION

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ABSTRACT

This paper introduces the need for improving the fuel efficiency of large goods vehicles (LGVs) and discusses the findings of research currently being undertaken at the University of Huddersfield in this field. A framework for categorising interventions is suggested and an evaluation is made as to their likely success. Interventions are sensitive to many variables and an example of how research findings into the variables and their degree of sensitivity for one specific intervention is introduced. The findings of the research are then taken into account to enable the production of accurate test plans.

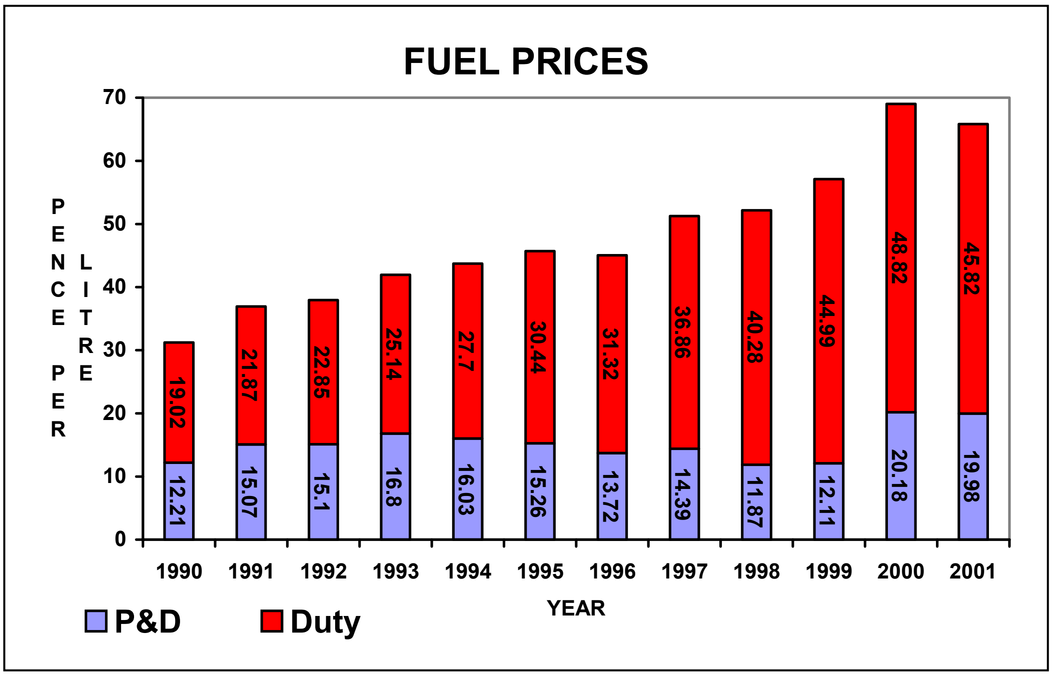
INTRODUCTION

The world's supply of oil is finite. Burning it in an internal combustion engine produces harmful emissions. The cost to transport operators of burning fuel is substantial and for many transport operators fuel is their highest cost. Against this background there is a small but growing industry selling interventions that claim to either improve fuel efficiency, reduce emissions or both. A fuel saving intervention is a product or service that claims to improve the fuel efficiency of a vehicle or fleet of vehicles. With over 100 fuel saving interventions on sale in the UK, the purpose of this paper is to help operators and their staff to differentiate between those that work and those that don’t. In other words, to help them distinguish between fact and fiction.

FUEL COSTS

The largest influence on fuel cost is not the producers and distributors (P&D) element but duty. The effect of duty on the price of diesel is shown in Chart 1. The data refers to the ex-VAT price of fuel every April. In 1990 duty represented 64.17% of the price. Eleven years later in April 2001, duty represented 69.64%, having peaked at 80.57% in April 1999.

Chart 1 UK diesel prices (excluding VAT)



Note: Duty from April 2000 refers to ULSD.

The cumulative effect of the fuel duty escalator, introduced in March 1993 can be seen as the upper sections of the bars in the chart increase in size. It could be argued that reductions in the price of crude oil and the costs of producers and distributors (P&D) were used by the Government to increase the duty levels to ensure a continual rise in the price of diesel.

In terms of costs a 38 tonne LGV travelling an annual distance of 160,000 kilometres (99,419 miles) and achieving an average fuel consumption of 8.4 miles per gallon (MPG) will use 53,806 litres (11,836 gallons) of diesel. This cost - immediately after the March 2001 budget - £35,404, assuming a bulk purchase price of £2.99 per gallon (65.8 pence per litre, excluding VAT).

From this analysis, it is clear that increasing the fuel efficiency of an LGV will reduce the pollutants emitted by such a vehicle and reduce the fuel bill incurred by fleet operators. Based on the figures in the previous paragraph, a ten-percent improvement in MPG would save £ 3,192 in the first year. It would also save 4,852 litres (1,067 gallons) of fuel and give an associated reduction in pollutants. Table 1 shows the costs of operating a 38 tonne unit. It can be seen that fuel costs are the most expensive although as a proportion of total costs they fall as the annual distance reduces.

