Institution: Queen's University, Belfast

Unit of Assessment: 12

Title of case study: New Eco-Friendly Hybrid Buses for London and Beyond

1. Summary of the impact (indicative maximum 100 words)

Using powertrain system models arising from QUB research **Wrightbus Ltd** developed an advanced eco-friendly hybrid diesel-electric bus which won the **New Bus for London contract worth £230M supplying 600 buses to Transport for London** (commencing August 2012)**.**

Demonstrating highly significant economic and environmental impacts the bus has twice the fuel economy of a standard diesel and emits less than half the CO_2 and NO_x. The full fleet **reduces annual CO_2 emissions in London by 230,000 tonnes**, improving air quality and reducing greenhouse gases.

The company continues to develop the technology in new hybrid vehicles **reaching worldwide, including USA, Hong Kong, Singapore and China**.

2. Underpinning research (indicative maximum 500 words)

Engine performance simulation research has been led by Professor Douglas since the mid 1990s. Prior to this, much of the predictions for engines used data from prototypes and operational systems, and little existed in reliable models which could be used effect in design. Much of the problem relates to the complexity of performance in a typical drive cycle which has a large number of constantly changing parameters and is therefore difficult to extract reliable average or predictive measures. The breakthrough was in developing the 1-D code which though of low fidelity allowed a complete predictive model to be established with reliable output. The work continued throughout the late 1990s with the development and implementation of component models for Internal Combustion (IC) engines [1,2] leading to the evolution of fully operational engine simulation code [3].

The success of the 1-D simulations allowed further development to the broader powertrain system using 2-D models (Douglas & McCullough, joined 1999) and linking several system elements together to provide a complete picture. This was achieved through the "Virtual Engineering Centre" [6] with the theory for modelling of powertrain systems and components [4], where the first simple vehicle models were developed and tested. The team built state-of-the art test cells for validation of performance over the full cycle. Validation of the models was a key aspect of the development and techniques were developed both on test rigs and on-road in vehicles and the data was compared with other published information. This investment was a key part in improving the reliability and accuracy of models, moving from the research environment to working prototypes in operation.

To this point much of the work had been focused around traditional IC engines but the capability now permitted consideration of hybrid diesel-electric drives, which was previously too challenging with existing approaches. **Since 2005 Douglas, with co-workers Fleck and Kee, led the final phase of this research, collaborating directly with Wrightbus on development of techniques for modelling of vehicle powertrains for hybrid vehicles [4,6,8].** From 2007 to 2009, full vehicle models were constructed, tested and validated and detailed component models for items

such as batteries, motors, inverters, were developed. The models were then assembled into useful design tools to allow Wrightbus to use them in assessing system designs. In particular the full drive cycle was investigated and the efficiency of each element of the system assessed. Each element was then tuned by industry (collaborations involving Wrightbus Ltd, Revolve Technologies Ltd) to allow maximum performance at all phases of the drive cycle. **It was the culmination of this capability in 2009 that provided the key to the Wrightbus success, allowing development of optimum performance across the whole system.**

In the last phases, working with the industrial partners on the development of the new generation buses **extensive on-road testing was undertaken at Millbrook testing facilities (2009), overseen by Douglas**, to capture real drive cycle data for validation and verification. The models were extensively checked for accuracy and reliability over a range of vehicles and over a range of drive cycles.

3. References to the research (indicative maximum of six references)

System Modelling:

1. M.G.Reid, R. Douglas. "Quasi-Dimensional Modelling of Combustion in a Two-Stroke Cycle Spark Ignition Engine". SAE Paper 941680, SAE Off-Highway Congress, September 1994. DOI: 10.4271/941680
2. *G. McCullough, R. Douglas, G. Cunningham and L. Foley. "The Development of a Two-Dimensional Transient Catalyst Model for DI Two-Stroke Applications." Journal of Automobile Engineers, Part D, Vol. 215, D8, pp 919-933, August 2001. DOI: 10.1243/0954407011528482
3. *T. Khossusi, G. McCullough and R. Douglas. "Modelling of Oxygen Storage in Automotive Catalysts". Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering, Vol. 218, No 11, pp 1349-1362, December 2004. DOI: 10.1243/0954407042580066

Vehicle Modelling:

4. *A. Simpson, R. Fleck, R. Douglas, R.J. Kee. D. Steele. "Development of a Heavy Duty Hybrid Vehicle Model". SAE paper 2009-01-2933, SAE Commercial Vehicle Engineering Congress and Exhibition, Rosemont, Illinois, US, Oct, 2009. DOI: 10.4271/2009-01-2933

*Best 3 outputs

Grants:

5. *R Fleck, R. Douglas, GP Blair, "Development of the QUB Engine Simulation Package". Funded by 6 companies, 1992 to 1996, £235,000*
6. *R. Douglas, R Fleck, "Modelling of Powertrain for Hybrid Buses, £66k, jointly funded via Invest NI and Wrightbus", 2008 to 2010*
7. *R. Douglas, R. Fleck, G. McCullough, R. Kee et al. "The Virtual Engineering Centre". In collaboration with 3 Engineering Schools. Funded by SPUR, 2001 to 2006, £5,100,000*
8. *R. Douglas et al. "The Total Thermal Management of a Hybrid Diesel-Electric Bus", TSB funded with Wrightbus,2010, total value £1.6m, £569k to QUB.*
9. *KTP007991 £192k 2010-2013 TSB & Invest N.I "To transfer the technology of Hybrid Modelling, enabling modelling of new configurations of the hybrid driveline for application in new city buses worldwide".*

4. Details of the impact (indicative maximum 750 words)

29,000 people die prematurely each year in Britain from man-made air pollution, mostly from vehicle exhausts, with London being one of the worst cities in Europe[#]. QUB technology is now being utilised to reduce this pollution.

