Draft Guidance Note – Executive Summary

Transit Bus Operational and Maintenance Practices to Maximize Fuel Economy

January 4, 2011

1. BACKGROUND

While fuel efficiency has been recognized as an important issue in urban bus transit, the goal of attaining better efficiency of the existing fleet through targeted maintenance actions has not received much systematic attention, and very little literature exists in the field to provide a step-by-step guide to implementing such targeted actions. This is partly because bus maintenance organizations are focused on the two most important factors for the public – providing adequate service in terms of passenger miles per day, and operating a safe system that minimizes customer and employee accidents. Fuel economy of the existing fleet is widely assumed by bus maintenance organizations to be maximized by following proper maintenance procedures, and special efforts to improve fuel economy are typically focused on purchasing new buses with improved technology. While this view is reasonable for new buses, targeted actions on older buses can yield overall fuel efficiency improvements that are significant and cost effective.

In an effort to catalyze solutions on urban transport, the World Bank' Energy Sector Management Assistance Program (ESMAP) focused on development of a global Knowledge Product in the form of a 'Guidance Note' (GN) on bus operational and maintenance procedures that is a practical and useful tool to guide the implementation of a program **that will enhance the fuel efficiency of buses**. The GN is directed towards city transit managers and their technical staff mainly in the developing countries to enhance the energy efficiency of the city transit.

The GN covers the following three areas:

- A technically proactive and rigorous fleet maintenance procedure/protocol.
- Indicators to measure and track effectiveness of maintenance practices from a fuel efficiency perspective.
- Training methods for drivers and mechanics.

2. LITERATURE REVIEW AND INTERVIEWS

A global search of papers on the effect of bus maintenance practices on fuel economy showed very limited literature on this topic and as a result the search was broadened to include publications on global fuel efficiency strategies across all businesses. In this case, a recent meta-study by the Pew Center for Global Climate Change[1] has identified a set of core principles by which corporations increase fuel efficiency and this is based on over 70 case studies of corporations. The **most important idea** that emerges from this meta-study is that fuel efficiency is not obtained from just a simple technical fix, but requires senior management attention, good data and metrics, employee participation and an attainable goal with a well specified technical path to meet the goal.

The literature on maintenance practices has also been summarized in meta studies conducted by the US Transportation Research Board[2] and key elements that have been identified to ensure high quality and repeatable maintenance include -

- a written maintenance plan that is updated periodically,
- documented repair and diagnostic procedures that mechanics must follow as Standard Operating Procedure,
- quality assurance checks on repairs conducted regularly by an internal team and periodically by an external audit team, and
- good data collection on bus performance in the field complemented by extensive data analysis with fleet management software.

[1] Prindle, W.R., From Shop Floor to Top Floor – Best Business Practices on Energy Efficiency. Prepared for the Pew Center on Global Climate Change by the ICF International. Virginia, Arlington, April 2010.

[2] Transportation Research Board. A Guidebook for Developing and Sharing Transit Bus Maintenance Practices. Transit Cooperative Research Program (TCRP) Report Number 109. Washington DC, 2005.

The driver has also been recognized as a key factor in enabling buses to obtain good fuel economy. Driver training programs, teaching drivers how to drive in a fuel efficient and safe manner, have been developed in many countries and they all share common content. **Driver training programs have been shown to improve fuel economy by 5 to 15%.** A key finding is that the benefits are obtained not through classroom training but from actual on-road training with a professional driving instructor.

Data from interviews with maintenance managers of city transit organizations in 8 cities across four countries ─ Brazil, China, India, and USA ─ in combination with data from the literature review were used to develop the GN that lays out a series of steps to be implemented by a bus maintenance organization that will result in measurable fuel efficiency improvements.

Interviews with maintenance managers of fleets around the world showed many commonalities in the approach to maintenance as well as some key differences. Most maintenance organizations are measured by senior management for their ability to have a high percentage of buses in the field daily, reduce failures in the field and operate safely. Fuel economy is rarely an important parameter (in spite of senior managements' claims to the contrary) to trigger maintenance actions and many organizations have the underlying belief that good maintenance automatically maximizes fuel economy, and this is partially true. Few organizations have benchmarked the fuel economy of their buses against the fuel economy of similar buses operating in nearby cities, and even fewer have any targets for fleet fuel economy. In the minority of cases where bus maintenance staff does pay a lot of attention to fuel economy, it is driven by senior management commitment and very detailed data collection on fuel economy at the bus and route specific level. Since many factors such as the bus technology and the driving cycle on a route affect fuel economy, collection of data at this granular level is required to institute an effective program to identify low fuel economy buses and repair them. Few organizations have implemented analysis of fuel economy at this level of detail. Hence, many organizations do not reward employees for fuel efficiency simply because they lack the data to identify who should be rewarded.

3. OPERATIONAL AND MAINTENANCE PROCEDURES

The key findings from the background research and interviews drove the development of the operational and maintenance procedures. The procedures recognize that improving fuel economy is not achieved through any simple technical fix. **It is possible only with senior management focus and employee participation, detailed data collection and analysis to benchmark and target efforts, maintenance directed at low fuel economy buses, good maintenance practices and quality assurance of repairs, well trained drivers and widespread communication of fuel economy results to all levels of staff.** These factors, working in synergy, create a culture of fuel economy in the organization and help improve fleet average fuel economy while eliminating low fuel economy outliers from the fleet.