Table 1 Annual operating costs (UK) for a 4 x 2 articulated unit

		% of annual operating costs
Capital Cost £	44,000	
Annual distance km	160,000	
Ownership period (years)	5	
Fuel consumption MPG	8.4	
Standing Costs		
Overheads £	9,487	12.10%
Vehicle Excise Duty £	1,200	1.53%
Insurance £	2,923	3.73%
Depreciation £	7,250	9.25%
Finance 5 years £	1,936	2.47%
Drivers £	27,047	34.50%
Standing costs per year £	49,843	
Standing costs per km £	0.312	
Running costs		
Fuel & Oil £	30,945	39.48%
Tyres £	995	1.27%
Maintenance £	4,547	5.80%
Total running costs per km £	0.228	
Total operating cost per year £	86,330	100.00%
Total operating cost per km £	0.54	

Source: Wilcox (2002)

For different types and configurations of vehicles, these costs will differ. For example, vehicles that operate at lower weights will have a better fuel consumption. Consequently, fuel costs may well be below that of driver costs. Using the Motor Transport Cost Tables for February 1996, February 1997, February 1998, February 1999 and February 2000 it is possible to show the impact of rising fuel costs on the total operating cost of a vehicle.

Table 2 shows the impact on a vehicle operating at a Gross Vehicle Weight (GVW) of 17 tonnes.

Table 2 Trend in costs for a 17 tonne rigid vehicle (1996 - 2000)

	1996	1997	1998	1999	2000
Standing costs (£/year)	33,654	34,668	36,069	33,853	34,445
Running costs (£/mile)	0.3771	0.3586	0.3642	0.3655	0.4138
of which fuel costs (£/mile)	0.2198	0.2181	0.2236	0.2263	0.2738
Fuel costs as % of operating cost					
60,000 miles p.a.	23.4	23.3	23.2	24.3	27.7
80,000 miles p.a.	27.6	27.5	27.4	28.7	32.4
100,000 miles p.a.	30.8	30.9	30.8	32.1	36.1
120,000 miles p.a.	33.4	33.7	33.6	34.9	39.1

Source Whiteing, Coyle and Bamford (2002)

It can be seen in Table 2 that standing costs have risen over the period by £791 (2.35%), running costs by £0.0367 per mile (9.73%) and fuel as a percentage of running costs has increased by 24.57%. Similarly in Table 3 which relates to 32.5 tonne articulated vehicles, standing costs have risen over the period by £2,642 (6.60%), running costs by £0.0915 per mile (21.54%) and fuel as a percentage of running costs has increased by 37.10%.

Table 3 Trend in costs for a 32.5 tonne articulated vehicle (1996 - 2000)

	1996	1997	1998	1999	2000
Standing costs (£/year)	40,015	42,784	43,411	41,676	42,657
Running costs (£/mile)	0.4247	0.4458	0.453	0.4538	0.5162
of which fuel costs (£/mile)	0.2585	0.2822	0.2893	0.2928	0.3544
Fuel costs as % of operating cost					
60,000 miles p.a.	23.7	24.4	24.6	25.5	28.9
80,000 miles p.a.	27.9	28.8	29.1	30.0	33.8
100,000 miles p.a.	31.3	32.3	32.6	33.6	37.6
120,000 miles p.a.	34.1	35.2	35.5	36.5	40.7

Source Whiteing, Coyle and Bamford (2002)

There was a reduction in standing costs between 1998 and 1999 due to the lower list prices for new vehicles. This will have impacted on the rest of the costs by increasing their percentage of the total cost (assuming they remained constant in absolute terms). The implication of this is that even if there had been no increase in the price of DERV, as a percentage its share would have risen. For large fleets who have considerable purchasing power and can command large discounts from truck manufacturers the percentage of total operating costs attributable to fuel can be even greater.

ENVIRONMENTAL ISSUES

Environmental issues have raised their profile in recent years. Individuals might not know how they personally are affected by emissions from vehicle exhausts but it has been suggested that the effect upon peoples' health, due to emissions from road transport, costs the country £1,500,000,000 per annum (Environment Agency, 1998). Against a background of a forecast increase in road traffic and emissions the Government is concerned and wishes to reduce this effect (McDonnell, 1999). Engines do produce harmful emissions. A description of these emissions and their effects is given in Table 4.

