A Platform for Automotive Transportation studies

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Abstract

This paper describes a low cost electronic instrument designed specifically for a road-pricing study but which is being extended to other automotive transportation studies. The instrument has been designed to address many of the data logging requirements of such studies and is easily re-programmable. Careful consideration has been given to installation and calibration cycles. The cost of the instrument is also a factor as many studies involve instrumenting large numbers of vehicles. The capabilities of the instrument are discussed and performance and reliability results are presented. Details of pilot studies completed in two European cities are presented and a review of on-going studies and plans for future work using the instrument are presented.

1. Introduction

One of the many problems facing researchers in automotive transportation is the difficulty in instrumenting the vehicles taking part in the trial. Common problems encountered are cost, lengthy and difficult installation and calibration procedures, poor reliability where non custom equipment is retrofitted to the vehicle, potential damage to vehicles and interference with vehicle instrumentation; in some cases it is possible that the safety of the vehicle might be compromised such as when in-circuit fuel meters are installed.

The cost of instrumenting vehicles is only partly accounted for by the high cost of equipment, which may not be ideally suited to the task. A substantial proportion of the cost is incurred during installation and, when the test is completed, recovering the instrumentation. Damage to equipment and to the vehicles may also be a factor.

Lengthy installation and calibration procedures also lead to other difficulties – many participants in a study are unwilling or unable to part with their vehicle for long periods of time i.e. hours, while it is instrumented. They are further discomfited by the sight of the vehicle undergoing what appears to be major surgery and tend to worry that the vehicle will not be satisfactorily restored at the end of the study. The ideal installation/ calibration procedure should be no more inconvenient or traumatic than a standard auto maintenance procedure such as changing spark plugs or an oil change. We will see later how closely our system approximates this "plug and play" ideal.

Much of the electronic equipment which may be fitted to a vehicle as part of a study is not suitable for extended use in such an environment; electrically and mechanically an auto is an extreme environment with very high voltages, high temperatures and a relatively low level of ingress protection. Careful attention to wiring and shielding is required to avoid compromising the integrity of the system. The result of poor signal integrity may be a complete failure of the installation/ calibration or worse still, from the point of view of the researcher, a set of unreliable or misleading data.

In addition, the scope of automotive transportation studies is broad, meaning that it is often necessary to revisit the design process many times when the focus of a study is changed or extended. This is a major impediment to the main purpose of a transportation study which is to gather data; effort expended on the design and installation process is largely wasted.

Our original motivation for considering the design of an instrument for traffic studies stemmed from our participation in a road pricing study funded by the EU. As part of this study it was necessary to evaluate the potential response of drivers to road pricing. To evaluate this, 50 vehicles in Dublin and Athens were instrumented.

The preliminary stage of the project focussed on specifying the scope of the road pricing trials and on establishing a methodology; a slightly different methodology was adopted in Athens from that used in Dublin but without significant impact on the choice of instrumentation. When this stage was complete the next task was to specify and source suitable instrumentation.

It soon became apparent that no suitable equipment was available which met the cost and functionality requirements of the project and, of necessity, it was decided that special purpose equipment needed to be designed and built. It was realised at this stage that the equipment should be designed so that it could be used in future traffic studies. We focussed on the needs of the road pricing study but we designed the instrument so that it would be easily re-programmed in-situ with a new suite of software. Generic interfaces were designed in to allow for straightforward connection to a variety of instrumentation.

Since this instrument was designed specifically for the EuroPrice project it came to be known as the EuroPrice Vehicle Instrument or EVI.

2. A review of instrumentation used in some recent studies

In this section we consider two studies conducted recently in Europe (EuroPrice) and North America (Sacramento Instrumented Vehicle Study) which involved instrumentation of automobiles. The experiences of these studies illustrate the difficulties associated with instrumenting even a modest number of vehicles.

2.1 The EuroPrice Trial

The first study, EuroPrice [1], was funded by the EU as an investigation into the effectiveness of road pricing as a tool for reducing traffic congestion. Pilot studies were conducted in two European cities – Dublin and Athens. Both cities have notorious traffic congestion problems. The pilot studies were conducted over a four month period using 25 instrumented vehicles in each city. Details of the results of the Dublin study are given in [2],[3],[4]. While there was some variation in the fine details between the pilot studies conducted in Athens and Dublin the main thrust of the studies was the same. As a result identical instrumentation was used in both cities. The configuration of the instrument was different to account for currency differences (at the time of the study the Euro had not been introduced and costings were displayed in Drachmas or Punts as appropriate) and metric/ imperial variations. Different formulae were used to calculate costs as the prevailing conditions in each city were different.

