Greater Wellington Regional Council

Technical advice concerning Wellington’s trolley bus network and potential alternatives

Responses to questions – 6 June 2014 updated 10 June 2014

Introduction

Price Waterhouse Coopers was engaged to undertake evaluation of the potential configurations of Wellington city’s future bus fleet. A detailed report was completed on 4 April 2014 and information from this report was used within the draft Regional Public Transport Plan (PT Plan) on which the Council recently consulted.

Jacobs was engaged to provide technical advice concerning Wellington’s trolley bus fleet and alternatives. A detailed presentation was presented and discussed at a workshop of all Councillors on 4 June 2014 (attached).

During the consultation on the draft PT Plan Councillors and submitters raised a number of questions. This document provides a response to questions, using input from Jacobs, Price Waterhouse Coopers and GWRC staff.

Structure

The document is structured as follows:

1. Questions relating to the overhead
2. Questions relating to the power supply
3. Questions relating to the existing trolley bus fleet and trolley buses internationally
4. Questions on alternative bus fuelling and other public transport options for consideration
5. Questions on PwC report
6. 2014/15 Annual Plan assumptions
7. Presentation slides
8. Jacobs staff profiles
9. Additional question

1. Overhead

a) It is true that the current trolley bus overhead wires are in overall good repair, and that no new major investment over and above the current levels is required?

Refer slides 19 and 21

Following staged investment since 2008, the overhead network is in the best condition it has been in for 30+ years, so that reliability is far superior on renewed sections and ongoing maintenance much lower.

30.7 km of wiring (37.7%) has been replaced since 2008, current projects will replace a further 18.3 km (projects 1 + 2 are under construction and 3 - 5 are scheduled for 2015-2016).

This totals 49.0 km or 60.2% of the overhead network.

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1 “Evaluating the impact of different bus fleet configurations” 4 April 2014
2 “Slides” refers to Jacobs presentation attached at the end of this note
2. Power supply

a) If you increased the amount of power through the wires would you need fewer substations? What would the implications of this be? If the voltage was increased to 750v then only 7 substations would need to be upgraded at a cost of $14m, is this true?

Refer slide 21, and 26 - 28

Modern trolley buses would require 750 V and would draw more power. It is very likely that the overhead network would cope with this, subject to satisfactory results from inspection of insulation and assuming ongoing renewal expenditure and routine maintenance.

However, increasing the voltage would require new transformers, rectifiers and control equipment such as circuit breakers and fault detection.

Existing substation equipment (except in two which have been replaced with modern transformer and rectifier equipment recently) is ‘museum’ age. If the equipment is not replaced, reliability will be reduced and the likelihood of extended outages increases, as a result of the lack of spares, lack of skilled technical staff experienced in this equipment and lack of system redundancy (more than one energy supply route).

A redesign of the system would be more likely to result in an increased number of substations rather than fewer.

Existing underground cabling (53km) is very old and deterioration in insulation is almost inevitable, and would almost certainly have to be replaced.

b) Is it true (submission 531) that “the substations and underground cabling of the trolley buses are not worn out or overloading, and only need quite modest expenditure in maintenance and ancillary protective gear to make them reliable, at a small fraction of the nominated $52 million replacement expenditure?”

Refer slides 26 – 27

This is incorrect. The existing system is overloaded – regular tripping without faults such as broken cables connecting to earth demonstrate this.

As stated above, existing substation equipment (except in two which have been replaced with modern equipment recently) is ‘museum’ age. Existing underground cabling is very old and deterioration in insulation is almost inevitable.

Jacobs considers that Wellington Electricity’s estimate of $52 million is likely to be light considering the need for underground cable replacement. Trenching in CBD areas typically costs $1,000 / m. The $52 million does not include WEL’s return on capital.

The $52 m + could be staged over say 5 – 10 years, addressing failures, most highly stressed parts and those that show higher levels of vulnerability in testing first. However, the system owner Wellington Electricity has advised that to keep the system operating beyond 2017, it requires that end of life circuit breakers and rectification equipment are replaced (as these components have the highest risk to system security, reliability, and operator safety).

Wellington Electricity considers the replacement of the underground cabling could be staged, but that this would provide low to poor levels of reliability until the replacement occurred.

This advice from Wellington Electricity is consistent with the advice provided by Vector Limited (its predecessor) to Stagecoach New Zealand in 2006, which was that the Vector would manage...
the system to ensure the life of the assets was 10 years, on the basis that after that they would be decommissioned.\(^3\)

c) **Is it true that the substations for the trolley buses are similar to those on the rail network?**

No. Half of the Wellington Electrified Area (WEA) substations are essentially brand new from the upgrade in 2010. All WEA sub stations are newer than 1949 (the oldest is Petone which is due for replacement under Government funded catch-up renewals), and the average WEA substation age is in the 1990’s. Many of the 1980’s substations are going to have some attention in the next Network Management Plan (asset management plan for the network) in terms of improved condition monitoring, equipment upgrades and part renewals. In addition, the rail system has redundancy built in.

3. **Existing trolley bus fleet**

   a) **Would the cost of modernising the trolleys be cheaper than replacing them with diesels?**

   Refer slides 30 – 31

   This depends on the extent of modernising undertaken. However Jacobs’ recommendation is that further refurbishing of the existing fleet is unlikely to prove a value for money investment.

   b) **What age are Wellington’s 60 trolley buses? The Regional Council report says they are ageing and ‘nearing the end of their lives,’ while some submitters claim that most are either 5 years old or 9 years old? How many years of life does the trolley bus fleet have?**

   It is very difficult to be definitive about the age of the trolley bus fleet because available information is conflicting. Jacobs has concluded the most likely position is:

   - The trolley buses are ‘refreshed’ 1980s vehicles with new Designline bodies delivered 2008-09
   - Running gear, electrical and control equipment mostly dates from the 1980s, but some has been replaced over time
   - The low floor three axle chassis appear to date from 2007-08
   - Some electrical and running gear is around 30 years old; other parts are newer
   - The passenger compartments are around 6-7 years old

   It is not possible to provide a clear cut answer to ‘How many years of life does the trolley bus fleet have?’ The remaining useful economic life of transport assets such as buses is primarily a function of four issues: reliability, availability (for use), maintenance costs, and passenger acceptance of comfort and condition.

   At some point, the conclusion is that something is costing so much to repair, is always breaking down and is so rarely available to use that it isn’t worth spending any more money and time on it.

   Jacobs’ conclusion is that the remaining life of the trolley bus fleet is likely to be in the range 5 – 10 years (i.e. up to 2019-2024), with mechanical and electrical failure leading to poor reliability, high maintenance costs and low availability the key issues.

\(^3\) Letter from David Tompkins, Vector Limited, to Allan Cannell, Stagecoach NZ, dated 21 March 2006
c) Can officers confirm whether trolley buses were simply ‘refreshed’ in 2007, as our report claims, or were they equipped with new bodies and motors, as some submitters claim?

Refer slides 30 -31 and response to question above and the additional information provided by GWRC staff below.

Stagecoach contracted Designline to refurbish the trolley buses in 2006, based on a one off design starting with the existing chassis and equipment re-utilised, with delivery of all buses expected by October 2009. This approach was taken as overseas sourced buses were expected to be at least three time the cost as the contract price, with European operators having paid $1 - $1.5 million per bus at that time.\(^4\)

The equipment that was re-utilized was the traction motor (with some modifications), the front axle and the rear drive axle, the steering box, and some solid state electrical equipment such as the lightening arrester and main fuse.