Table 4 Major pollutants and their effects

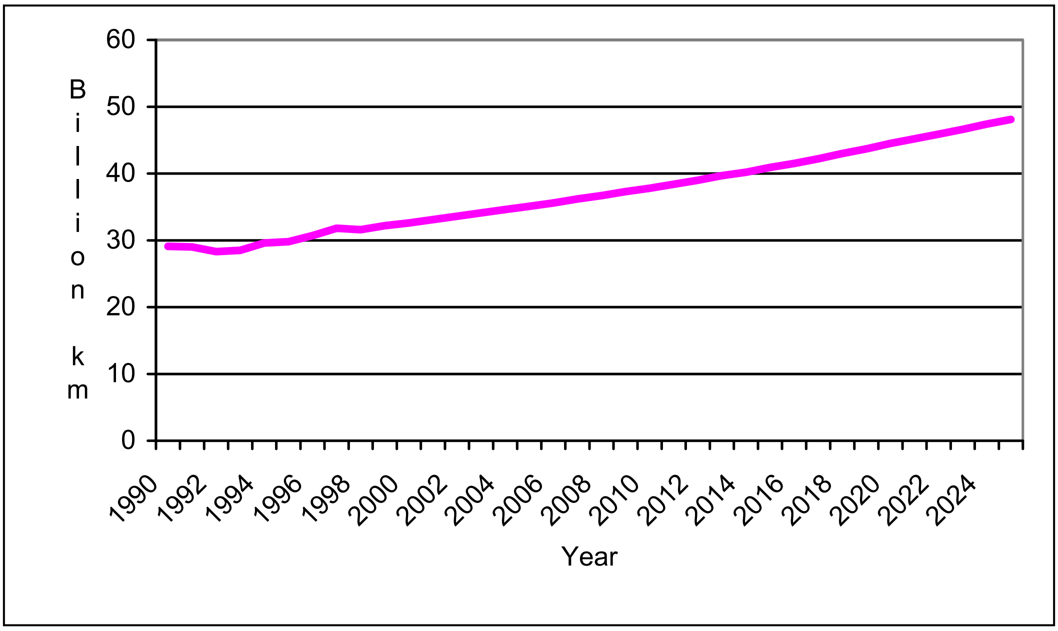
POLLUTANT	EFFECT
CARBON MONOXIDE (CO)	Produced by incomplete combustion of carbon, mainly from fossil fuels. Road vehicles account for 90% of emissions in the UK. CO is responsible for the production of Carboxyhaemoglobin (COHb) in the blood, which impairs delivery of oxygen to the heart, brain and other tissue.
OXIDES OF NITROGEN (NOx)	Road transport is the main source of nitric oxides, which account for 51% of total emissions, of this nitrogen dioxide (NO_2) injures the smallest air passages of the lung and increases susceptibility to respiratory infections. Low exposures of NO_2 may trigger asthma
NITRIC OXIDE	Included in these is nitrous oxide, estimated to be 250 times more powerful than CO_2 as a greenhouse gas.
BENZENE	This is one of a large number of aromatic hydrocarbons. Exposure to benzene can cause irritation to the skin, eyes and upper respiratory tract. Further exposure can cause depression, headaches, dizziness and nausea. The World Health Organisation states “no safe level for airborne benzene can be recommended as benzene is carcinogenic to humans and there is no known safe threshold level”.
CARBON DIOXIDE (CO_2)	Another by product of burning fossil fuels and accounts for an estimated 50% of global warming, of which 20% is derived from motor vehicles.
PARTICULATES (PM)	These are emitted by diesel engines and are believed to carcinogenic.

There is the dilemma of people wanting mobility and the freedom that goes with mobility and the impact upon society as a whole of emissions from vehicles that give mobility. Similarly whilst people may consider LGVs to be smelly, dirty and obtrusive they want products delivered by such vehicles on the shelves and in the refrigerators when they go shopping.

To reduce the amount of emissions (unburned hydrocarbons, oxides of nitrogen, carbon monoxide and particulates) produced by diesel engines, a series of regulations have been introduced. These regulations, known as ‘Euro’ standards, are steadily reducing the permitted quantity of emissions from new vehicles. In environmental terms a modern diesel engine with an efficient combustion process will produce 2.6 tonnes of carbon dioxide plus other emissions for every 1,000 litres of fuel burned. Any improvement in fuel consumption clearly has major environmental benefits, by helping to reduce the level of all emissions. In 1999, ultra low sulphur diesel (ULSD) became available with a lower rate of duty. In 2000, standard diesel was all but completely replaced by ULSD. Many operators complained that when they switched to ULSD their fuel consumption deteriorated due to lower density and hence energy content of ULSD.

From October 2001, all new LGVs must be equipped with engines that meet the EURO 3 emission standards. Whilst EURO 3 engines will reduce some emissions, it was originally suggested that they would reduce fuel efficiency by 8% (Grace, 1997). More recent estimates suggest that the reduction in efficiency will be in the range of 0% to 3% (Phillips, 1999). The implication of this for vehicle operators was that fuel bills would increase further and more carbon dioxide will be produced due to the reduction in MPG. Operators were faced with increased fuel bills because they would be buying engines which were less fuel-efficient, and a fuel that had a lower energy content. Additionally, as shown in Chart 2 there is an actual and forecast growing trend in LGV kilometres. The result of these combined factors is a potential increase in carbon dioxide.

Chart 2 Forecast billion kilometres (LGV) 1990 – 2025



Source: McDonnell (1999)

Any intervention that increases fuel efficiency will clearly reduce the environmental impact of a vehicle. With the high cost of fuel in the UK, a successful intervention could, depending upon the cost of the intervention, reduce operating costs.

The key question for those responsible for the fuel bill is - which interventions will work for me?

