Hybrid Buses – the benefits of matching to real routes

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ABSTRACT

Existing city buses are able to cover a wide operational envelope in terms of speed, acceleration and grade. This significantly exceeds the requirements of many routes particularly in flat, busy cities. The purchase and operating costs of a conventional bus are not particularly sensitive to performance level, but this is not true for a hybrid bus. Limiting the performance envelope of the bus can significantly reduce the size, weight and cost of the major systems on the vehicle. However it is essential to fully understand the real route requirements and to use accurate simulations to optimise the vehicle specification. This is being done using on-route measurements and ADVISOR simulations.

INTRODUCTION

Newbus Technology Limited are developing innovative hybrid buses based on a thorough evaluation of the vehicles' requirements and whole system design. Vehicle dynamic performance is one area being closely looked at.

Throughout the world, city buses are generally specified to be capable of relatively high speeds and climbing severe grades. In the UK, a typical modern vehicle can maintain around 50 mph on the level and climb a 25% grade fully laden. Clearly these are excessive capabilities in many city applications where traffic speeds are generally low and steep grades are not encountered. A typical London bus for example, such as that shown in Figure 1, will not exceed 30 mph in operation on almost all routes. The level of power available on the more recent designs is indeed sufficient to achieve longitudinal acceleration levels that can cause passenger discomfort, especially for standing passengers, if the vehicles are not driven carefully.

Because the purchase cost of a conventional bus is not heavily influenced by its power level, and in many markets fuel cost is not a prime concern, there has been little impetus to reduce power levels. In fact, drivers have expressed a strong preference for highly powered vehicles. There is also some concern that buses can accelerate quickly to match traffic speed.

In the design of a hybrid vehicle there is increased motivation to reduce the peak power level of the vehicle, as this has a significant influence on the size, weight and cost of all of the drivetrain components including the battery. There is also a significant efficiency benefit in avoiding the use of a large heat engine at low power levels. Reducing vehicle unladen weight further reduces the power requirement. In a future commercial environment, where fuel use is likely to become more heavily penalised, reduced fuel consumption will clearly become important.

As with any optimised vehicle, there is clearly a danger of unexpected performance shortfall. It is therefore necessary to collect representative data about actual in-service route dynamics and its variability. This then forms a qualified basis for careful simulation during vehicle design. It is only through working with statistical data during the simulation process that one is able to gain insights into the 'best' specification and to demonstrate the practicality and benefits of reduced envelope designs.

Figure 1 Picture of London bus on route

Measured data also provides a solid basis for 'what-if' investigations of more radical proposals such as limiting driver authority.

POTENTIAL FOR A REDUCED ENVELOPE BUS

Because a bus has a relatively fixed duty, there is scope to produce a range of vehicles with the performance of each model tailored to a class of routes. Whilst there are undoubtedly operational considerations such as a preference to be able to switch any bus to any route, in reality there are many cases where a vehicle remains on one type of route throughout its life. However, commercial considerations make it attractive to investigate whether the distribution of route requirements would support a single initial reduced envelope design that would cover a reasonable number of route applications whilst showing significant benefits. This can only be done by measurement of route characteristics.

It must be emphasised that there is no attempt to design a bus specific to a single route, rather a 'route class-specific' vehicle. Having said this, the Newbus designs will incorporate adaptive features to allow automatic tailoring to individual routes within the class.

IN-SERVICE DATA REQUIREMENTS

Although it is clear that many routes offer scope for a reduced performance envelope design, it is necessary to collect a significant sample of on-route dynamic data to allow the potential benefits to be studied by simulation. This can be divided into route topological characteristics and statistical on-route dynamics.

ROUTE TOPOLOGY

The gradients found on a route, their length and the speeds at which these are driven have a strong influence on both peak power and intermediate energy storage requirements for hybrid designs. It is therefore important to characterise a selection of routes in this respect. Initially, measurements are being made to establish typical cases and some idea of spread across the routes in a city. This allows the likely benefits to be identified before more extensive characterisation is carried out.

OPERATIONAL STATISTICS

It is also essential to investigate the distribution of dynamics on a single route caused by varying traffic conditions and as a result of different driving styles. It is important to understand the causes and scale of such real-world scatter. This is being carried out by measuring vehicle dynamics on selected routes for an extended period and identifying the variations within this. The objectives are to establish what are acceptable performance levels, how prevalent is 'over-driving' and how significant would be the effects on route timings of performance limitations.

DATA COLLECTION METHOD

Initial studies have been based on data collected for London Bus by Millbrook. These have allowed overall route dynamics and scatter on one typical route to be identified. These data were obtained from an instrumented vehicle in service.

