AN INTRODUCTION TO EVALUATING FUEL SAVING AND EMISSIONS REDUCTION TECHNOLOGIES IN 'LIVE' OPERATIONS

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1 INTRODUCTION

Pressure to reduce fuel costs and environmental impact is relentless. Reducing fuel costs and environmental impact obviously has great attractions for an operator of vehicles. However, achieving these two goals is not an easy task. Whilst advances in engine technology and vehicle design have resulted in improvements in fuel consumption and reductions in emissions, there remains a major focus on emissions from diesel engines. Specifically, particulate matter (PM) and nitrogen dioxide (NO_2).

Improving fuel consumption will reduce all emissions and hence the overall environmental impact of a vehicle. Therefore, in this case we are only looking at improving fuel consumption as measured by miles per gallon (MPG) or litres per 100 kilometres (l/100km). Reducing mileage and fuel consumption through improved routing and scheduling or improving energy intensity through use of double deck trailers is not being considered here. The number of fuel saving and emissions reduction interventions advertised in various media runs into millions. So how should a person charged with being responsible for improving fuel consumption proceed?

It is essential to understand the issues involved and what help is available. The aim of any test or trial is to deliver an accurate result in which faith can be had. The issues in the main revolve around which interventions to select, how to structure a test and how to manage (collect and analyse) the data. Recent projects confirm that there is still a seasonal influence upon fuel consumption in the UK and that the months of December, January and February tend to cause high levels of volatility in the data. Subsequently, 'live' testing in these months should be avoided. Ideally, testing would be conducted between April and September when winter diesel is not in the system.

2 BACKGROUND

In 2002 "Fuel Saving Interventions: Facts and Fiction" was published which established the twelve categories of fuel saving intervention shown in Table 1. Seven were deemed technical and five managerial. In the intervening years this categorisation has been found to still hold true.

Table 1 Intervention categories that influence fuel efficiency

No	CATEGORY	EXPLANATION	EXAMPLES 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	This 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.

Coyle M, Murray W and Whiteing AE (2002)

Focussing on categories 1 – 7 there are several testing regimes available, each with their own specific advantages and disadvantages. These are an engine dynamometer, chassis dynamometer, test track and ‘live’ in operations. The first three testing regimes (dynamometers and test track) can be applied in such a way that they work as a filter before moving to 'live' testing. 'Live' testing uses up the operator's management time and the data is subjected to the many variables that exist and inevitably increase the volatility in the fuel consumption data. Therefore, it would be sensible for an operator to require these filter tests to have been completed before moving to 'live' testing. Table 2 shows the category of intervention and which tests can be applied.

Table 2 Categories and tests

No.	CATEGORY	ENGINE DYNAMOMETER	CHASSIS DYNAMOMETER	TEST TRACK	LIVE
1	Specific fuel consumption of the engine	Yes	Yes	Yes	Yes
2	Transmission efficiency of the drivetrain	N/A	Yes	Yes	Yes
3	Rolling resistance	N/A	N/A	Yes	Yes
4	Aerodynamic drag	N/A	N/A	Yes	Yes
5	Acceleration resistance	N/A	N/A	Yes	Yes
6	Climbing resistance	N/A	N/A	N/A	Yes
7	Braking resistance	N/A	N/A	N/A	Yes

Most vehicle operators are highly sceptical of the claims made for fuel saving interventions and do not have the resources to adequately evaluate the impact of such interventions upon their vehicles. Furthermore, an often-heard refrain from operators is that they do not run their vehicles on dynamometers or test tracks; they run them in the real world. If fuel savings and the related emissions reduction cannot be proven under the controlled conditions associated with a dynamometer or test track, then it is unlikely they will prove to be effective when tested in 'live' conditions. Additionally, operators have expressed concern over any implications to a vehicle's warranty when interventions are applied. Where the vehicle is owned by a company other than the operator then the vehicles' owners must be involved in the process. Given the 'neither prohibit no endorse' response from vehicle manufacturers the 'no-harm' principle needs to be borne in mind.