Although GWRC was advised that the existing chassis was being used, the chassis would have required modification to convert to 3 axles and GWRC officers have been informed verbally that a new chassis was used on the 3 axle buses – it appears likely that plans changed during the design process. The trolley buses have new aluminium bodies with wheelchair ramps as they are all super low floor.

d) Is it true that ‘international experience is that the cost of overall trolley bus operations and maintenance is not very different from diesels, as they are cheap to maintain and have long lives and low energy costs?’

Refer slides 11 and 33

This can be true for modern trolley bus fleets but is generally not for aged fleets. The costs of power supply equipment, distribution networks and overhead wires generally make trolley bus operation more expensive than diesels. Jacobs’ small scale evaluation for WCCL based on modern trolley buses and articulated diesel buses concluded trolley buses were about 10% more expensive to run, excluding costs of power supply equipment, distribution networks and overhead wires.

e) What would be the financial implications of withdrawing the trolleybus fleet after only approximately 9 years of operation?

In regard to trolleybuses the only costs GWRC will need to consider at the end of the 10 year trolley bus contract in 2017 are those for the decommissioning of the trolleybus overhead network.

The contract for the provisions of bus services on trolley bus routes provides for no further payments for capital assets if the contract is extended past 2017 – in other words, GWRC has no further liability for the capital value of the trolley buses at the end of the current contract term.

The operator would also need to dispose of the buses. It is likely that this would be at little net cost, but substantial sale proceeds are most unlikely.

f) Is the use of trolley buses declining around the world?

Refer slides 32 – 34

Yes, by nearly all information and measures available.

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\(^4\) letter from Bruce Emson to GWRC CEO 29 May 2008
g) Could the buses be altered so that they are battery power when off the wires, and recharge the batteries whilst on the wire, making them more flexible?

Yes, this could be done.

However Jacobs concludes it is very unlikely to prove to be a cost effective investment. It would necessitate upgrading the power supply system (WEL’s estimate of $52 million, not including return on capital, and considered light by Jacobs).

h) Could we run trolley buses for another 5 years? What would the impact of doing this?

Refer slide 31.

Yes, they could be run for 5 years, or more, but with the impact of declining reliability, increasing maintenance costs and reducing availability. These will all impact on quality of service provision, and hence on the desirability and market share of public transport.

4. Alternatives for consideration

Hybrid diesel electric

a) How quickly could you get a hybrid bus?

Delivery lead times from Original Equipment Manufacturers likely to be 7 – 9 months.

Preparing to run and maintain a fleet would take longer, as would a properly structured tendering and acquisition process, necessary to ensure probity and the best financial and operational outcome.

b) What type of Hybrid would be suitable for Wellington?

In the immediate term, parallel diesel electric hybrid. This is same principle as Prius and Camry hybrid cars, where diesel motor charges batteries, but can provide power to the wheels directly to give greater acceleration and power when required. Braking is regenerative, recharging batteries.

c) What would the life of a hybrid bus for urban service and school service?

This is likely to be very similar to existing diesel buses – 20 years route service plus a few years for lighter school duties. A few are likely to be shorter due to collision damage or other incidents. However, reliable hybrid operations have only been established for 2 – 3 years so there is no evidence available to support this.

d) What would you need to trial and how much would it cost?

A trial could consist of 1 or 2 hybrid vehicles introduced into the fleet.

There will be personnel training, maintenance equipment and personnel training and one off administration and evaluation costs for the period of the trial.

Volvo indicates that it only provides vehicles with a rented battery, with a $ / km or $ / month charge. This spreads the battery replacement cost (currently estimated at $40,000 each 5 years) evenly over the operating period. Operating cost differential will be substantially influenced by battery hire cost ($700 – $800 / month – fuel cost savings)
e) **How much would a double decker/single decker hybrid cost?**

The latest information from Volvo states that the two Volvo B5RLE hybrid 11.4 m vehicles undergoing trial in Adelaide and Perth cost AUD$600k. It is possible that the cost in NZ could be a bit lower than this if locally assembled (under licence) with reduced air conditioning demand. Costs are likely to decline with reductions in battery pricing and volumes in NZ purchases, and worldwide sales volumes.

Volvo has a double decker diesel hybrid B5TL which is undergoing trial in London. It complies with the European vehicle width specification of 2.55 m, but not the NZ and Australian specification of 2.5 m. Cost ~$800k for double decker – possibly conservative, but redesign to get to 2.5 m wide rather than existing 2.55 m would add cost.

f) **Is it true that diesel electric hybrids do not save enough diesel to justify their much higher purchase prices, and battery replacement costs?**

Refer slide 42 – 43

This was true for early vehicles – many used more fuel than conventional diesels. But recent Volvo experience is that fuel savings are 30 – 35% in Australian conditions.

g) **Do hybrid buses use more fuel than conventional diesels?**

Refer slides 42 – 43 and answer to question above.

h) **Are hybrids more complex and expensive to maintain than a modern diesel bus?**

More complex – yes.

More expensive to service – not once appropriate staff are engaged, trained and experienced. The maintenance task has a lot more computer and IT skill requirement and not purely mechanical fitting and adjustment requirement. There is a much greater electrical skill and knowledge component.

i) **Could a hybrid bus run purely on its battery along the Golden Mile when in normal everyday operation, would this type of running significantly affect the battery life?**

The hybrid vehicle technology can be configured to give the driver control from the driving position to switch from hybrid mode to full electric if entering an air quality zone like the Golden Mile. Alternatively, the vehicle can be configured to be done remotely by setting up GPS coordinates in which a signal is sent to the hybrid management system that switches the vehicle from hybrid to electric and then back to hybrid once the vehicle is clear of the zone stipulated. At this stage the life expectancy of the battery is around 7-8 years but there is no evidence available at this stage that suggests using the vehicle in and out of hybrid mode reduces the life cycle of the battery more than normal operation. Due to the distance and potential travel time in the peak along the Golden Mile, there could be an issue for charging the battery as the interchange location is so close to the start of the Golden Mile. However this could be overcome by accepting the interchange as a hybrid location. The typical range between charge phases is 30-40 minutes.

j) **Can officers confirm that there have been two New Zealand experiments with hybrid buses that have failed if so, what were they?**

There were trials of early hybrids in Auckland and Christchurch, both of which had issues with reliability and expense, consistent with overseas experience with early models. These issues have been resolved with more recent Original Equipment Manufacturer sourced hybrid models.
In June 2010 Auckland's early generation hybrid-power buses were taken off the road indefinitely because of reliability issues and were replaced with diesel vehicles. The City Circuit free service was introduced in 2003, using three red hybrid-electric buses arriving at 10-minute intervals on a route encompassing Britomart, Queen St, the Sky Tower and university campuses. Each bus cost ~$560,000 - twice the price of a new diesel bus. Ratepayers met the bulk of the cost, with the Auckland Regional Transport Authority paying $786,000 a year, Auckland City Council $40,000, and the Heart of the City business association chipping in.

The Christchurch city zero-fare shuttle was introduced in 1999. When the 3 buses were introduced they were powered by 54 solid gel, water-cooled batteries, charged via regenerative braking. This was supplemented by an auxiliary power unit (APU), using low emissions, diesel powered generator. The diesel engine was built to Euro 2 specifications. As in Auckland the buses had reliability issues and were expensive to run and maintain. The Shuttle service ended after the 2011 earthquake.

Electric buses

a) Is it true (submission 516) that battery/hybrid buses will weigh more and carry fewer passengers than conventional buses, and that they will need more energy to overcome their extra weight? Refer slides 44-45.

Yes, they are heavier, but typically 20 – 25% heavier not 40% (refer question below).