FUEL SAVING INTERVENTIONS

There are three key performance indicators (KPIs) relating to fuel efficiency:

- Reducing total distance travelled such as through improved routing and scheduling
- Reducing total fuel used to move goods, such as through the use of double deck trailers
- Improving fuel consumption measured by MPG for example through driver training

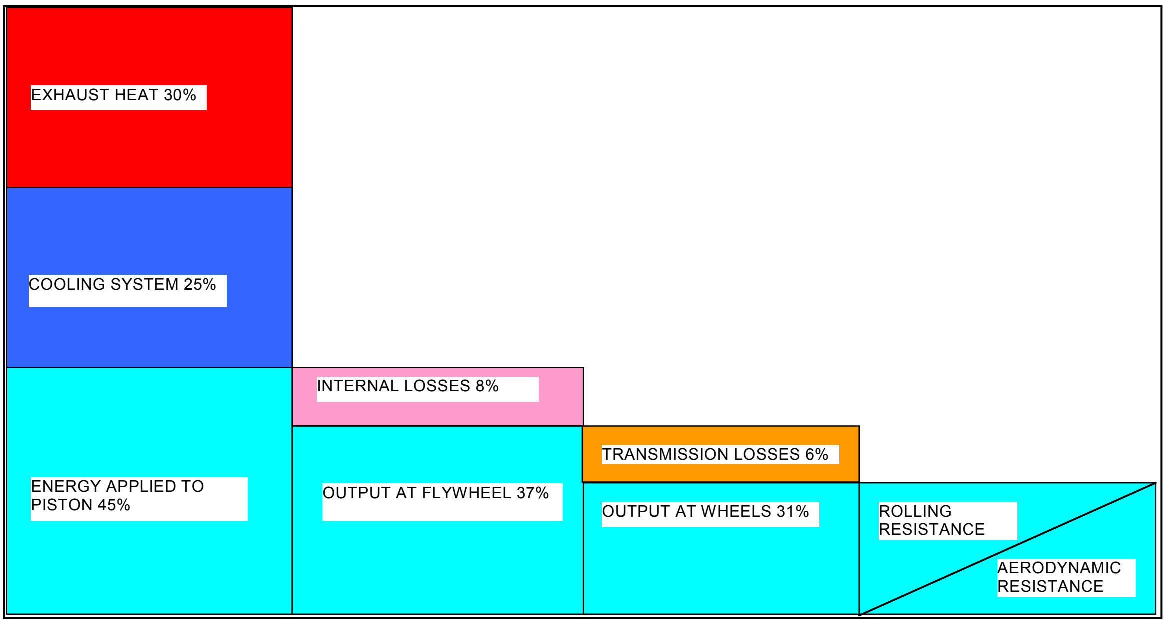
Care has to be taken when considering these KPIs because for example if a double deck trailer is introduced to an operation the fuel consumption as measured by MPG will deteriorate but the fuel consumption measured by fuel intensity will improve.

It is possible to identify over 100 fuel saving interventions on sale in the UK. In order to place these interventions into relevant categories it is necessary to examine the design characteristics of a vehicle that influence fuel consumption and the other key features which relate to the operational characteristics. The dissipation of the energy is shown in Figure 1.

> "Chemical energy enters the engine in the form of fuel; the fuel is burnt to produce heat energy; the heat increases the pressure of the gas and produces mechanical energy."
>
> Hillier, 1974

Losses occur in the change process as the energy is transferred from the engine to the tyres where it is used to overcome the rolling resistance within the tyre and the aerodynamic drag. As the road speed increases the importance of aerodynamic resistance increases. In Figure 1 the energy moves from the left hand column to the right hand column. The rectangles in Figure 1 are not to scale and the percentage values indicated are generalised because as will be shown in this paper they can vary due to many factors such as engine condition, type of transmission system, type of operation and vehicle type.

Figure 1 Energy Dissipation



The right hand bar contains two elements, rolling resistance and aerodynamic resistance. The relationship between them changes considerably as the road speed increases hence the diagonal is shown in the diagram. With over 100 fuel saving interventions on sale in the UK the next step having established how energy is dissipated is to categorise the interventions.