2.1 NO-HARM PRINCIPLE

This is an important factor to be considered in any trial where the intervention might harm a component. In the absence of any industry standard tests, or where an industry standard test regime is so expensive that an intervention supplier cannot afford the test, then alternatives need to be considered. For example, when an intervention is being tested on an engine such as a fuel or oil additive or an alternative fuel, engine oil analysis is recommended. The analysis should include three samples before the intervention is applied to check that the engine has no problems before the test begins. and to determine if there is trend developing in wear, chemistry and contamination. On-going sampling should take place at agreed intervals during and after the test has been completed. This is important for all concerned, the vehicle owner, operator and intervention supplier.

In the case of a fuel additive, no-harm testing is essential due to the high cost of fuel systems and small micron clearances between components operating with pressures of more than 2,500 bar.

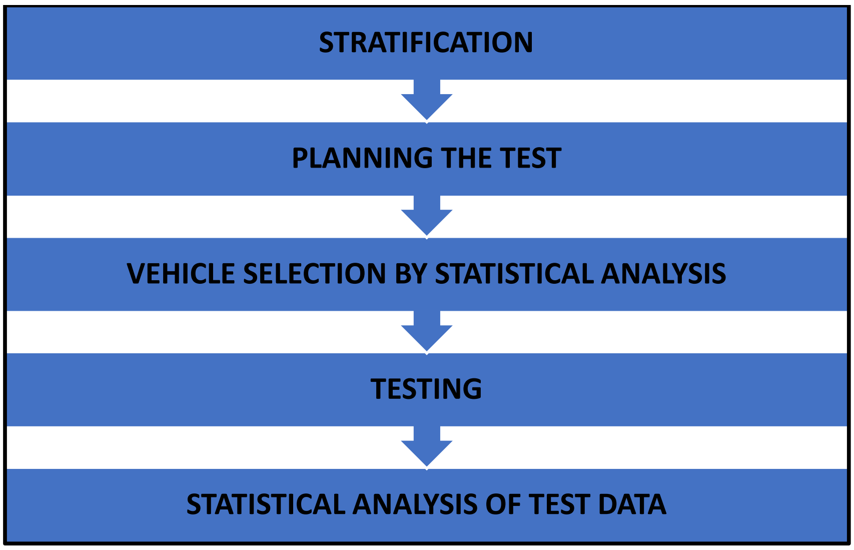
3 ‘LIVE’ TESTING: A FIVE STAGE PROCESS

Whilst testing in ‘live’ conditions can seem a bit daunting, it is possible to break it down into five basic stages. These five stages form part of the Imise Fuel Saving Intervention Testing System (IFSITS), which is a proven scientific approach designed to address the many concerns operators and suppliers of interventions have, associated with ‘live’ testing. IFSITS includes a statistical programme that selects ‘test’ and ‘control’ vehicles based on being able to obtain the most accurate result; thereby, removing the need for a vehicle operator or intervention supplier to have any knowledge of statistics. Its mathematical programming can also be used to evaluate data generated from testing on an engine dynamometer, chassis dynamometer and at a test-track.

In addition to the no-harm principle, vehicle owners will want to ensure that there is adequate insurance to cover any costs incurred if harm takes place or is suspected to have taken place. Where harm is suspected it is only fair and proper that an investigation is undertaken by an independent body. In addition, oil analysis of powertrain components is recommended when lubrication based interventions are being tested.

An overview of how the various processes link together in ‘live’ testing is shown in Figure 1 below.

Figure 1 Process Overview



For a test to be accurate and reliable the process needs to be robust and the statistical analysis rigorous. Ideally there should be more than one ‘test’ vehicle and several ‘control’ vehicles. Any test plan must take into consideration operational constraints and the type of intervention being tested. There are two important issues to be dealt with. These are the test process (the robustness) and the statistical processes involved (the rigour). To remove the problem of non-statisticians dealing with statistical processes an easy to use computer programme has been developed to undertake the necessary statistical process. The test process needs, where possible, to include repeatability and ‘before’, ‘after’ and ‘as before’ conditions. The statistical processes and test processes are both part of IFSITS, as part of its scientific approach to testing. Due to the powerful proven statistical techniques employed in IFSITS the test period can be reduced to 30 working days for the most basic test. This enables extended testing if required or for staggered testing and reduces the impact of seasonality (Coyle M, Murray W & Whiteing A E 1998).