There will be an impact on carrying capacity, depending on vehicle tare, NZ axle load limits and the assumption about average mass per passenger. Reductions could range from 11 to 42 people on a 65 passenger vehicle (see slide 45). A review of the axle load limits is underway and the issues of heavier urban bus axel weights on high demand routes in major cities has been identified for consideration as part of this process.

b) Is it true without the use of overhead wires for recharging battery electric buses would be 40% heavier than equivalent diesel buses and thus carry one third fewer passengers? Therefore we would need 3 battery buses to carry the same number of passengers that 2 trolley buses or diesel buses could carry?

Refer slides 44-45 and answer to question above.

c) What would be the infrastructure and requirements to power battery electric buses – including charging stations, depot etc.?

Refer slides 46-47

Charging at depots will require several MW of power – typical of a medium factory, and requiring 11,000 V feed. Connection cost will be highly location specific (distance to 11 kV feed) plus network capacity increases, likely to cost $1-2 M pa, plus energy costs. The physical ‘power points’ will cost $500-$1000 each.

5. Questions concerning PwC report

a) What is the estimated price of oil that is used in the PwC cost benefit analysis?

The Ministry of Business, Innovation, and Employment (MBIE) forecasts for oil prices were used. These are the accepted values used when factoring in fuel price movements for government forecasts.
b) Could a sensitivity analysis of future diesel and carbon costs be carried out to help inform the decision on future fleet options?

Yes - a sensitivity analysis could be undertaken.

- Fluctuations in the diesel price may make a difference. MBIE do run alternate scenarios for fuel prices, so it would be a matter of recalibrating the model to that alternative scenario
- Carbon prices will make absolutely no difference. They are a tiny part of the overall benefits and costs so it would take significant shifts in the price to see any difference. It is important to note as well that a "social cost of carbon" was used which replicates the accepted environmental impact of carbon emissions. The "market price of carbon" (as currently charged in New Zealand via the ETS), or the market price in most places in the world is considerably less than the social cost used in the report.

c) Could a cost benefit analysis of the different fleet options be carried out that includes health, carbon emissions, fuel savings etc., which are presently externalities in the PwC analysis?

All these variables are in the report and the modelling, they are just not itemised (so as to be consistent with the NZTA approach).

d) What was the fleet replacement programme for the baseline scenario?

The PwC report assessed different combinations of bus types against a trolley/diesel combination “base case”. In the base case, as diesel buses came to the end of their life (20 years) then they were replaced with Euro V diesel buses, and the existing trolley buses were replaced by a new modern trolley bus system in 2018.

There was a separate scenario (the ‘run down’ scenario5) which aimed to identify the minimum possible investment profile – this scenario assumed the addition of Euro III buses to the fleet, brought to Wellington from other parts of New Zealand. This scenario was intended to provide context by explaining the significant investment involved in maintaining the existing bus fleet, and was shown as a comparison to the base case described above. The run down scenario was not included in the comparison of potential future options.

e) Do the option 1 costs in the PWC report include complete replacement of the trolley bus fleet?

Yes, the ‘diesel and trolley’ option replaces all of the current trolleys in the fleet with new trolleys.

f) Have the social and environmental costs of the different fleet options been included in the overall PWC analysis? And have potential fuel savings of the different options, and reduced greenhouse emissions, been included in the overall cost benefit analysis? Or are those costs ‘externalised’?

The PwC cost benefit analysis was undertaken in line with the NZ Transport Agency’s Economic Evaluation Manual, using whole of life costs over a 40 year evaluation period. As per the report, monetised benefits that have been included in the PwC report relate to those that may be realised from time savings and emission reductions (p30).

The relative emission profiles for the different bus fleets were included in the PwC cost benefit analysis where they were able to be monetised according to Transport Agency criteria. As per page 33, emissions for CO2, PM10, and NOx were monetised and included in the cost benefit analysis. CO and HC emissions were not able to be monetised but were included in the wider economic evaluation.

Fuel costs (as therefore potential savings) have been included in the cost benefit analysis (p35).

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5 See PwC report page 7
Outside of emission costs, the other social cost included in the analysis is the case study of noise impacts on the golden mile. As a case study only, this was not included in the CBA. The reason for this is that the NZTA Economic Evaluation Manual was not designed to evaluate whole of network impacts.

**g) Why did the PWC report not consider the option to partially use trolley buses —eg on 2-3 routes of the spine until 2022 -- or the option of upgrading trolley buses with batteries and other new technologies, rather than simply scrapping them?**

The analysis was undertaken based on the current bus network and routes due to the need to compare "like with like" in terms of the network. Jacobs have advised that further upgrades to the existing vehicles are unlikely to be cost effective, nor deliver a reliable ongoing solution consistent with modern standards (see slide 31).

**h) What are the capital costs of installing battery-electric buses into Wellington, and were they included in the PWC baseline assessment?**

The option to replace buses with electric buses was included in the assessment. The electric buses included in the analysis related to 'opportunity' charging buses rather than overnight charging buses. The present value capital cost of this option was approximately $200 million. As outlined in the report, there is considerable uncertainty surrounding the costs of electric buses as they are an emerging technology. It is worth noting that as per the defined options, this assumes that both trolleys and diesels are replaced with electrics.

**i) Was the cost of pulling down the overhead wires included in the PWC assessment? (#594)**

The cost of pulling down the overhead wires was not included in the assessment. This was based on an assumption that the decommissioning costs would not be costs incurred by GWRC.

Some submitters have quoted $20m to remove the overhead network. This has been sourced from a table in the draft PT Plan (page 85), and is actually the indicative capital cost overhead network renewals from 2014-20, including an allowance for removing the overhead wires after 2017 equivalent to one year’s normal renewal costs. The majority of this amount is expected to be used on upgrading sections of the overhead considered likely to fail, and in making health and safety improvements.

**6. Diesel buses and emissions**

**a) What are the greenhouse gas emissions for each of the diesel euro standards?**

Refer slides 36 – 39.

**b) Is it true that greenhouse gas emissions for Euro 5 buses are greater than for Euro 4 buses and are on a par with Euro 2?**

No – see reductions in emission standards on slides 37 and 38. Also see requirement for Euro IV and later to maintain these standards for 7 years and 500 / 700,000 kilometres, and conclusions on fuel consumption on slide 40.

The important thing with CO2 emissions is diesels by their nature have much lower CO2 emissions than petrol vehicles comparing like with like. A Euro 5 diesel car has half the CO2 emissions of a Euro 5 petrol car. If there were petrol buses, it is likely that the difference would be greater.

Current Euro standards do not include CO2 directly, and therefore calculating CO2 by Euro standard relies on assumptions. PwC has compiled a graph, assuming each Euro diesel bus lower
than Euro V is assumed to be approximately 5% less efficient than the next higher standard. For example, Euro IVs are assumed to be 5% less efficient than Euro Vs.

c) **Do we have data on the health costs of diesel buses? (S18)**

An assessment was not explicitly undertaken relating to health costs in the PwC report. The monetised values applied to $\text{CO}_2$, PM10 and NOx emissions may partially capture this. It is important to note that there have been a range of studies in NZ and overseas that assess the health impacts of diesels. These studies are often linked to the types of diesels in the fleet at the time so it would be difficult to value health impacts of a future fleet.

The World Health Organisation (WHO) has recently announced that diesel is a carcinogen. It has been defined as a probable carcinogen for some time, which is why emissions are regulated in New Zealand and in most Western countries. In addition to diesel, emissions from motor vehicles known to cause adverse health effects are the gases carbon monoxide, nitrogen oxides, volatile organic compounds and sulphur dioxide, as well as solid particulate matter. Other gases (such as ozone) and secondary particulate (sulphates and nitrates) can form in the atmosphere from reactions involving some of these primary emissions.