To make it practical to collect what is likely to become large amounts of data it was important to develop a robust and low-impact data collection approach. It is also attractive to achieve the required level of accuracy without excessive cost, particularly as it may be necessary to monitor a significant number of vehicles in parallel. Finally, it was considered important to be able to collect the data remotely both to save time and to minimise the effect of such data collection on driving style.

The approach taken is to use a vehicle-mounted GPS receiver to collect 3 dimensional fix and time data. This is supplemented by 3-axis accelerometers that can be used to provide some data during any loss of GPS signal, for example in 'urban canyons' or under bridges. The accelerometers used are able to read gravitational force and can therefore be used to measure vehicle inclination when the vehicle is stationary or moving with constant velocity. The data is processed to give a 'most likely' set of readings before being stored in flash memory. A radio modem will be used to allow remote data access.

GPS data are recorded once per second, the accelerometer data are measured more frequently and filtered down to be recorded at the same rate as GPS data. This has the benefit of allowing peak accelerations to be captured and improves accuracy when integrating to estimate velocity and displacement.

DATA COLLECTION EXPERIENCE

Initial trials of the equipment have been encouraging, particularly the horizontal data. This was checked against a GIS map on a portable PC in real-time during initial data collection to allow the quality of the data to be assessed and to investigate the type of features that caused difficulty. In general a reasonable number of satellites were in view, even in city streets and the only difficulties came when passing under bridges. The route included a section along some relatively narrow London streets and there was some evidence of loss of precision caused by reflections from tall buildings. This is not thought to be a problem as such minor events can be processed out of the data. Although the results confirmed that achievable vertical GPS repeatability is quite good for measurements taken close in time, this is not sufficiently good to estimate grade. The use of full differential GPS is being considered, but may not offer enough improvement to be worthwhile.

The accelerometer pack gave good results which are clearly independent of the GPS data quality, however it proved difficult to reliably isolate gradient data from longitudinal accelerations on normal vehicle runs. Further work is under way to improve these measurements. Figure 2 illustrates the speed variation along the initial route measured. Figure 3 illustrates the variation in speed distribution from different runs on the same day.