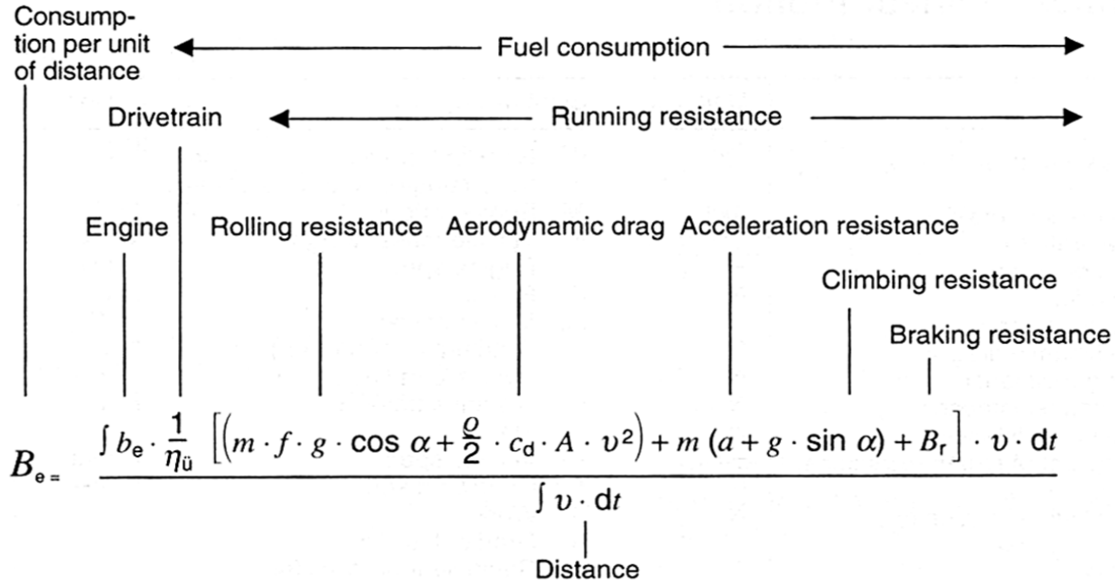
CATEGORIES OF FUEL SAVING INTERVENTIONS

The formula below shows the standard engineering formula for modelling fuel consumption (Bauer, 2000). Bauer's formula only relates to the resistances that are influenced by the design and build of the vehicle and body. It does not refer to managerial or operational factors that can influence fuel consumption.

$$B_{e} = \frac{\int b_{e} \cdot \frac{1}{\eta_{ü}} \left[\left(m \cdot f \cdot g \cdot \cos\alpha + \frac{\varrho}{2} \cdot c_{d} \cdot A \cdot \upsilon^{2}\right) + m\,(a + g \cdot \sin\alpha) + B_{r}\right] \cdot \upsilon \cdot dt}{\int \upsilon \cdot dt}$$

The individual components in Bauer's formula and their relationship to the various types of resistance are shown in Figure 2.

Figure 2 Explanation of the design features in Bauer's formula



Symbol		Unit
B_e	Consumption per unit of distance	g/m
$\eta_{ü}$	Transmission efficiency of drivetrain	–
m	Vehicle mass	kg
f	Coefficient of rolling resistance	–
g	Gravitational acceleration	m/s²
α	Angle of ascent	°
ϱ	Air density	kg/m³
c_d	Drag coefficient	–
A	Frontal area	m²
υ	Vehicle speed	m/s
a	Acceleration	m/s²
B_r	Braking resistance	N
t	Time	s
b_e	Specific fuel consumption	g/kWh

Source: Bauer (2000)

Whilst Bauer's formula identifies key features it is derived from vehicle engineering and does not include five factors that are of major importance to any operator, namely:

1. the effectiveness of the routing and scheduling
2. the fuel efficient driving technique of the driver
3. ensuring that the vehicle used is correctly specified for the work undertaken
4. effective maintenance
5. effective fuel consumption monitoring.

Using Bauer's formula it is possible to group fuel saving interventions into seven different categories based upon the design and build factors they represent (Table 5). Five additional factors (management), as outlined above, are also included.

Table 5 Intervention categories that influence fuel efficiency

No	CATEGORY	EXPLANATION	TYPES OF INTERVENTIONS APPLIED
1	Specific fuel consumption of the engine	The fuel used to produce a specific amount of power.	Oils and additives that claim to reduce friction. Combustion enhancing equipment or additives that claim to raise thermal efficiency.
2	Transmission efficiency of the drivetrain	The power and transmission losses due to friction within the gearbox, final drive and where fitted the hub reduction.	Transmission oils and additives that claim to reduce the friction between the components.
3	Rolling resistance	Is the product of the deformation process that occurs at the contact point between the tyre and the road surface.	Tyres that claim to have a reduced coefficient of rolling resistance. Devices to monitor or maintain tyre pressure.
4	Aerodynamic drag	The losses due to overcoming the resistance of the air to motion.	Aerodynamic aids that reduce the drag coefficient.
5	Acceleration resistance	Resistance caused by the apparent increase in vehicle mass due to rotating masses. For example, the flywheel.	None, other than the development of new materials that are lighter.
6	Climbing resistance	Resistance to a vehicle moving up a slope.	None.
7	Braking resistance	When applying the brakes the vehicle's kinetic energy is being absorbed rather than used to propel the vehicle.	Driving technique
	FACTORS NOT IN BAUER'S FORMULA		
8	Transport efficiency management	Reducing the distance travelled.	Improved routing and scheduling through the use of computerised packages.
9	Driver's fuel efficiency skills	Consistently minimising the fuel used.	Driver training. On-board computers.
10	Correct vehicle specification	Matching the vehicle specification to the work to be done.	Ensuring that the vehicle has the correct powertrain (engine and transmission ratios).
11	Effective Maintenance	Immediate repair of harmful fuel faults.	Excellent procedures and links to fuel consumption reports.
12	Monitoring	Spotting changes in fuel consumption.	Fuel monitoring systems and on-board computers.

Factors 8 - 12 are managerial in nature and the issue arises as to who will manage these factors to ensure fuel consumption is optimised? This is suggested as the role of the 'fuel champion'.

Based upon the framework established in Table 5 for categorising interventions the next stage is to take a view as to which are the most likely to succeed in improving fuel efficiency.