There is extensive information available about the health effects of these pollutants. GWRC undertakes air quality monitoring in Wellington, and the most recent reports show that air quality at monitoring sites located next to heavily trafficked roads in central Wellington, Ngauranga and Melling, although poorer than that measured at the residential sites, met all national standards and guidelines for the three indicator pollutants measured.

Based on data in GWRC transport models, diesel buses travel approximately 1.7% of the total vehicle kilometres by diesel vehicles in Wellington, and account for approximately 2.9% of diesel fuel consumption in the region.

d) **Is it true that modern diesel technology produces more CO2 emissions than older diesel technologies, as some submitters claim?**

$\text{CO}_2$ emissions in the PwC report were based on a bus efficiency x emission per MJ basis. As later model diesel buses have been assumed to be more efficient in energy use than prior models, the analysis shows $\text{CO}_2$ emissions to reduce with newer diesel technologies.
It is likely that post 2020 Euro standards for heavy diesel engines will be in g CO2 per kilometre travelled across each manufacturer’s whole fleet sales. This would make tracking progress easy and focus attention on a single performance measure.

e) **What is the cost of a Euro 5/6 with and without air conditioning?**

$450,000 for a 12m around 45 seat two door low floor route bus with air conditioning. With no air conditioning there would be a saving of $20 - $25 k (this would adversely affect resale value and could render vehicles very difficult to sell).

f) **Is it true that Euro 5, 6 and 7 diesel buses are complex and expensive to service and maintain, as some submitters claim?**

Yes and no. They require different skills, including a greater reliance on IT skills. This can make servicing by inappropriate staff or by inadequately trained and experienced staff more expensive, slower and less reliable. Such staff would probably perceive the maintenance as more complex and difficult. It is similar to learning a new computer program – initially they seem complex and difficult, but with appropriate training, experience and coaching, they become easier over time. Eventually the new program will seem superior to the old.

g) **Is it true that modern diesel buses are in practice no cleaner than older buses?**

Refer slide 36.

We can find no evidence to support this statement.

h) **Is it true that Euro 5 & 6 buses use more fuel than Euro 4 or below buses?**

Refer slide 40.

Yes, first examples of new generation Euro standard diesels generally do use more fuel, typically 5-10% more, but this varies quite considerably across manufacturers. As manufacturers gain more experience meeting the tighter standards, consumption generally reduces.

Fuel consumption is generally the highest priority consideration in selecting vehicles. Scania’s better consumption Euro IV led to great market share gains. It appears that Volvo’s superiority with Euro V has reversed this.

i) **Is it true that Euro 5 & 6 buses require complex dust particle filters and post combustion additives and exhaust treatment which further increases their running costs, and makes them vastly more complex and expensive to maintain than equivalent Euro 4 and earlier buses?**

Diesel engine manufacturers use various methods to achieve compliance, and Selective Catalytic Reduction (SCR) using AdBlue, a urea compound in exhaust treatment, plus Diesel Particulate Filtration (DPF) are commonly used methods to reduce particulates.

AdBlue is believed to add about 4% to fuel cost (seeking confirmation from other sources). DPF will increase costs, but are not believed to be significant (seeking confirmation).

Jacobs is not aware of evidence from bus or truck operators that these systems are expensive or difficult to service.

j) **Is it true that diesel engines will not be able to maintain compliance beyond 2020?**

Refer slide 41.

It is important to recognise that Euro standards applying when a vehicle is added to a fleet must be met at that time. There is no requirement to improve the performance of existing engines to...
meet later, more stringent regulations. This is why GWRC can continue to run earlier Euro standard engines when current standards are Euro V / VI.

It is not possible to say when these standards have not been defined or published and their achievability assessed. It is likely that post 2020 Euro standards for heavy diesel engines will be in g CO2 per kilometre travelled across each manufacturer’s whole fleet sales, which would make CO2 emissions the only measure.

7. **2014/15 Annual Plan assumptions**

a)  *Is it correct to say (submission 76) that the assumption in the Public Transport plan is that the cost of oil will be around $95 per barrel?*

It is correct that the proposed Annual Plan had oil at $US 95 per barrel and the NZ/US exchange rate at 0.80. Both of these will be reviewed and revised if necessary for the final Annual Plan. These are GWRC budget assumptions, and not factors that have been used in evaluating the options for the future bus fleet configuration.
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GWRC Councillor discussions
4 June 2014

Greater Wellington Regional Council
Te Pane Matua Talao

Agenda and issues

Welcome and introductions 0930
Presentation from Jacobs SKM team 0945
  • Objectives
  • Current situation
  • Power supply related issues
  • Overhead related issues
  • Trolley bus vehicle issues
  • Possible alternatives
Discussion 1030
Next steps 1130
Conclusion by 1300
Project objectives

• To provide sound technical advice to enable GWRC Councillors to make an informed decision on the future public transport service for Wellington:

• Will trolley buses form part of the fleet?

• Specifically identified issues:
  • Traction power
  • Overhead networks
  • Public transport vehicles and capabilities
  • Approximate cost estimates
  • High level evaluation of benefits and issues / risks

Background and current situation

• GWRC contracts to NZ Bus Limited and Wellington Cable Car Limited for trolley bus services and overhead infrastructure expire 30 June 2017

• Need to plan for actions well ahead of contract expiry

• PwC engaged to identify and evaluate vehicle fleet alternatives to meet desired service performance improvements – reporting April 2014

• Improved reliability, reduced transit times, reduced vehicle congestion in CBD

• PwC study informed by Public Transport Spine Study completed in June 2013, which recommended Bus Rapid Transit for the spine route:
  • Dedicated bus lanes
  • High capacity new buses
  • Improvements to improve frequency and journey times.

• PwC’s evaluation was against a base case of maintaining power and overhead infrastructure, and replacing diesel buses as they reach end of life with current Euro V / VI. Total Present Value of minimum investment of $463 M; $355 M in infrastructure, mostly electrical supply related, and $108 M in new bus capital and operating costs
Background and current situation

- PwC: substantial investment in vehicles required, based on age and NZTA’s 20 year bus life limit
- And an assumption that due to “trolleys and associated infrastructure nearing end of life...trolleys will exit the fleet in 2018” (p 31) – addressed later
- PwC considered 11 fleet options with combinations of trolleys and buses powered by diesel, hybrid diesel-electric, overnight charge electric, opportunity (wayside) charge electric and hydrogen fuel cell
- The evaluation estimated capex and opex and calculated NPV totals. Benefits were calculated relative to the baseline over 40 years (p10)

Background and current situation

- PwC’s conclusions on cost, against baseline of current fleet mix and new diesels Euro V / VI, favoured diesel and hybrid diesel-electric buses:
Background and current situation

• PwC’s overall conclusions were:
  • Maintaining the current fleet and network configuration is the poorest performing option (excluding hydrogen fuel cell buses)
  • Greatest environmental benefits come from replacing the early Euro diesel buses, regardless of the replacement fuelling
  • All options offer environmental benefits, including those that scrap the trolleys in favour of Euro V / VI diesels
  • Four options enable cost savings and increase environmental and efficiency benefits:
    – Euro V+ diesel
    – Hybrid diesel-electric
    – Electric
    – Accelerated hybrid introduction

This raised a number of issues, particularly:

• Are the costs to retain the trolley bus power supply infrastructure and overhead really as high as assumed?