3.1 STRATIFICATION

A stratification process is required. This involves a desk based evaluation of which interventions will have the greatest impact for given vehicles and their operational profile. It involves considering the different operational profiles of vehicles in the depot, different configurations and separate shift patterns where vehicles are double shifted. A financial analysis is also included, which normally has two approaches. The first is the maximum amount of money returned in a specific time period. The second is the fastest payback. It is for the operator to choose its preferred cost benefit mechanism.

This process may, or may not, include evidence from dynamometer or test track testing, depending upon the category of the intervention and the operator’s view on dynamometer and test track testing. Whatever the evidence, it must be viewed dispassionately.

3.2 PLANNING THE TEST

The ideal test plan would involve many vehicles from which to choose ‘test’ and ‘control’ vehicles. However, this is not always the case, so it is necessary to consider the different test plans available and choose the most robust. The actual selection of vehicles by statistical analysis will be dealt with in Section 3.3.

3.2.1 THE IDEAL TEST

The ideal test is where there are many vehicles available to be ‘test’ and ‘control’ vehicles. Consider as an example, all the vehicles in the depot are of the same configuration and have the same operational profile. Different manufacturers vehicles and age profiles are dealt with in the stratification and selection by statistical analysis.

The daily fuel consumption data for the previous three months (this is a minimum) is uploaded to the IFSITS system to identify and rank the vehicles suitable for inclusion in the trial. For example, if out of a depot fleet of 40 vehicles the IFSITS statistical programme has concluded that only eight are found to produce data good enough to warrant their being included in a 'live' trial. The potential for these eight to be used in the trial is then discussed with the local management for their input. There is no point placing a vehicle in a trial if it is about to be replaced, or if there is some other operational reason for an exclusion. With the 'test' and 'control' vehicles confirmed by statistical analysis and the knowledge of the local management the ideal test will enable both 'intra' and 'inter' analysis. 'Intra' is where an individual vehicle's data is analysed based on its own baseline and then its own data generated during the test period. Where possible, if the intervention can be removed or switched off then an 'as before' period can be used to generate data, which can be analysed against the 'test' data. A double check has been facilitated. 'Inter' vehicle analysis is where a single 'test' or 'test' vehicles are compared against the 'control' vehicle or vehicles.

Depending upon what the intervention is, it should be introduced in a staggered manner. Of the eight selected vehicles, three might be chosen as 'test' vehicles and five as 'control'. Should a 'test' vehicle be damaged or taken off the road for some reason then a 'control' vehicle might - depending upon the intervention - become a 'test' vehicle. This also fits into a staggered introduction plan.

The baseline period of thirty days does not delay the start of the trial because the data has already been deemed acceptable by IFSITS. The daily data for the 'test' and 'control' vehicles can be fed daily into IFSITS prior to the intervention being applied; thereby saving the initial thirty-day baseline period. Fuel consumption data submitted daily reinforces the quality of the test and is important as an element of the project management discipline. If there is a sudden change in the fuel consumption data it could indicate a change in the operational profile or vehicle condition.

In Figure 2 below there is only the 'test' vehicle. In this case 'intra' vehicle analysis can be conducted between the first baseline data (days 1 to 30) and the fuel data from when the intervention is applied. The intervention is then removed or switched off after the end of work on day 60 and an 'as before' baseline period is produced (days 61 to 90). This enables a second 'intra' vehicle analysis to be conducted.