SUCCESSFUL FUEL SAVING INTERVENTIONS - A SUBJECTIVE APPROACH AND A SCOPING STUDY

Following extensive research undertaken at the University an initial view was formed as to which categories of interventions are likely to be successful in most transport operations. Whilst this is subjective it produces a starting point for the development of an intervention testing programme. Table 6 shows the intervention categories and the view that was taken as to their likelihood of success.

Table 6 Intervention categories - likelihood of success

No.	CATEGORY	LIKELIHOOD OF SUCCESS	TYPE
1	Specific fuel consumption of the engine	LOW	Design
2	Transmission efficiency of the drivetrain	LOW	Design
3	Rolling resistance	LOW	Design
4	Aerodynamic drag	HIGH	Design
5	Acceleration resistance	LOW	Design
6	Climbing resistance	LOW	Design
7	Braking resistance	LOW	Design
8	Transport efficiency management	HIGH	Management
9	Driver's fuel efficiency skills	HIGH	Management
10	Correct vehicle specification	MEDIUM	Management
11	Effective Maintenance	MEDIUM	Management
12	Monitoring	MEDIUM	Management

It is important to differentiate between design and non-design factors. Design factors cannot be changed quickly or inexpensively and by definition are built into the vehicle. Non-design factors are influenced by management. Management can decide whether or not to introduce driver training and whether or not the operation or part of it would benefit from the use of computerised vehicle routing and scheduling (CVRS). ‘Correct vehicle specification’ bridges the divide between design and non-design. It achieves this by ensuring that the design factors in the vehicle specification are optimal for the job. For example, vehicles operating in a hilly terrain may need a different powertrain specification to those operating in a relatively flat part of the country. Similarly, the body for a vehicle transporting high density products will not need to be as large as one transporting low density products. It is the role of management to ensure that they supply appropriate and adequate information to the person who draws up the specification for the vehicle fleet.

Obviously, there can be overlap between some of the categories such as monitoring and maintenance. Similarly, more than one intervention could if necessary be tested at once on the same vehicle, assuming that they were not mutually exclusive. The importance of the categories that influence fuel consumption will vary according to the sort of work that the vehicle does. For example, a high speed trunking vehicle will use a lot of energy to overcome aerodynamic resistance whereas a LGV that does a lot of delivery and collection work in an urban environment will encounter less aerodynamic resistance.

Reducing friction in the engine will have a noticeable effect where the engine is operating under a load where there is a significant loss to internal engine friction. It might be argued that engines that operate under such conditions for a substantial amount of time have been incorrectly specified for the job. Such interventions can be tested on an engine dynamometer where the power, torque, specific fuel consumption (SFC) and exhaust gases can be analysed. Interventions that claim to improve combustion can also be tested on an engine dynamometer which will remove many of the variables that can be found when testing on a test track and when testing 'live’ in an operation. By claiming to improve the combustion process, such an intervention can be evaluated through the use of exhaust gas analysis. Interventions that claim to reduce frictional losses in the transmission system can be tested on a chassis dynamometer.

In most of the literature, especially the product marketing material, there is the question of whether other effects such as **seasonality** or the **Hawthorne effect** have been taken into account. Furthermore, a problem with averaged data is that it is not possible to determine the range of the results and whether any 'outliers' or 'stragglers' are exerting an influence.

To check the validity of the view taken in Table 6 a scoping study of operators' successes and failures using interventions was undertaken. Eighty two operators who had tested fuel saving interventions were asked to state which interventions they had tested and whether their tests had been successful. Table 7 lists the types of intervention tested, the number times an intervention was tested and the success and failure rates. If the testing was rigorous and the analysis of the results was thorough then the success rates indicated by the percentages in column four can be interpreted as a guide as to which interventions should be tested. There are three main limitations with Table 7. The first is that no hard data was supplied to check their findings. The second is that some operators were not aware of seasonality so their judgements could be flawed. Thirdly, there is no way of knowing how rigorous the analysis was. Despite these limitations it gives a starting point to identify interventions with the best chance of working.

Table 7 Success and failure rates for interventions

Intervention	Category	Attempts	Successful		Unsuccessful	
			Actual	%	Actual	%
Driver training	9	42	40	95%	2	5%
Changed vehicle specifications	10	35	33	94%	2	6%
Improved routing and scheduling	8	38	35	92%	3	8%
Different vehicle manufacturers	10	39	32	82%	7	18%
Aerodynamics	4	49	38	78%	11	22%
On board data recording	12	33	21	64%	12	36%
Semi/Fully synthetic engine oil	1	33	20	61%	13	39%
Semi/Fully synthetic transmission oils	2	27	16	59%	11	41%
Low energy tyres	3	24	11	46%	13	54%
Fuel bonus	12	23	9	39%	14	61%
Fuel additive	1	25	7	28%	18	72%

Source Coyle (1999)

Putting aside seasonality, Table 7 provides a lead as to which interventions operators found to the most effective. A review of Tables 6 and 7 indicates that the most successful interventions are likely to be:

- driver training/drivers fuel efficiency skills
- vehicle specification/vehicle manufacturer
- transport efficiency management/routing and scheduling
- the design or technical intervention most likely to improve fuel efficiency is the use of aerodynamic aids.