• Intuitively, difficult to see how scrapping trolleys which are emission free at the vehicle and have low emissions at electricity generation could lead to better environmental performance overall

• Is the trolley bus system really in as poor condition as concluded?
Background and current situation

Wellington Public Transport Spine

The June 2013 Wellington Public Transport Spine study confirmed the route for the 9.5 kilometre public transport spine between Kilbirnie / Newtown and Wellington Railway Station.

The study concluded that a Bus Rapid Transit (BRT) system provided the highest BCR.

Wellington Cable Car commissioned SKM to undertake a brief study into the potential for trolley bus operation of the BRT, including comparisons with diesel buses.

Background and current situation

Trolley Bus Operation of BRT systems – international experience

The SKM study identified significant trolley bus operated BRT systems:

❖ **Quito, Ecuador.** One of the city’s BRT lines is trolley bus operated but the other lines built subsequently are diesel operated

❖ **Mérida, Venezuela.** A 10 kilometre line, the first stage of a more extensive BRT system, opened in 2007

❖ **Tehran, Iran:** 6.9 km busway operated by trolley buses since 1992

❖ **Proposal for a new trolley bus operated BRT line in Leeds, UK**
Background and current situation

Vehicle Cost comparison for modern articulated diesel (Euro V+) and trolley buses

- Energy cost for articulated BRT vehicles (2012 price levels):
  - Diesel $0.47 per kilometre
  - Trolley bus $0.30 per kilometre
  - Diesel cost is expected to rise faster than electricity in Wellington

- Maintenance costs for diesel and trolley buses are expected to be broadly similar.

- Overhead catenary maintenance (excluding capital renewal) for the trolley bus operation was estimated at $37,000 per track kilometre per year, based on WCC figures

- Overall, trolley bus operation of the BRT system was estimated at 10% more than diesel bus operation

- This analysis did not assess power supply or overhead – a basic assumption was that existing arrangements and infrastructure would be adequate

<table>
<thead>
<tr>
<th></th>
<th>Articulated Diesel Bus</th>
<th>Articulated Trolley Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Price per bus (2012 prices)</td>
<td>$700,000</td>
<td>$1 million</td>
</tr>
<tr>
<td>Buses required (AECOM data)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total Purchase Price</td>
<td>$28 million</td>
<td>$40 million</td>
</tr>
<tr>
<td>Payment period (operating life of bus)</td>
<td>18 years</td>
<td>24 years</td>
</tr>
<tr>
<td>Residual (resale) value</td>
<td>$35,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>Interest rate</td>
<td>7.5%pa</td>
<td>7.5%pa</td>
</tr>
<tr>
<td>Annual payments for 40 bus fleet (2012 prices)</td>
<td>$2.92 million</td>
<td>$3.64 million</td>
</tr>
</tbody>
</table>
Background and current situation

Service delivery comparison: Euro V+ diesel and modern trolley buses

- When comparing similar vehicles of the same age, there is little evidence of differences in vehicle operating speeds
- Trolley buses typically have better acceleration profiles than diesel buses
- Modern trolley buses are equipped with ancillary batteries enabling them to more easily bypass breakages in the overhead power supply than was the case in older trolley buses
- In the NZ environment, trolley buses have lower local and remote carbon emission than other jurisdictions
- They are quieter than diesel buses
- The overhead wiring and supports may be considered as a negative visual impact when compared with diesel bus operation

<table>
<thead>
<tr>
<th>Lyall Bay to Karori</th>
<th>Average Travel Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips tracked 2012</td>
<td>9,339 0%</td>
</tr>
<tr>
<td>Trips tracked 2013</td>
<td>8,863 33%</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
</tr>
<tr>
<td>Difference (%</td>
<td></td>
</tr>
<tr>
<td>2013 Breakdown</td>
<td></td>
</tr>
<tr>
<td>Trolley trips</td>
<td>2,943 33%</td>
</tr>
<tr>
<td>Diesel trips</td>
<td>5,920 67%</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
</tr>
<tr>
<td>% quicker for diesels</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Karori - Lyall bay</th>
<th>Average Travel Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips</td>
<td>7,968 0%</td>
</tr>
<tr>
<td>Trips</td>
<td>7,865 36%</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
</tr>
<tr>
<td>Difference (%)</td>
<td></td>
</tr>
</tbody>
</table>

Route 3 Summary Data - March to August 2012 and 2013

Trolley buses are around 10% slower on Route 3 – Karori / Lyall Bay
(The Green Route)
Background and current situation

Service delivery comparison - diesel and trolley buses

![Graph showing travel times for Route 3 - Karori Park to Lyall Bay]

**Route 3 - Karori Park to Lyall Bay**
Trolley & Diesel Travel Times (Mar-Aug 2013)

**Background and current situation**

**Service delivery comparison – diesel buses replacing trolleys**

- Analysis of requests for diesel buses to replace trolleys January 2012 to August 2013 provided to PwC showed replacement rates:
  - Varied from 8% - 32%
  - Averaged 24.3% over the 20 months analysed
  - Averaged 12.8% if Karori Tunnel excluded

- Causes recorded were:
  - Karori Tunnel 200
  - Road works 108
  - Overhead maintenance 78
  - Trolley bus mechanical 17
  - Weather 14
  - Street special event 6

- Fleet flexibility
Discussion

Scope and issues – power related

- **Overhead wiring:**
  - What condition is it really in?
  - What is required to improve reliability?
  - Could existing overhead cope with higher power demand from modern articulated trolley buses?
Overhead related issues

• Total overhead wiring covers 81.4 km, over 54.7 km of roads

• Annual overhead maintenance and capital upgrade costs have ranged $6 – $8 M, or $73 - $98 k / route km / annum currently

• This appears high against preliminary benchmark figures (Yarra Trams)

• Wellington Cable Car Limited mapping (next slide) shows:
  • 30.7 km of wiring (37.7%) has been replaced since 2008
  • Current projects will replace a further 18.3 km (projects 1 + 2 are under construction and 3 - 5 are scheduled for 2015-2016)
  • This totals 49.0 km or 60.2% of network

• Reliability is far superior on renewed sections, and ongoing maintenance much lower

• Following staged investment since 2008, the network is now in the best state it has been for 30 + years
Overhead related issues

• What is required to improve reliability?
  • Continue rewiring and upgrade program
  • Replacement of roadside poles and supports
  • Current annual renewal expenditure $1.0 - $1.5 M probably adequate

• Could existing overhead cope with modern trolley buses?
  • This would require voltage increase to 750 V from 550 V
  • Current vehicles draw 200 A steady and up to 600 A upon starting fully laden on inclines – new trolley buses will draw more power

  • Our conclusion is probably YES, subject to satisfactory check of insulation, assuming ongoing application of renewal expenditure and routine maintenance

Discussion
Power supply related issues

- The overhead network is supplied by 15 substations. The major components are:
  - 15 converter transformers
  - 19 mercury arc AC/DC rectifiers, 2 solid state rectifiers
  - 53 DC circuit breakers
  - 53 km of buried DC cables

23

Power supply related issues – current equipment
Power supply related issues – current equipment

Transformers and rectifiers have been replaced in two substations
the balance have not

Power supply related issues

Power supply current issues: underground supply cables, substations, DC rectifiers etc

• What is really required for upgrade and maintenance to provide reliability and meet current safety and other standards?
  • Wellington Electricity has estimated a total replacement cost of $52 M, not including return on capital
  • If the system is to continue operating reliably a staged replacement of assets is required
  • Failure is very difficult to predict – could last 20 years, could fail tomorrow
Power supply related issues

Power supply current issues: underground supply cables, substations, DC rectifiers etc

• **Is system overloaded?**
  • YES - Regular tripping / overloading is occurring

• **Other issues:**
  • Lack of personnel skills and knowledge with such old equipment
  • No spares: failure = no supply for weeks
  • Earth fault protection on the system is being installed by WCCL, but not integrated with WE equipment
  • $250 k per cabinet to upgrade protection – there are 50 (ie $12 m) WCCL budget $5 m for this

---

Power supply related issues

• **Could power supply system cope with increasing voltage to trolley buses to 750 V?**
  • UNLIKELY – this is a risky proposition for cables - it increases stresses on cables and reduces life expectancy
  • Essential to replace transformers and rectifiers
  • Underground cable would almost certainly have to be replaced
Discussion

Vehicle related issues – trolley buses

What is the age of the current trolley bus fleet and what is its life expectancy?