To demonstrate the importance and effectiveness of the instrument to this study which focussed on energy and transport demand issues, some detail on the Dublin pilot study is presented here.

The objectives of the Dublin pilot study were to:

- Evaluate user response if road use pricing were to be introduced in Dublin
- Measure the resulting changes in private transport demand
- Establish the effectiveness of in-vehicle meters for road use pricing
- Investigate if the pricing levels used, which correspond to the marginal external costs, are effective.
- Note and observe potential problems for a full-scale trial of road use pricing in Dublin.

2.1.1 The EVI

The EVI is a programmable display and data logging instrument specifically for use in logging 'trip data' and displaying road use costs and depleting budget to the car driver. It is an 'in-car' instrument and in most respects is a 'one-fits-all' solution in that it can be retrofitted to almost all models of car. It interfaces to, in most cases, existing vehicle instrumentation.   Vehicle speed and distance travelled are determined from the tachometer.

The EVI records details of a driver's car usage, such as number of trips, distance and duration of the trip over an extended period (up to 3 months). In addition, it can calculate a cost for each trip according to a predetermined formula. The cost may include components related to congestion pricing as well as the conventional cost elements such as fuel, wear and tear and depreciation, if required. The particular pricing mechanism, with some restrictions, may be chosen by the researcher. Feedback on cost is provided to the drivers by means of a display panel.

The recorded data is stored in non-volatile memory and may be uploaded to a spreadsheet package via a serial interface at any time. Windows '95 based software is provided to configure the EVI and to retrieve the experimental data.

2.1.2 Functionality of the EVI

The basic functionality of the EVI is that of a trip-meter. For each trip it records the following information:

- Time and date of the start of the trip
- Duration of the trip
- Distance travelled
- A speed profile for the trip i.e. the speed is sampled at 10 second intervals and recorded with some data reduction
- A profile of engine speed is also recorded in a manner similar to the above.
- The computed cost of the trip
- The number of stops during a trip (i.e. when the car is idling – this gives an indication of congested conditions where necessary).

The trip data are stored in chronological order and indexed so that, under certain circumstances, the data may be viewed by the researcher. Information on costs, trip lengths, budget remaining and charge rates are presented to the driver on a real-time basis by means of an LCD display. The details, like the make up of the cost function, vary per site and are detailed later.

2.1.3 Programmability

The EVI has already been described as a 'programmable' instrument and this requires some clarification.

The EVI programmability is three-tiered. The most basic level, Tier 1, is that available to the installation engineer which provides for:

(a)   Calibrating the EVI for different tachometer types

(b)   Simple proofing and fault finding Tier I operations are EVI front panel operations.

At the next level, the EVI may be programmed with details of:

- The costing regime to be applied
- Initial value parameters for the selected costing regime
- Currency option
- Display parameters such as font, language, currencies etc.
- Distance meter used i.e. miles or kilometres
- Date and time of daylight savings changes to be made to the real time clock
- Vehicle identification information e.g. registration number, participant details
- Tachometer details for some models. Also at this level, the researcher may:

(i)   retrieve the data at any time

(ii)   re-initialise the EVI, thus erasing any accumulated data

Tier II programmable options use the PC interface and should be done prior to installation. Since the EVI normally uses the car battery/charging system as the power source, a separate power supply is provided to power the instrument on the bench.

Tier III operations are only available to the developer. As such they include such functionality as

(i)   addition of a new costing function

(ii)   addition of a new display option

Tier IV options are available to change the functionality of the instrument.

2.1.4 Costing Function

As stated earlier, distance and time based pricing was used, the form of which is as follows:

$$C = a\,D + b\,T$$

where C = Generalised Cost, D = Trip Distance, T = Trip Time and a, b = coefficients (or weights), effectively charge rates

The charge level is therefore a function of the distance (primary) and time (secondary) of the trip and the charge rates. As all of the parameters are known (or can be estimated in the case of trip time), the approximate cost of the trip is generally known prior to departure.