Figure 2 Single test vehicle no control vehicle

	TEST VEHICLE
Days 1 to 30	Baseline
Days 31 to 60	Intervention applied
Days 61 to 90	Intervention removed/Baseline

In Figure 3 there is at least one 'control' vehicle available. This enables both 'intra' and 'inter' vehicle analysis. The degree of difference between both vehicles' baseline periods (days 1 to 30 and 61 to 90) can be analysed and compared to the degree of difference between days 31 to 60 for both the 'test' and 'control' vehicles.

Figure 3 Test and control vehicle(s) not staggered

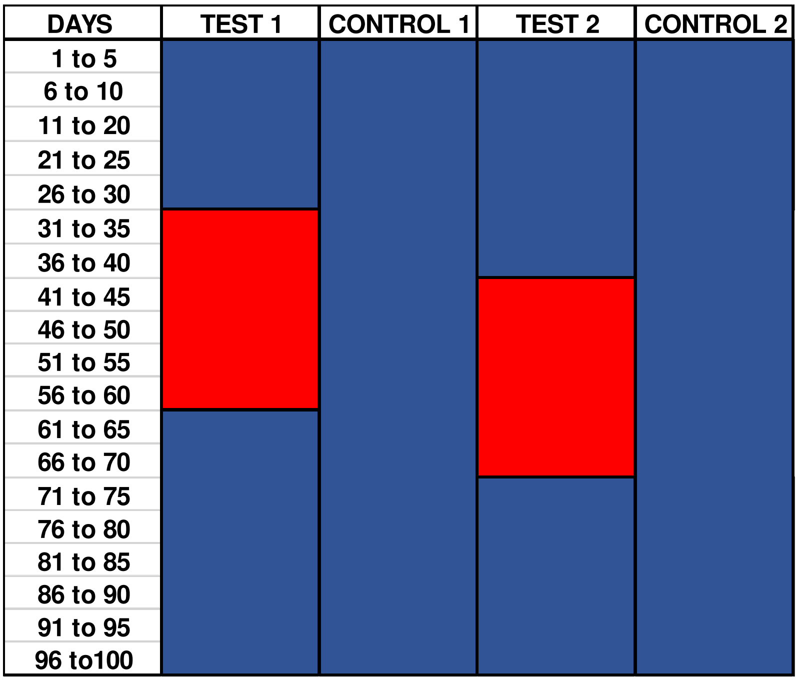
	TEST VEHICLE	CONTROL VEHICLE
Days 1 to 30	Baseline	Baseline
Days 31 to 60	Intervention applied	Baseline
Days 61 to 90	Intervention removed/Baseline	Baseline

Staggering the introduction of an intervention ensures a more robust trial, but does increase the trial period. It helps to increase robustness through introducing repeatability. A staggered test enables repeatability and when conducted with a 'control' vehicle also permits 'intra' and 'inter' vehicle analysis. This is potentially the most robust testing format.

It can be seen in Figure 4 that both 'test' vehicles (Test 1 and Test 2) can be subjected to a major analysis. Test 1 and Test 2 can be subjected to 'intra' analysis both 'before', 'after' and 'as before'. Both Test 1 and 2 can also be subjected to 'inter' vehicle analysis with Control 1 and Control 2. This level of analysis using powerful proven statistical techniques minimises the potential for events not linked to the intervention to be responsible for an improvement in fuel consumption.

The red area represents days when the intervention is applied and the blue when no intervention is applied.

Figure 4 Staggered testing with more than one vehicle



Whilst only two 'test' and two 'control' vehicles are shown in Figure 4 more test and control vehicles can be involved, subject to them being selected by both IFSITS and the local management.

3.3 VEHICLE SELECTION BY STATISTICAL ANALYSIS

Random selection of vehicles whether they be ‘test’ or ‘control’ is unscientific. It increases the risk of selecting vehicles with high levels of volatility in their data, which leads to less accurate analysis. The vehicles that will provide the most accurate results are selected by analysis conducted by a statistical programme in IFSITS. The vehicles are ranked according to their level of accuracy and a cut-off point is applied. Vehicles beyond the cut-off point should not be considered for involvement in the test. The selected ‘test’ and ‘control’ vehicles are then discussed with the local management to maximise the robustness and accuracy of the test. The importance of the local management knowledge should never be underestimated.