- The trolley buses are ‘refreshed’ 1980s vehicles with new Designline bodies fitted in 2007-08
- Conflicting information about history and what was done when
- Running gear, electrical and control equipment mostly dates from the 1980s, but some has been replaced over time
- The low floor three axle chassis appear to date from 2007-08
- Some electrical and running gear is around 30 years old; other parts are newer
- The passenger compartments are around 6-7 years old
Vehicle related issues – trolley buses

• What is the age of the current trolley bus fleet and what is its life expectancy?
  - New trolley buses typically have a life expectancy of 25-30 years
  - Remaining economic life is about the ratio of reliability, availability and maintenance costs, with a bit of comfort consideration
  - At some point, the conclusion is that something is costing so much to repair, is always breaking down and is so rarely available to use that it isn’t worth spending any more money and time on
  - Our conclusion is that the remaining life of the trolley bus fleet is likely to be in the range 5 – 10 years, with mechanical and electrical failure leading to poor reliability, high maintenance costs and low availability the key issues
  - Further upgrades to the existing vehicles is unlikely to be cost effective, nor deliver a reliable ongoing solution consistent with modern standards

Vehicle related issues – trolley buses

• Is it correct to say that trolley systems are declining worldwide?
  - Probably YES, but
  - It’s hard to be definitive. The hard evidence we have been able to find identified:
    - 321 trolley bus systems in 315 cities
    - Of these, 127 (39.6%) were still operating, the balance had closed
    - Majority in Eastern Europe
    - In the last 20 years we found:
      - 19 trolley bus systems reported as opening
      - 72 closing
      - Of those opening, 4 also closed
    - UITP states 40,000 trolley buses in 370 systems, but without supporting evidence
    - Wikipedia suggests around 300 systems currently, with 800 at various times
  - Wellington remains the sole survivor of Australasian trolley systems, including Adelaide, Auckland, Brisbane, Christchurch, Dunedin, Hobart, Launceston, New Plymouth, Perth and Wellington
Scope and issues – vehicle and fuelling

Is it correct to say that trolley systems are declining around the world?

The key issues driving the withdrawal of trolleybus routes have been:

- Change in power supply arrangements (e.g., in the UK tram and trolleybus systems were developed by local authorities who also owned the electricity supply network. When the ownership of the power supply systems transferred to the National Grid, the cost of power supply increased and the municipal operators switched from electric traction to diesel power)

- Demographic change – urban sprawl and the collapse of old industries. It was more difficult to respond to these changes with trolley buses rather than diesel buses because the patronage on individual routes was too low to justify the provision of the infrastructure.

- Traffic management measures such as one way systems require either the relocation of the overhead wiring or contra-flow trolley bus lanes (the contra-flow lanes are not necessarily a bad public transport outcome, but may be a poor traffic solution).

- The inability to fit pantographs to trolley buses is a constraint on their reliability, affecting overhead damage enormously.

Scope and issues – vehicle and fuelling

Is it correct to say that trolley systems are declining around the world?

Where trolley bus systems have been retained, it has often been on core routes with high service frequencies and short distances between stops. These are typically established corridors through high density residential and commercial centres. Car ownership in these corridors will be lower than elsewhere in the urban area (but this may be because of the existence of the high frequency public transport service). For example, many surviving trolleybus routes link – among other things – student residential areas and education campuses.

Where new trolleybus routes have been introduced, they have typically been:

- On high frequency spine corridors (usually as Bus Rapid Transit systems)

- As a means to regulate public transport service delivery – this is a factor driving the NGT proposal in Leeds, UK

- To reduce the impact of diesel vehicle exhaust fumes in congested urban areas (e.g., Bogota, Colombia and Merida, Venezuela)

- Encouraged by foreign aid and international politics – so the South American systems are based on European trolley bus manufacturers rather than light rail systems promoted by manufacturers in the USA.
Scope and issues – vehicle and fuelling

Diesel
- Are modern diesels in practice no cleaner than older models?
- Will diesel engines be able to meet post 2020 Euro standards?

Diesel electric hybrids
- Are diesel hybrids cost effective? Do they save enough fuel to offset greater capital and battery replacement costs?

Battery electric buses
- Are battery electric buses 40% heavier and thus able to carry fewer passengers? Does their range limit them to single shift operations?
- What are the capital costs for charging infrastructure?

Other fuelling

Vehicle related issues - diesel

- Are modern diesels in practice no cleaner than older models?
  - We can find no hard evidence supporting this

  - Reductions in emissions allowed Euro I – Euro VI (1992-2013, heavy vehicles, steady state testing) are:
    - CO: 66.7% Carbon monoxide
    - HC: 88.2% Hydro carbons
    - NOx: 95.0% Oxides of nitrogen
    - PM: 98.4% Particulate Matter
  - Transient testing was introduced from Euro III in 2001 with reductions required:
    - CO: 27%
    - NMHC: 79% Non methane hydrocarbons
    - CH4: 69% Methane
    - PM: 94%
  - Emission durability requirements were introduced with Euro IV in 2005
  - There is a Boris Johnson article in The Telegraph 6 April 2014 saying this, but without supporting evidence
  - We found a 2006 report claiming that NOx emissions in real world conditions were much worse than those achieved in testing – issues raised addressed in Euro V standards
## Vehicle related issues

### Table 1
EU Emission Standards for Heavy-Duty Diesel Engines: Steady-State Testing

<table>
<thead>
<tr>
<th>Stage</th>
<th>Date</th>
<th>Test</th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>PM</th>
<th>PN</th>
<th>Smoke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro I</td>
<td>1992, ≤ 85 kW</td>
<td>ECE R-49</td>
<td>4.5</td>
<td>1.1</td>
<td>8</td>
<td>0.612</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1992, &gt; 85 kW</td>
<td></td>
<td>4.5</td>
<td>1.1</td>
<td>8</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro II</td>
<td>1996.1</td>
<td></td>
<td>4</td>
<td>1.1</td>
<td>7</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1998.1</td>
<td></td>
<td>4</td>
<td>1.1</td>
<td>7</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro III</td>
<td>2000.1</td>
<td>ESC &amp; EL R</td>
<td>2.1</td>
<td>0.66</td>
<td>5</td>
<td>0.10</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Euro IV</td>
<td>2005.1</td>
<td></td>
<td>1.5</td>
<td>0.46</td>
<td>3.5</td>
<td>0.02</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Euro V</td>
<td>2008.1</td>
<td></td>
<td>1.5</td>
<td>0.46</td>
<td>2</td>
<td>0.02</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Euro VI</td>
<td>2013.01</td>
<td>WHSC</td>
<td>1.5</td>
<td>0.13</td>
<td>0.4</td>
<td>0.01</td>
<td>8.0×10¹¹</td>
<td></td>
</tr>
</tbody>
</table>