With the establishment of a group of interventions felt to be those most likely to improve fuel efficiency it now becomes necessary to produce a test methodology. Irrespective of the subjective judgements any intervention must be tested in the most rigorous manner, which is what will be examined next.

AN EXAMPLE OF AN INTERVENTION AND ITS SENSITIVITIES

Prior to testing an intervention it is necessary to collect as much information as possible to identify what are the key variables and how sensitive the results of any test might be to these key variables. An example of the depth of the research required before designing a test plan will now be given.

The intervention concerned relates to tyres that claim to improve fuel efficiency. These have been described variously as ‘low energy tyres’ or ‘eco tyres’ amongst other similar names.

The moment that the wheels begin to turn the tyre deforms and this deformation absorbs energy, which is then converted to heat. The energy absorbed by the tyre has been produced in the engine. The less energy that is absorbed the greater fuel efficiency of the tyre. The coefficient of rolling resistance is not a constant and can change as certain variables change.

> "The increase in the co-efficient of rolling resistance *f* is directly proportional to the level of deformation, and inversely proportional to the radius of the tire (sic). The coefficient will thus increase in response to greater loads, higher speeds and lower tire (sic) pressure".
>
> (Bauer 2000)

Different parts of the tyre absorb different amounts of energy. Other factors can also influence tyre rolling resistance (Ramshaw and Williams, 1981). There appears however, to be no agreement amongst tyre manufacturers as to how much energy is absorbed by the different parts.

> "Michelin calculates that 60 to 70% of the energy is absorbed in the tread area, 10 to 20% in the sidewall and 15 to 20% in the bead area. Continental puts the rolling resistance contributed by the tread itself at 28%".
>
> (Sowman 1996)

Rolling resistance is of major importance in Bauer's formula and is only surpassed by aerodynamic drag at high road speeds. The use of cosine α in Bauer's formula is to reflect the impact of travelling on anything other than a flat level road. Such a component does however have only a minuscule effect in the overall formula.

Bauer's formula makes no reference to cornering resistance so it must be assumed that it reflects rolling resistance only when travelling in a straight line. Gillespie (1999) states that at lower speeds (without defining a lower speed) the coefficient of friction rises approximately in a linear way with speed

$f_r = 0.01\ (1+V/100)$

where

f_r = rolling resistance coefficient
V = speed in MPH

and that over a broader speed range (again undefined) the coefficient rises in a speed squared manner. He introduces the following formula, which was developed at the Institute of Technology in Stuttgart

$f_r = f_o + 3.24 f_s\ (V/100)^{2.5}$

where

V = speed in mph
f_o = basic coefficient
f_s = speed effect coefficient

The elasticity of the road surface can also influence the rolling resistance coefficient. The elementary coefficient of rolling resistance values for different surfaces as shown in Table 8. For example, a heavy truck operating on a concrete surface would suffer a coefficient of friction value of 0.012 whereas if operating on sand the coefficient of friction value would rise to 0.25, an increase of 1,983 per cent.

Table 8 Elementary rolling resistance coefficient values

	SURFACE		
VEHICLE TYPE	CONCRETE	SURFACE MEDIUM HARD	SAND
Passenger cars	0.015	0.08	0.3
Heavy trucks	0.012	0.06	0.25

Source Gillespie (1999)

Gillespie (1999) introduces a third formula developed at the University of Michigan Transportation Research Institute. This supplies constants for different road surfaces. For a radial ply heavy duty truck tyre the formula is:

$f_r = (0.0041 + 0.000041\ V)C_h$

where:

V = speed in mph
C_h = Road surface coefficient

= 1.0 for smooth concrete
= 1.2 for worn concrete, brick or cold blacktop
= 1.5 for hot blacktop

It is noticeable that all three formulae have speed as a variable. This raises the question as to whether or not any interventions applied to this area would be sensitive to speed. That is the intervention only works when the vehicle operates above a certain minimum speed.

The air pressure within the tyre determines the tyre's elasticity which along with the mass and the road speed will determine the amount of deformation. Under-inflated tyres will result in greater deformation leading to a deterioration in fuel efficiency.

> "…20 per cent under inflation of a truck tyre can be expected to cut tread life short by between 22 and 25 percent… the same 20 percent under inflation produces a 10 per cent increase in rolling resistance leading to a deterioration in fuel consumption of around two per cent."
>
> Wilcox (1999c)

Through its influence on tyre deformation, tyre pressure has an import influence on rolling resistance and ultimately fuel consumption. In a test conducted at the 2001 IRTE/BTAC Event trailer tyres on a tri-axle trailer were under inflated (95 psi instead of 125 on the front and middle axles and 130 psi on the rear axle). This resulted in a 2.7 per cent deterioration in fuel consumption (Wilcox 2001).

Earlier attempts (pre 1999) to introduce low energy or ‘eco’ tyres failed because the claimed savings could not always be validated and the tyres were wearing more quickly (Truck 1997 and Cameron, 1999). It was also noticed that the earlier low energy tyres had less tread on them and specifically in the case of Michelin, three to four millimetres less tread depth (Freight, 1997).