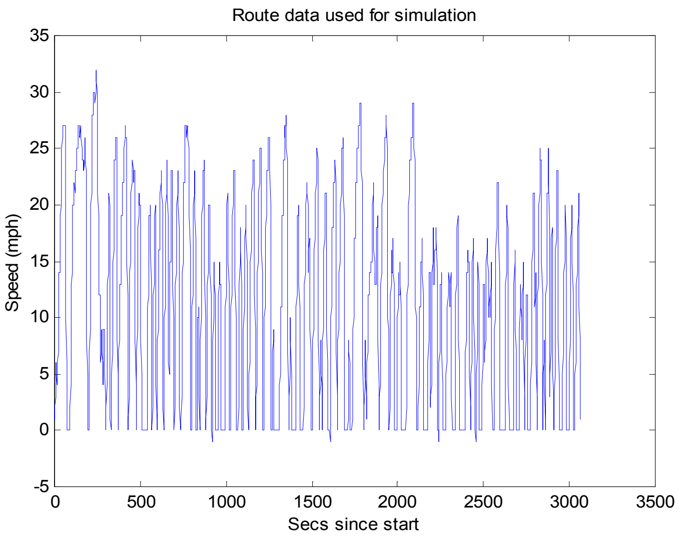

Figure 2 Measured route data used for simulation

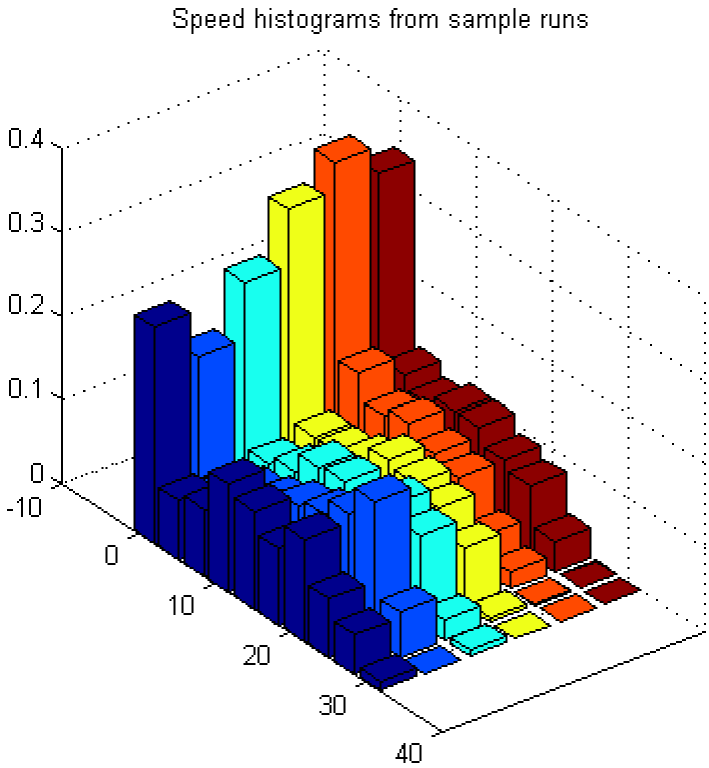

Figure 3 Fraction of time in different speed (mph) bands for consecutive runs

Following initial trials it was decided for future work to carry out an initial 'topology' measurement on each route, where precautions could be taken to ensure good grade information was obtained by stopping frequently along the route. The statistical data can be collected quite effectively in-service as planned. The GPS/accelerometer pack has proved itself effective for both types of measurement.

CHOICE OF ADVISOR

ADVISOR was chosen as the simulation tool for this project for a number of reasons:

- Its open-source format allowed visibility of the simulation process and ease of adaptation to specific requirements
- Processing of measurement data was performed in Matlab and was therefore easily linked to ADVISOR.
- The wide range of models available to allow work to be quickly started

ADVISOR SIMULATION STRATEGY

CONVENTIONAL VEHICLE

The initial route data was input as a cycle to an ADVISOR model with component models reflecting the design of a typical London diesel bus as shown in Figure 1. The fuel consumption derived from the simulation (5.52 mpg) compares well with actual values that are in the 5-6 mpg range for this type of route. The simulation's level of achievement of the demanded (measured) speed profile was also compared with likely load patterns during the day and confirmed that the simulation was giving a realistic model of the vehicle. Figure 4 illustrates the match at the selected payload. The ADVISOR results give fuel consumption in miles per US gallon rather than the figures above, which are in miles per UK gallon.

HYBRID VEHICLE

A hybrid simulation model was then created based on the Newbus hybrid design and used to investigate the performance of alternative hybrid designs.

ROUTE DATA

The use of real route data is preferred to standard cycles as the design is being optimised for representative routes rather than to a particular standard. This is more relevant for fixed-route vehicles such as buses. It is also important to include the effects of variability between drivers and different traffic conditions. An example of this is the change in speed profiles as the bus moves into the city centre.