A standard balance between distance and time pricing of 3:2 was used, the only criterion being that the time based part of the charge should be less than that of distance to eliminate the potential dangers of time based pricing suggested by [5]. Further work would be required to identify the ratio for optimum user response and safety. The only criterion used in the selection of the off-peak charges was that there would be a significant increment between the peak and off-peak period charges. The selection of charge levels requires further work as only limited study of this issue was allowed here.

2.1.5 Results of Europrice Trial in Dublin

Much of the focus of the Europrice work was on the likely impact of road pricing on individuals. To create an incentive, a cash budget was given to each individual i.e. a sum of money was given to them from which they could pay the road pricing charges if they chose to do so. If they chose to reduce the number of trips they made by car, they were allowed keep whatever remaining budget they had at the end of the test period.

The EVI was used to log data for a period of weeks before road pricing was applied and for another period of weeks during the road pricing phase. The data was

downloaded from each vehicle into an Excel spreadsheet after the road pricing phase and cleaned of noise (i.e. trips where someone switched on the ignition but turned it off again without moving etc).

Statistical analysis was performed on the data, primarily to examine if the road pricing stimulus had invoked a change in behaviour manifested by some changes to the following variables:

- Number of trips made
- Distance traveled
- Time spent driving
- Amount spent on road pricing

More detail is presented in [2] on the impacts of road pricing on the individuals but a summary of the results is presented in Table 1.

VARIABLE (per week)	BEFORE AVGE / WEEK	AFTER AVGE / WEEK	% CHANGE	t-test result (>1.725 - 95% conf)
Total Trips	24.5	23.1	-5.7	1.38
Peak Trips	10.2	8.0	-21.6	3.63
Off-peak Trips	14.3	15.1	+5.6	0.95
Total Travel Time (mins)	422.6	382.7	-9.4	1.82
Peak Travel Time (mins)	234.8	193.2	-17.7	2.9
Off-peak Travel Time (mins)	187.8	189.5	+1.0	0.11
Total Distance Travelled (km)	158.5	138.9	-12.4	1.87
Peak Distance Travelled (km)	74.7	56.2	-24.8	3.49
Off-peak Distance Travelled (km)	83.8	82.7	-1.3	0.12
Total Amount Spent	39.9	32.8	-17.8	2.34
Amount Spent in Peak Period	28.9	22.3	-22.6	0.18
Amount Spent in Off-peak Period	10.9	10.5	-1.0	0.4

Table 1: Dublin EuroPrice Trial Results

It can be seen from Table 1, that the variables associated with the peak periods are significantly influenced by road pricing (significance > 1.725). In the case of peak period trips made by car, an average reduction of 21.6% was noticed. There was also some reduction in the 'total' variables but as they are related, the influence of changes in the peak period will also have an effect here.

As expected, due to the low charges imposed in the off-peak periods, there was little impact on the variables.

2.2 The Sacramento Instrumented Vehicle Study

The U.C. Riverside Center for Environmental Research and Technology presented results of a large scale study (550 cars over a 12 month period) at The World Car Conference in 1997. Some details and results of this study are presented in [6]. The main goal of the study was to accumulate second by second speed data in the greater Sacramento area. This data is useful in determining average trip speeds, driving styles, seasonal differences in trip times and so on. The equipment requirements were not dissimilar to those of the EuroPrice study and again non-standard equipment was used. They have reported difficulties with uploading of data – data was retrieved from the instrumentation at monthly intervals – and with unreliability. They have also reported difficulties with installation and de-installation.

3. The Design Specification for the EVI

The main features of the design are:
- Extensibility – the instrument is a platform with some core functionality which can be augmented with standard software and hardware plug ins
- Rapid installation and calibration procedure – not quite plug and play but this is the aim
- Long term reliability - fault tolerance, backup capability, tamper proof
- Non intrusive installation – should be inconspicuous, small, easily removed
- Measurement, recording and display capabilities
- Low manufacturing cost

The instrument has the following measurement capabilities:

- Distance measurement. The distance travelled per trip is recorded.
- Speed is measured and recorded on a per second basis during each trip. Storing raw data records of trip speed is impractical for studies of long duration e.g. 90 days or longer. So, some data reduction is done from which the speed profile can be reconstructed offline.
- Fuel consumption. Instantaneous fuel consumption is recorded over the trip duration. Again, as with speed measurement it is impractical to store length fuel consumption records so data reduction is employed and a decimated version is stored. Total fuel consumption is available but instantaneous fuel consumption as a function of vehicle operation condition e.g. speed, engine revs and so on, is more informative.
- Trip statistics. It is important to be able to characterise the nature of the driving cycle. Obviously, motorway driving will have fewer stop/ start sequences than city driving. The instrument records start/stop sequences on a per km basis over the duration of a trip. Other trip statistics recorded include trip duration, average speed, start and end times for the trip and the date of the trip. This information is useful in analysing traffic trends.
- Cost of the trip. Since the original motivation for the design of this instrument was to conduct a road pricing study it is essential to be able to calculate a cost for the trip which is then displayed to the participant.