% reduction: 66.7% 88.2% 95.0% 98.4%

a - PM = 0.13 g/kWh for engines < 0.75 dm³ swept volume per cylinder and a rated power speed > 3000 min⁻¹

### Table 2
EU Emission Standards for Heavy-Duty Diesel and Gas Engines: Transient Testing

<table>
<thead>
<tr>
<th>Stage</th>
<th>Date</th>
<th>Test</th>
<th>CO</th>
<th>NMHC</th>
<th>CH₄⁺</th>
<th>NOx</th>
<th>PM</th>
<th>PN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro III</td>
<td>2000.1</td>
<td>ETC</td>
<td>5.45</td>
<td>0.78</td>
<td>1.6</td>
<td>5</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Euro IV</td>
<td>2005.1</td>
<td></td>
<td>4</td>
<td>0.55</td>
<td>1.1</td>
<td>3.5</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Euro V</td>
<td>2008.1</td>
<td></td>
<td>4</td>
<td>0.55</td>
<td>1.1</td>
<td>2</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Euro VI</td>
<td>2013.01</td>
<td>WHSC</td>
<td>4</td>
<td>0.16</td>
<td>0.5</td>
<td>0.46</td>
<td>0.01</td>
<td>6.0×10¹¹</td>
</tr>
</tbody>
</table>

% reduction: 27% 79% 69% 91% 94%

a - for gas engines only (Euro III-V: NG only, Euro VI: NG + LPG)
b - not applicable for gas fueled engines at the Euro III-IV stages
c - PM = 0.21 g/kWh for engines < 0.75 dm³ swept volume per cylinder and a rated power speed > 3000 min⁻¹
d - THC for diesel engines
e - for diesel engines, PN limit for positive ignition engines TBD

Vehicle related issues

Table 3

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Period*</th>
<th>Period*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Euro IV-V</td>
<td>Euro VI</td>
</tr>
<tr>
<td>N1 and M2</td>
<td>100 000 km / 5 years</td>
<td>160 000 km / 5 years</td>
</tr>
<tr>
<td>N2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N3 ≤ 16 ton</td>
<td>200 000 km / 6 years</td>
<td>300 000 km / 6 years</td>
</tr>
<tr>
<td>M3 Class I, Class II, Class A, and Class B ≤ 7.5 ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N3 &gt; 16 ton</td>
<td>500 000 km / 7 years</td>
<td>700 000 km / 7 years</td>
</tr>
<tr>
<td>M3 Class III, and Class B &gt; 7.5 ton</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Mass designations (in metric tons) are "maximum technically"
* km or year period, whichever is the sooner


Vehicle related issues

- Do later Euro specification compliant engines use more fuel?
  - YES – particularly the first models meeting the new specification may use 5 – 10% more
  - But this reduces over time as more experience is gained by manufacturers on how to more effectively meet the requirements
  - When considered in the context of "are newer Euro engines in practice no cleaner than older ones?", the size of increased fuel usage is not enough to offset the gains from the very much lower emission standards of later Euro standards
  - Later Euro V + that require AdBlue for Selective Catalytic Reduction (SCR) increase operating costs – by about 4% of fuel cost
Vehicle related issues - diesel

• Will diesels meet post 2020 Euro standards?
  • Hard to say when these standards have not been finalised, much less published – due in 2015 see http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm
  • EU is working on a comprehensive heavy vehicle CO2 reduction strategy
    • The standard is likely to be in the form of maximum CO2 per kilometre over whole fleet, as now in place for light vehicles
  • Has EC ever deferred an implementation or changed standards due to concern too many would fail?

Vehicle related issues – diesel electric hybrids

• Are diesel hybrids cost effective? Do they save enough fuel to offset battery replacement costs?
  • Early examples – NO
  • Newer examples (last 2 – 3 years) – YES
  • Consistent advice is that Original Equipment Manufacturer sourced hybrid models (OEM) are the only ones to consider – Volvo, Scania, Mercedes – several thousand in use from each worldwide
  • This means one manufacturer is responsible for all aspects – driveline, electrical storage, diesel engine, coachwork and ancillary functions
  • Capital costs: understand marginally more expensive than diesels
  • Fuel (and emissions) savings typically 30 – 40%
    – Savings only with stop start city operation – they perform worse on highway
    – Wellington should be a good candidate, as more energy will be lost through braking heat due to terrain
Vehicle related issues – diesel electric hybrids

• Are diesel hybrids cost effective? Do they save enough fuel to offset battery replacement costs?
  • Battery replacement interval typically 5 – 7 years provided they survive the first 12 months
  • Typical cost $5,000 for battery (ie $500 / kWh for 4.5 – 5.0 kWh battery)
  • Biggest issues have been:
    – Reliability / availability
    – Maintenance costs, particularly due to:
      ▶ Incompatibilities between equipment from various suppliers
      ▶ Proprietary equipment providers refusing to provide diagnostic equipment enabling bus companies to do their own maintenance

Underlines OEM recommendation

Vehicle related issues – battery electric

• Are battery electric vehicles 40% heavier and thus able to carry fewer passengers?
  • NO: but they are typically 20 – 25% heavier
  • The impact on maximum passenger carrying capacity will depend on bus tare mass and GVM limit
  • Most battery electric buses to date have been mid size ~ 35 seaters – like Adelaide’s Tindo

Adelaide’s Tindo solar electric bus. Photo www.adelaidecitycouncil.com
Vehicle related issues – battery electric

• Are battery electric vehicles heavier and thus able to carry fewer passengers?
  - YES – with current battery weights and GVM limits
  - Typical tare weights for 12 m 65 - 70 person capacity diesel buses are 10 - 12 t
  - Batteries typically weigh around 2.5 t for 300 kWh required for 200 km range, so
  - Battery buses will be 12.5 - 14.5 t, or 25% - 21% heavier
  - Assuming GVM for NZ two axle bus with tandem rear tyres is 16 t, max passenger numbers or 54 at best, and 23 at worst
  - Assuming current limit is 65 people, reduction could be between 11 and 42 people
  - Potentially quite substantial impacts on passenger carrying capacity

Vehicle related issues – battery electric

• Does their range limit them to single shift operations?
  - Without recharging en route, battery swap or very fast recharging, YES
  - Very fast recharging can be associated with premature battery failure if selected batteries cannot cope
  - Capital costs closely guarded
  - TOSA en route charging electric bus Geneva
Vehicle related issues – battery electric

• **Electric bus capital costs**
  - Electric buses have been 2 – 5 times purchase price of diesels
  - Battery life typically 5 – 7 years and $150,000 to replace
  - Charging infrastructure capital cost highly dependent on how many buses are to be charged and the speed of charging: the biggest cost is getting several MW of power to the depot – which is highly location specific but also reflect network impacts – which could run into $1 – 2 M pa, plus energy costs
  - Individual ‘power points’ are $500 - $1,000 each depending on quantity and specification
    - There is a trade off between speed of charging and how many vehicles need to be charged at once

**Vehicle related issues – battery electric**

• **Can existing trolley bus infrastructure be used to power a new battery electric bus system?**
  - HIGHLY UNLIKELY
  - Inability to cope with power demand and short time available for charging at stops
  - Technically doubtful
Vehicle related issues – other fuelling systems

• CNG:
  • Substantial fleet experience in Perth and Brisbane
  • Comparable capital and operating costs
  • Gas availability at depot?
  • Challenges with fires – particularly Mercedes