Wrightbus is the UK's largest bus manufacturer producing a range of buses which it now exports globally. Wrightbus used the models and capability arising from this QUB research to improve their range of hybrid buses, **resulting in contracts of more than £230M for 600 buses and growth in the company to a workforce of over 1400 high value manufacturing jobs**. Most notably the work helped Wrightbus secure the contract to replace the iconic Routemaster for Transport for London. In tests at Millbrook Proving Ground, the engineering test vehicle emitted only 640 grams per kilometre (g/km) of CO_2 and 3.96 g/km of Oxides of nitrogen (NO_x) – less than half of the CO_2 emitted by a current diesel bus (1295g/km) and under half of the NO_x emitted by a current diesel bus (9.3g/km). **In testing, fuel economy was also better than twice that of a standard diesel bus at 11.6mpg.**

The hybrid bus model is a simulation of the complete vehicle which allows designers to assess the performance of the bus (power and fuel usage) over the whole drive cycle in a city, with its numerous stops, starts, accelerations and decelerations. It was developed with the express aim of assisting in the design of hybrid drivelines for city buses, to specify components and to optimise control strategies. The model has almost 50 person years of research embedded within based on extensive theoretical work and experimental validation. The pivotal capability is that the model works reliability over the whole drive cycle allowing designers to tune engine and powertrain performance at all points.

This was directly introduced to Wrightbus, Ballymena initially through a Knowledge Transfer Partnership (KTP, commenced 2010) to implement the model into their design process for new hybrid buses. It is now **routinely used by their engineers for specification of hybrid buses and has been applied in a series of projects**. It is accepted as an important design tool and has been well validated for accurate prediction of fuel economy and emissions of the Wrightbus product range. This key capability allowed partner company Revolve Technologies Ltd., working with Wrightbus, to develop an engine management system which controls performance and doubles the efficiency of the vehicle.

As well as the modelling and design of hybrid bus systems, this approach is now being applied to evaluate the performance of new technologies and for optimising non-hybrid powertrains. Wrightbus is continually searching for lower fuel economy and better efficiency as their global market grows. They have now employed one of the QUB research team members who developed the vehicle model as their technology specialist.

The economic impact of this research has therefore been more widespread throughout the global bus industry through the vehicle modelling work in **collaboration with Wrightbus Ltd, the leading manufacturer of city buses in the UK** and an **exporter across the world from Singapore and Hong Kong to Las Vegas.** The research contribution has assisted Wrightbus in improving their range of hybrid buses, in evaluating various technologies for fuel economy improvement.

The New Bus for London had **star billing during the London Olympics with the first 4 prototypes operating and on display throughout 2012**. The **Lord Mayor of London**, Boris Johnson, has acclaimed "*Christmas has arrived early in the form of this revolutionary new bus…it is the **latest, greatest masterpiece of British engineering and design**, and I am certain it will become a much loved and iconic vehicle akin to the legendary Routemaster from which it draws so much inspiration*". Since 2012 buses have been gradually introduced to Central London routes and being operated by Arriva.

Moreover the bus is seen as a way to improve London's air quality. The full fleet will reduce NO_x emissions by 57% and an astounding 230,000 tonnes of CO_2 every year. Air pollution costs the UK £15bn per year, mainly from the cost of treating respiratory diseases (e.g. asthma) and heart attacks that air pollution causes[#].

The success is now attracting further investment from the partners in the TSB supported project "**The Total Thermal Management of a Hybrid Diesel-Electric Bus**" with Douglas and McCullough leading the QUB team, and in 2012, a new development project was set up in collaboration with Flybrid Automotive Ltd to apply the flywheel storage as used in Formula 1 cars to city buses.

[#]*Guardian article "All Choked Up- Why is our air so dirty" 20th March 2013*

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Company contacts relating to Wrightbus associated claims:

Engineering Director, Wrightbus Ltd, Ballymena.

2. Articles on hybrid bus testing at Millbrook

http://www.greencarcongress.com/2009/05/revolve-gemini-20090514.html

http://www.thegreencarwebsite.co.uk/blog/index.php/2009/05/16/best-fuel-results-yet-for-double-decker-bus/

3. Articles on London Buses

http://london.gov.uk/media/mayor-press-releases/2011/12/mayor-heralds-the-arrival-of-the-new-bus-for-london
http://www.london.gov.uk/media/mayor-press-releases/2011/11/mayor-drives-first-new-bus-for-london-off-production-line

4. Article on Thermal Energy Recovery Project

http://www.lowcvp.org.uk/lceb/monitoring/details.asp?id=35