3.1 Description of EVI Hardware

The EVI is a microprocessor based instrument with the following features:

- 16 bit microprocessor
- RS232 interface for communication with a host computer e.g. PC
- Real-time clock calendar
- 256 K electrically programmable memory (flash)
- 2 K battery backed ROM
- 128 x 128 backbit dot matrix LCD and LCD controller
- 3 opto-isolated counter timers

3.2 EVI Software

The EVI software comprises the following modules:

1. User interface – front panel interface
2. User interface – host computer interface
3. Cost function calculation:
     - Dublin
     - Athens
4. Real-time clock calendar interface
5. Display interface
6. Tachometer interface
7. Rev counter interface
8. Fuel meter interface
9. Pulse oximeter interface
10. Digital temperature sensor handling
     - Identification
     - Location and interrogation
11. Data base: storage of trip data

3.3 User Interface – Front Panel

The primary functions of the front panel interface are to provide access to the EVI data for the researcher and to allow the participant to check his driving record, or as in the case of the Dublin trial, to change phases at specified times. The installation engineer also has access to the calibration procedures. Once the calibration procedure is completed and verified this function is disabled.

4. Summary and Conclusions

The instrument designed for the EuroPrice study was successfully used to conduct the road-pricing studies in Dublin and Athens with no reported equipment failures or significant difficulties with installation or calibration. The studies were conducted over relatively length periods with some vehicles recording data for up to six months.

Configuration of the instrument was simplified by providing a simple Windows based GUI. No real technical expertise was required either to configure the instrument or to upload the data at the end of the trial.

Installation and calibration was occasionally more laborious than anticipated. In Dublin, the installations were done in the Department of Mechanical Engineering at Trinity College by a qualified mechanic. In Athens a mechanic with experience in installing taxi meters carried out the installations. The mechanic was well versed in this procedure and had fewer difficulties than anticipated in completing the installation and calibration. Most installation problems arose because of difficulties in interfacing to the vehicle tachometer. So, while the instrument could not be described as 'plug and play' it is not particularly difficult to use.

In situ re-programming of the instrument was very successful and considerably simplified the whole design and debugging process. It also allowed the vehicles to be instrumented before the software was complete and fully debugged.

The instruments were used successfully and generated extremely useful data for the analysis of transport policy on transport users. An average reduction of 21.6% in the number of trips made by individuals was found when testing road pricing in Dublin. Without the instrument, the researchers in this case would have been relying on the integrity of the individuals to log all of their car trips in a diary. Whilst in some types of studies, this is a useful way of proceeding, in this particular case it was imperative that the trip data could be verified independently.

4.1 Further Development

Further work is on-going to apply the instrument in new traffic studies. It is planned to conduct a repeat of the road-pricing study In Dublin to assess any variations in traffic flows due to recent changes in the traffic system e.g. the introduction of quality bus corridors.

Fuel consumption is of great interest in transportation studies as are vehicle emissions under a number of operating conditions. Ideally, instantaneous fuel consumption data over a trip duration are needed rather than gross fuel consumption. In-circuit fuel flow meters are problematic in terms of cost, installation and de-installation difficulties and possible impact on the integrity of the fuel flow line. Fuel consumption may be measured quite cheaply for vehicles with electronic fuel injection without modifications to the fuel line. In a single-point fuel injection system the instantaneous fuel consumption is proportional to the length of time for which the solenoid is open and the engine r.p.m can be determined from the number of opening sequences. The same principle can be extended to all electronic fuel injection systems. Further development work is being carried out to add this capability to the EVI for a future study.

There are some caveats of course. While the instrument is readily re-programmable, at its present level of development creating a new application requires in-depth

system knowledge which is really only available to the designers at the time of writing. Before this device can be released to the transport research community at large it is essential to automate the development of new functional blocks. This work is on-going.

5. References

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