In late 1999 and early 2000 the tyre manufacturers re-launched their fuel efficient tyres with claimed savings of 6%. However, as Sowman indicated, as energy tyres wear, their lower rolling resistance advantage reduces. Therefore, operators need to assess the savings over the life of a tyre including regrooving and retreading rather than basing decisions on the results of short term testing that compares new standard tyres and new fuel efficient tyres. Issues of a short tyre life - 100,000 kilometres for a fuel efficient tyre as opposed to 250,000 for a standard tyre - still arise even with the new generation of fuel efficient tyres (Cameron 1999). If fuel efficient tyres do have a shorter life than standard tyres then another factor to be taken into consideration is that new energy tyres have a higher rolling resistance than a well worn ordinary tyres (Sowman 1996).

Any test process, either ‘live’ or test track based must be designed to ensure that the key variables are taken into account to ensure that there is no bias in the test. The research suggests the following as key variables to be considered if testing fuel efficient tyres on a test track:

- Are the test and control tyres new or old?
- Are the tread depths equal?

- What is the speed profile of the test?
- Are the tyre pressures optimal and how often will they be checked to ensure that they have maintained their pressure?
- Is the vehicle or vehicles being tested the same weight at which it normally operates?
- Is the test ‘back to back’, that is tyres swapped between vehicles and the test cycle repeated?

Testing ‘live’ in an operation should consist of:

- Test and control vehicle groups.
- Paired vehicles in each group having the same operational profile (weight, speed and operational hours).
- Regular tyre pressure checks.
- Tyres swapped between some of the paired vehicles to show repeatability.
- Minimum of weekly fuel consumption analysis.

Upon completion of the test or series of tests the trade off analysis would have to include any premium paid for fuel efficient tyres, the value of any proven fuel savings over the life of the tyres and any increased costs associated with shorter tyre life (should this be proven).

CONCLUSION

Improving fuel efficiency is important to reduce environmental impact and improve the profitability of operators.

The key outputs from the research discussed in this paper are summarised as follows:

- Most of the energy content of fuel is wasted.
- A system for categorising interventions has been proposed and explained.
- Marketing based claims made for many interventions should be treated with caution because the interventions can be sensitive to technical and operational variables. This means that results may not be repeatable.
- A hierarchy of interventions and success rates has been produced to guide the research as to what interventions should be tested first.
- Testing of fuel saving interventions is an intensive and complex problem but if the test process is to be rigorous and produce robust data then the research must be done first.
- Few of the published results, especially in the product marketing literature, have been subject to independent rigorous statistical analysis.
- Fuel efficiency should be seen in the context of reducing the total fuel used and not just improving MPG.

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Biography - Dr Michael Coyle

Michael Coyle has more than 25 years experience in the transport industry. He has worked as a vehicle technician, Large Goods Vehicle (LGV) driver, lecturer in motor vehicle studies, depot manager, project manager and driver training executive. Academically he has a teaching qualification, a BSc (Hons) in Transport and Distribution, a MSc in Operational Research and his PhD was based upon improving the fuel efficiency of LGV fleets. Since completing his PhD he has established his own research, consultancy and training company – IMISE Limited.

Michael is a Fellow of the Royal Society for the encouragement of Arts, Manufactures and Commerce (FRSA), Member of the Institute of Logistics and Transport (MILT), Member of the Operational Research Society, Registered as Incorporated Engineer (IEng) and a Member of the Society of Operations Engineers professional division The Institute of Road Transport Engineers (MSOE, MIRTE). An example of projects he has worked on and other duties he performs are:

- Advisor to the Government's transportenergy> best practice (formerly Energy Efficiency Best Practice Programme) 1998 – to date.
- Results marshal BTAC technical evaluation event – June 2003;
- Sustainability specialist in the Department for Transport SAFED 2 project 2003;
- Lead consultant on the initial EEBPP project Safe and Fuel Efficient Driving (SAFED 1) 2002;
- Senior Fuel Economy Advisor to the Simon Management FEA consortium 2003 – to date;
- Technical advisor to the TRL Fuel Economy Advisor (FEA) consortium 2002 – 2003;
- Appointed honorary advisor to the AE database in Hong Kong (December 2002);
- Major contributor to the UK Government 'SAVE IT' Fuel efficiency videos;
- Contributing author to UK Government's Fuel Saving Devices Guide (GPG 313);
- Major contributing author to UK Government's new Fuel Management Guide (GPG 307);
- Designer of fuel efficiency software;
- Co-opted member of the Logistics Management Committee of the Cold Storage and Distribution Federation 1999 – 2001;
- Member of IRTE/BTAC Fuel Efficiency and Technical Evaluation Planning Committee 1998 – to date;
- Co-opted member of the IMechE Automobile Division, Operators and Users Committee 1999- to date;
- Co-opted member of Technical Committee of the Institute of Road Transport Engineers 1998 – 2000;
- Contributing author to Croner's "Operational Costings Newsletter" 2000 – to date and
- Contributing author to ‘Fuel Efficiency’ in Croner's Energy Management 1998 – 2002.

Dr Coyle has achieved fuel efficiency improvements of the order of 3% to 40% across a range of vehicles and fleets.