• Hydrogen fuel cell:
  • Initial trial vehicles have had very expensive capital and operating costs
  • PTA Perth spent $10 M on three vehicles

Discussion
Technical advice concerning Wellington’s trolley bus network and potential alternatives

GWRC COUNCILLOR WORKSHOP
4 JUNE 2014
Summary profiles of Jacobs staff who provided technical advice to GWRC regarding the trolley bus system and alternative vehicle options

Steve Manders

Qualifications
BA Honours (Psychology) University of Melbourne
MA (Applied Psychology) University of Melbourne
Certified Workplace Trainer (Category 2), Kangan Institute of TAFE
Certified Workplace Assessor, Kangan Institute of TAFE

Affiliations
Member, Supply Chain and Logistics Association of Australia (SCLAA)
Member, Market Research Society of Australia
Member, Australian Psychological Society

Experience
Steve has 25 years management consulting experience in Transport Planning, supply chain and logistics. He joined Jacobs in 1999, following 12 years consulting in transport and supply chain management with Henderson Consultants. His prior experience included commercial roles in express freight, rail, road transport and the taxi industry, plus public sector roles with V/Line and VicRoads in rail planning, driver licensing and training, heavy vehicles, dangerous goods and road safety.

Steve has experience covering all transport modes, with significant project and previous work roles in rail, road and port sectors. He has strong skills in industrial market research, covering one on one interviewing, focus groups and quantitative methods.

He has been a sessional lecturer for transport and supply chain courses at Monash University, RMIT and the Australian Institute of Management. He has presented training courses, facilitated workshops and spoken at numerous conferences.

Steve Rafferty

Qualifications
Bachelor of Science (Mathematics), Newcastle upon Tyne Polytechnic
Master of Science (Transport Engineering), Newcastle upon Tyne University

Affiliations
Fellow and former section chairman, Chartered Institute of Logistics and Transport

Experience
Steve has over thirty years’ experience in the planning and implementation of transport facilities and services. He has undertaken operational analyses of bus, rail and ferry services and advised public and private sector clients on various transport projects ranging from demand responsive minibus operations to high speed rail lines.
Richard Fairbairn

Qualifications
BSc.Eng.(Power Systems), University of Natal, Durban, South Africa
MSc.Eng. (Power Systems), University of Natal, Durban, South Africa
PhD. (Power Systems), University of Natal, Durban, South Africa

Affiliations
CPEng & IntEng (New Zealand).

Experience
Richard is a Power Systems Engineer with 20 years’ experience in the analysis, development, design and management of electrical infrastructure. He has a wide range of experience within the electrical industry ranging from the justification of power system projects (including board papers) through to the detailed system studies (load flow, transients, dynamics, EMTP studies, harmonics, reliability, ELF and earthing studies). He has worked successfully in both consulting and utility environments, more recently holding various senior roles in an electrical distribution company. He has been exposed to most facets of a utility company (from network development to line/substation maintenance). Richard has also delivered evidence during public hearings and written electrical & gas utility asset management plans. His work experience also includes extensive involvement with the valuation of network assets and due diligence work.

Richard is also Jacobs Practice Leader for electrical earthing and is an active CDEGs software user (for the design/investigation of earthing systems, ELF levels and LFI). Work undertaken has included substation earthing, transmission line ELF/earthing and LFI on gas/water pipe line and railway lines.

Terry Wilkinson

Qualifications
Bachelor of Science (Civil), Loughborough University of Technology

Affiliations
Registered Professional Engineer NPER 3
Member, Institution of Civil Engineers (UK)
Member, Institution of Engineers, Australia

Experience
Terry is Jacobs senior Overhead design engineer. He has 40 years’ experience on a wide range of DC and AC electrification projects in the UK (starting with the West Coast Main Line), Taiwan (Main Trunk Line Electrification), USA (North East Corridor Improvement Project), Africa (Zimbabwe Railway Electrification), Chile (El Teniente mine upgrade), New Zealand (Auckland Rail Corridor Electrification Study). Australian projects have centred on Victorian tram and train but include Railcorp (McDonaldtown, Lidcombe, Homebush), Perth (Mandurah, Rio Tinto), Brisbane (Airport Rail Link) and Adelaide (Dry Creek Yard, Glenelg tram upgrade). Terry has a skill base that includes Overhead design, project management, contract specifications, standards, technical specifications, compliance checking, asset condition reporting and computer programming. Terry runs an in-house ‘masterclass’ forum for the team to study all engineering aspects of Overhead.
The following information was received from Jacobs after the original Bus fleet options questions
and answers document was circulated to Councillors.

Is it true that the exhaust filtration systems used to reduce particulate matter in diesel exhausts of
Euro V and later series engines are ineffective in removing the smallest and most dangerous sizes of
Particulate Matter (PM$_{2.5}$)?

This is difficult to answer conclusively, because nearly all testing does not distinguish between
different sizes of particulate matter. This is because none of the Euro standards separate different
sizes of particulate matter, but defines maximum total quantities of all particulate matter permitted.

Jacobs has been able to identify only one study that compared quantities of different sizes of
particulate matter in diesel exhaust from buses fitted and not fitted with Diesel Particulate Filters
(DPFs).

This study dates from 2005, before DPFs were the standard method to enable diesel engines to meet
Euro IV and later standards for Particulate Matter. The study was carried out by the Connecticut
Academy of Science and Engineering, was sponsored by the Connecticut Transportation
Department, and was accessed from http://docs.trb.org/01015091.pdf by Jacobs on 7 June 2014.

This study tested two standard diesel buses and two hybrid buses on standard bus routes in and
between Enfield, Farmington and Avon in Connecticut for 18 months, using on vehicle testing
equipment. The study shows that particulate filters were effective in reducing all sizes of
particulates, from 10 nm to 130 nm (0.01 to 0.13 micrometres). The combination of DPF on the
hybrid vehicles was more effective than DPFs on the standard diesel buses for the smallest size of
PM (PM$_1$). The relevant section and chart is reproduced below (Executive Summary, pp xii to xiii).

![Particulate emissions](image)

As for the gaseous emissions, the PM results may be summarized very simply: for a given route
and for all fuel/exhaust system configurations, the results for the hybrid buses and for the base
clean-diesel diesel buses were virtually identical.

However, unlike the gaseous emission results, there was a very large reduction in the particulate
emissions when the buses were fitted with diesel particulate filters and operated on ultra-low-sulfur fuel.

To illustrate this reduction, we focus on the results for the Farmington Avenue route, a route
typical of urban service. The data are shown in Figure 3.
Note that the New Zealand maximum for sulphur levels is 10 ppm (see http://www.beehive.govt.nz/release/consumers-get-cleaner-petrol-and-diesel), and the ultra-low-sulphur diesel fuel in the study was defined as having a sulphur content of less than 15 ppm. The Connecticut study was done in early 2000s, when acceptable sulphur levels in diesel were much higher than now, and trialling ultra-low sulphur diesel was of great interest in itself.

On the basis of this study, and the apparent absence of others demonstrating alternative outcomes, Jacobs concludes that it appears likely that Diesel Particulate Filters as used on Euro IV and later engines are effective in reducing all sizes of Particulate Matter in diesel bus exhausts.
Additional Information provided by PwC: Wellington bus fleet emissions

PwC has provided the following estimates of Wellington city bus fleet emissions to show the difference in fleet emissions between the current bus fleet and a future fully electric fleet using either modern diesel or diesel-electric hybrids as the transition path. The change in emissions results from change in the composition of the fleet and reductions in the numbers of buses (as a result of both the new Wellington bus network and the use of high capacity buses).
### Euro VI then Electric

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