4 TESTING

There are many elements that go into making a test successful and ensuring an accurate result. Two of these elements (stratification and planning the test) have already been discussed. These other elements include matters such as communication and basic project management disciplines.

It is important that the trial and its purpose is communicated to all members of staff so that they know what is happening and where necessary their role in the trial. Lines of communication need to be established throughout the company.

Basic project management skills such as setting out what will happen and when, sometimes referred to as outcomes and milestones need to be established. Additionally, the responsibilities and authority of individuals involved needs to be set out and communicated to staff. These elements should be recorded in a formal document to ensure that there is a recognised structure to the trial.

5 STATISTICAL ANALYSIS OF TEST DATA

For many vehicle operators, how to tell whether an intervention has worked is a major issue and statistical analysis is not something with which most people are comfortable. IFSITS takes the stress out of this by applying a series of proven powerful statistical tests to the data. The data is simply uploaded and IFSITS does the rest. All statistical tests have strengths and weaknesses, which is why IFSITS applies a series of tests to increase the rigour of the analysis.

It is important to note that the fuel consumption data from ‘test’ and ‘control’ vehicles should be forwarded to the IFSITS operator daily. This ensures that any unusual data can be highlighted and questioned within 24 hours. Then a decision can be made as to whether it should be used in the analysis or not.

The output from IFSITS at the end of the trial can consist of different results. In the first case, all the statistical tests state that the intervention has worked to different degrees. Being different tests, they will produce figures showing different levels of improvement in fuel consumption. Thereby, producing a range with which to work. In the second case, all the tests produce figures showing that the intervention has not worked and as in the first case there will be a range of figures. The third and more complex case is when you get a mix of answers; one or more of the tests shows an improvement whilst one or more of the tests shows no improvement. At this point the IFSITS operator needs to investigate the data further using a specially designed algorithm.

This specially designed algorithm is also used to check the data to ensure that any change was due to the intervention and not some other event. This is an extremely important check, especially when the improvement has been a very low percentage. It is even more important when the test was not staggered. A good example is where an intervention is applied and a few days later the improvement takes place, but the improvement is due to some other event. For example, a reduction in the weight being carried, a major change in the weather or vehicle maintenance work, all can have an effect. With daily data, the exact day of the change can be identified and investigated. This also reinforces the need for 'control' vehicles and staggering the introduction of an intervention.

6 OTHER CONSIDERATIONS

It is not always possible to conduct an ideal test and so other considerations come into play.

6.1 FULL DEPOT TEST – NO CONTROL VEHICLES

In some cases, such as a fuel treatment of bulk fuel tanks it might not be possible to have separate 'test' and 'control' vehicles. In this case it might be possible to use anther depot as a 'control' depot. This is risky and should only be considered after certain common sense and statistical tests have been undertaken. The common-sense approach involves ensuring that vehicles in the 'test' and any potential 'control' depot should ideally be similar and have comparable operational profiles. The statistical tests include checking the correlation in the depots' weekly fuel consumption figures over a lengthy period. Even with a strong correlation, one greater than 0.8 absolute, an additional check is required.

This additional check is a weekly difference analysis. An example is shown in Table 3 below. The correlation between Depot A and Depot B is 0.84. The differences are not consistent and fluctuate between -0.39 MPG difference and -0.07 MPG. Therefore, it would be unwise to use one as a 'control' depot.

Due to their being no consistency, any improvement in either depot will be distorted by anything between 0.39 and 0.07 MPG due to their negative values. The lack of a consistent difference can have a significant impact on the outcome and a false result generated. In this particular example the difference could be up to -0.32 MPG (-0.39 to -0.07) a considerable amount, which carries a lot of risk with it.