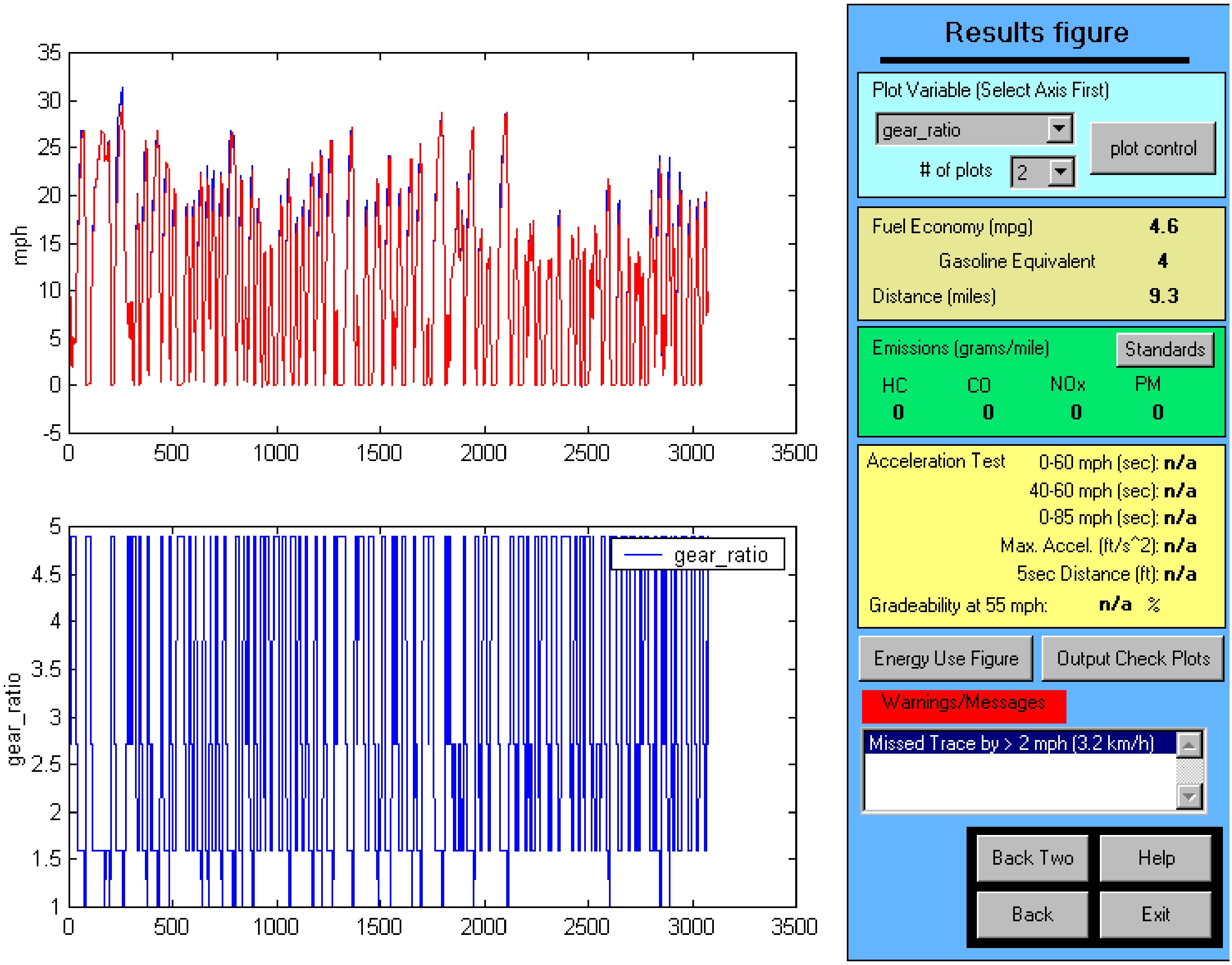

Figure 4 Results for conventional vehicle

ADVISOR MODELS

Initial vehicle models are derived from the built-in ADVISOR sub-system models, suitably modified to reflect the conventional and Newbus vehicle designs. As the development progresses it is anticipated that more of the elements will use Newbus-specific models. These will be particularly important for the Newbus custom hybrid controller, which incorporates a number of new features, and the battery model, which is to include a battery damage model to assess in-service battery lifetime. Some particular modelling issues arose during the work:

FLUID FLYWHEEL

The conventional bus uses a fluid flywheel rather than a torque converter and this was modelled as a manual gearbox with slightly higher numerical ratios in the lower gears combined with reduced overall efficiency.

PAYLOAD

The payload was set by running the model with increasing load until the best match with the measured speed was achieved. In reality the payload changes with time and at some time it would be interesting to look at changes in this as part of the simulation as it has a major influence on fuel consumption and the performance required.

ACCESSORY LOAD

It would be helpful to be able to model varying accessory loads as these can vary with engine speed and/or strategy. Without this the load tends to be overstated on the average or understated at the peaks. It is planned to capture real operational data in this area.

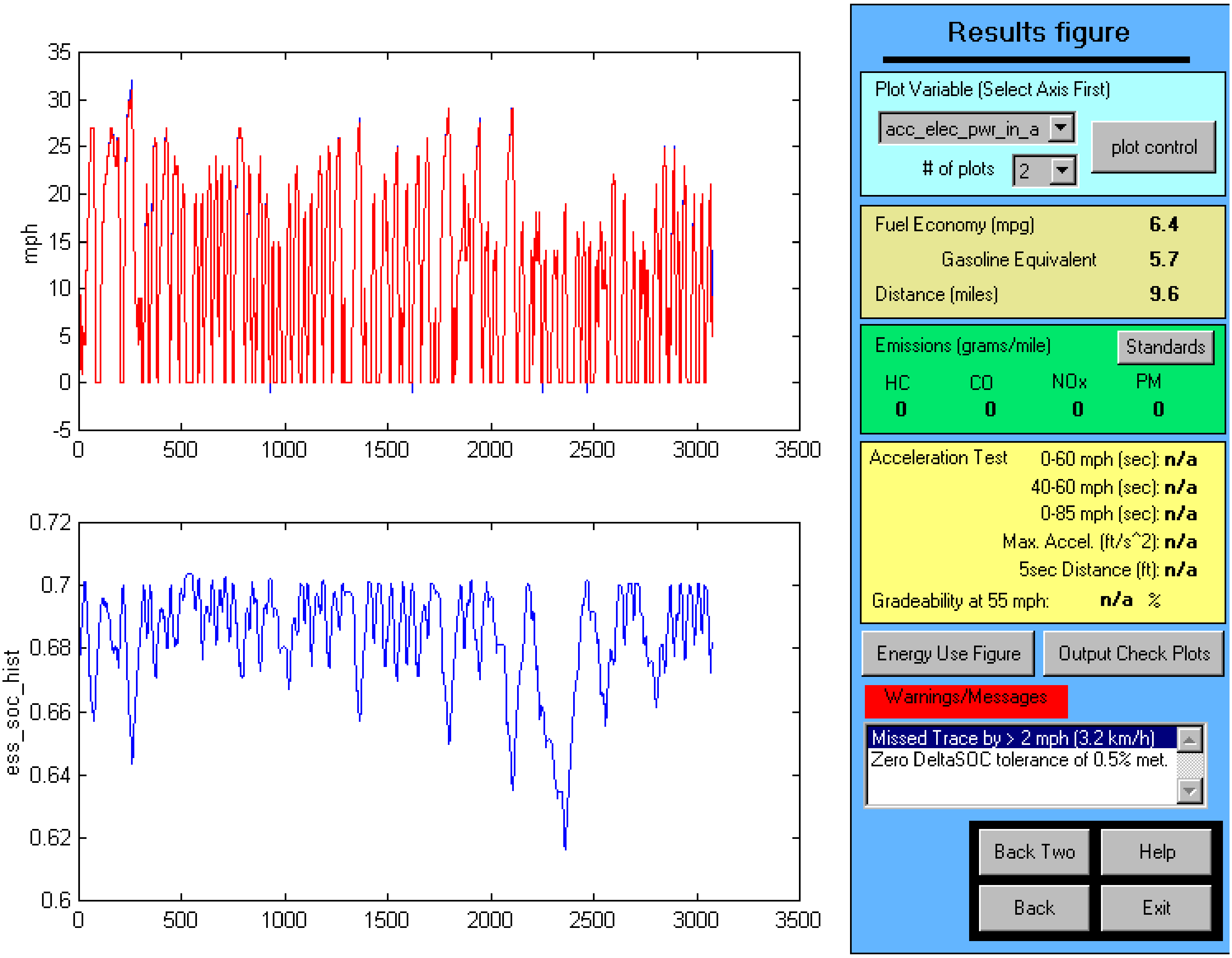

Figure 5 Reduced envelope hybrid results

REAR WHEEL DRIVE

It would be helpful to put this in explicitly. Even though this is almost certainly immaterial here, it would be comforting to know that everything was the correct way round.

FUEL CONVERTER 'SWEET SPOT'

Some effort was taken to match the generator and fuel converter to bring the fuel converter operating point to maximum efficiency at low operating speed. This may be possible in a more efficient way with more familiarity with ADVISOR.

MOTOR/CONTROLLER SPEED OPTIMISATION

The optimisation tool was found to be very useful in setting overall reduction ratio.

INITIAL FINDINGS

Initial results from the first ADVISOR hybrid models are shown in Figure 5. Significant fuel savings were possible in comparison with a 'full-envelope' hybrid design. As is generally recognised, it is necessary to carefully match the individual elements of the hybrid driveline to deliver the potential of each hybrid design.

The initial simulations confirm that a reduced envelope vehicle could service all sections of the route measured in London. In many cases the acceleration levels currently used offered no savings in route timing, but clearly reduced passenger comfort and increased fuel usage and emissions. There is therefore scope for further reductions by further reducing performance, though this clearly depends on the results of ongoing route measurements.

NEXT STEPS

The data collection technique is to be used in a number of UK cities to collect a representative sample of route data. This will then be characterised and used as simulation data for a new reduced power hybrid design. The use of carefully chosen actual route data will allow detailed assessment of the operation of the new vehicle and optimisation of its control strategy.

The process of in-service measurement coupled with detailed ADVISOR simulation will allow a thoroughly researched requirements specification to be drawn up for the vehicle with a high level of confidence of successful operational performance.

Future simulation work will include emission data and cover the spread between routes, drivers and time of day in more detail.

CONCLUSIONS

Initial results confirm the potential for a lower power hybrid design that offers lower purchase and operating costs, and reduced emissions in comparison with higher power hybrid designs. Ongoing work will develop this approach and allow the optimum power level to be specified taking environmental and commercial considerations into account.

The use of in-service dynamic measurements coupled with ADVISOR simulation is essential to allow this approach to be carried out with confidence.

By actually capturing measurements from vehicles in service it was possible to validate the data on a conventional vehicle before moving to a hybrid design.

The Newbus reduced envelope hybrid shows a reduction in fuel consumption of almost 40% over a conventional bus. This is achieved with battery cycling designed for long service life.

ACKNOWLEDGMENTS

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

GPS:

Global Positioning System

GIS:

Geographical Information Software