Table 3 Two close depots

	DEPOT A	DEPOT B	DIFFERENCE	
Week	MPG	MPG	ABS	%
11	9.41	9.80	- 0.39	-4.15%
12	9.24	9.57	- 0.33	-3.55%
13	9.55	9.76	- 0.21	-2.21%
14	9.62	9.80	- 0.18	-1.88%
15	9.49	9.82	- 0.32	-3.41%
16	9.80	9.93	- 0.13	-1.36%
17	9.65	9.72	- 0.07	-0.74%
18	9.53	9.83	- 0.29	-3.06%
19	9.70	9.95	- 0.26	-2.65%
20	9.63	9.71	- 0.09	-0.90%
21	9.83	10.02	- 0.19	-1.94%
22	9.97	10.03	- 0.07	-0.68%

To use another depot as a ‘control’ depot both common sense and statistical analysis must confirm that it is viable.

Therefore, the solution is to apply an intra depot (all vehicles) analysis like that shown in Figure 2. Only core vehicles should be used in the analysis. That is vehicles that are producing fuel consumption data regularly in the total period under analysis and removing any vehicles that have undergone any maintenance that may influence their fuel consumption. The data from the core vehicles baseline is compared against the data from the core vehicles’ thirty days in test condition. If possible an ‘as before’ period for the core vehicles can be undertaken and the data compared with the test period data.

6.2 COMPARISON WITH LAST YEAR’S DATA

Comparing recent fuel consumption data with data generated the same time last year is not recommended for several reasons. It is highly unlikely that the weather conditions are the same. Has the operational profile remained the same? What were the road conditions, were there any major roadworks, then or now? Only core vehicles that were active during the complete period (last year and now) can be included in the analysis. Vehicles that were active last year, but not currently, need to have their data excluded. New vehicles active now, that were not active in the same period last year also need to have their data removed. Any remaining vehicles need to have their maintenance records checked to ensure that no major maintenance work had been undertaken that could have influenced their fuel consumption.

Table 5 below shows the weekly differences in MPG at the same depot between two consecutive years. It can also be seen that there is no consistency and the differences are both negative and positive. The range of difference is 0.67 MPG (0.29 to -3.9).

Table 5 Consecutive years.

	Year 1	Year 2	Difference	
			Abs	%
Wk 11	9.46	9.41	0.05	0.6%
Wk 12	9.53	9.24	0.29	3.1%
Wk 13	9.56	9.55	0.02	0.2%
Wk 14	9.57	9.62	- 0.05	-0.5%
Wk 15	9.56	9.49	0.06	0.7%
Wk 16	9.57	9.80	- 0.23	-2.4%
Wk 17	9.35	9.65	- 0.30	-3.2%
Wk 18	9.64	9.53	0.10	1.1%
Wk 19	9.57	9.70	- 0.13	-1.3%
Wk 20	9.80	9.63	0.18	1.8%
Wk 21	9.69	9.83	- 0.14	-1.5%
Wk 22	9.59	9.97	- 0.38	-3.9%

This shows why it is inadvisable to compare fuel consumption data produced at the same time last year.

6.3 LONGEVITY

How long the impact of an intervention is maintained – its longevity – needs to be factored into any cost benefit analysis. If it is a one-off cost with a permanent impact it is a simple analysis. If it is an on-going treatment such as a fuel additive the cost benefit analysis is still not too difficult. Where periodic dosing or treatment is required the question arises as to what is the minimum dosage to achieve the maximum effect and at what frequency.

7 REVIEW

'Live' testing of a fuel saving intervention is a scientific endeavour, incorporating the knowledge of the operational managers and powerful statistical processes. It is not easy and needs to be managed as a project incorporating project management skills. Few operational mangers have the statistical skills necessary to conduct the rigorous analysis required to identify acceptable 'test' and 'control' vehicles and then to determine if a fuel saving intervention has been proven to work. That is why IFSITS includes the powerful proven statistical techniques required thereby negating the need for managers to have statistical skills.

8 SOURCES

Coyle M, Murray W & Whiteing A E (1998), Optimising Fuel Efficiency in Transport Fleets, paper presented at the Logistics Research Network Conference, September 1998, Cranfield University, pp 4-5.

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