Accordingly, **a 16 step program (see Table 1) is suggested** that addresses each of the key factors recognized from the background research and interviews. The steps offer clear and detailed path of the actions required to create this culture of fuel economy so that the benefits are permanently institutionalized in a transit fleet. Further, once a sample of poorly performing buses and drivers are identified, a focused attention is necessary to ensure their performance returns to average or better. This GN recognizes that some simple steps need to be taken first at the depot and if these do not work, a second tier of more complex steps (at a central or more specialized repair facility) needs to be taken. Larger transit organizations follow the two step method for maintenance. The GN provided a checklist applicable to most diesel and CNG powered buses that should be incorporated into the program.

Since these steps are based on industry best practices, many of them (like driver training for fuel efficient driving) have been widely implemented but several others such as setting specific fuel efficiency goals or employing special maintenance for low fuel efficiency buses, have been implemented only in very few areas. Improving fuel efficiency of the existing fleet is not a simple process and will require implementation of most if not all of the 16 steps.

The following sections of the GN explain each step in some detail. In some cases, they can be described only generally as the details will be site specific.

Table 1: Recommended steps for developing transit bus maintenance practices

Level	Step	Action
Management	Step 1	Appoint a senior executive to be in charge of fleet fuel economy and tie his/her bonus and career to meeting fuel economy goals.
	Step 2	Benchmark and set appropriate fuel economy goals by bus type for each year
	Step 3	Communicate the fuel economy results achieved each year to both employees and the public.
Data Collection and Analysis	Step 4	Automate data collection to the extent feasible and use analysis software to support maintenance
	Step 5	Set up data QA/QC procedures
	Step 6	Analyze the data for untangling the effects of driver, route and bus related effects on fuel economy (FE)
	Step 7	Use data to refine periodic maintenance
Bus Maintenance and Repair	Step 8A	Select 10% of the fleet showing the lowest FE and conduct 15 simple checks at depot
	Step 8B	Conduct detailed checks at central facility if bus passes step 8A
	Step 8C	Compare pre-repair and post repair fuel economy data in these buses to estimate program benefits
	Step 9	Check repair quality on a random and periodic basis
	Step 10	Obtain mechanic sign-off on repairs for traceability
	Step 11	Require independent team audit of repairs across depots
	Step 12	Retrain mechanics and update repair procedures periodically
Bus Drivers	Step 13	Train drivers in fuel efficient driving techniques and periodically re-train them
	Step 14	Select the 5 percent of drivers with the lowest fuel efficiency and have special additional training
Employee Communication and Rewards	Step 15	Publicly display the fuel economy performance by driver and bus depot to employees
	Step 16	Reward mechanics at the depot level and drivers individually for exceeding targets

3.1 Management focus and objectives

3.1.1 Overview of three steps for management

The interviews with a range of bus maintenance organizations showed that all consider fuel efficiency to be very important but surprisingly few incorporate fuel efficiency in many important issues. **This is due to the fact that most urban transit systems place the highest priority on safety, timeliness (which translates to bus reliability) and maximizing service with their assets available.** The management organization focuses on how many buses are fielded each day, how many accidents occur in the field, the number of revenue passenger miles or kilometers, and how many injuries occur to workers and bus riders. Fuel economy is widely regarded as an outcome and there is the general belief that periodic maintenance that provides good reliability automatically maximizes fuel economy. Typically driver training is the primary area where fuel efficiency is emphasized along with safety and courtesy. This focus and belief are generally correct as the public wants frequent service in clean buses that are safe, but the public have no knowledge of (or interest in) fuel economy. However, incremental management efforts directed towards fuel economy can yield surprisingly good benefits if it becomes an integral part of core management strategy. The following three steps can provide this focus.

Step 1: Appoint a senior executive to be in charge of fuel economy

In general, maintenance organizations monitor fuel economy closely and take corrective actions against buses and depots that report fuel economy much worse than average. Yet, the fuel economy function is integrated with other operations and maintenance functions and the study team did not find any organization with an executive whose responsibility was to **maximize** fuel economy, with one exception Beijing Xiang Long (BXL) Bus Company. BXL has a special management group focused on energy efficiency and has paid considerable attention to this data. In most other companies, there was focus on low performance vehicles but no attention was paid to high fuel economy vehicles to see if their performance could be replicated across the fleet. In addition, even the focus on low efficiency vehicles is typically directed towards those buses that are 15+% worse than average, i.e. the outliers. Moreover, the study team found no organizations that actually set **targets** for fuel economy for either the short term (within one year) or long term. A senior executive whose responsibility is fuel economy can provide the required management focus. The study team does not intend to imply that this is the only focus of the particular executive but it should be one major focus.

The need for senior management involvement is a key finding of the Pew meta-study and the study team found evidence of how that changes the attitude to fuel economy in the Brazilian bus company (Julio Simoes Bus Company – Sao Paolo Urban), where management is now focused on reducing the carbon footprint.
The key requirements for this step are:

- the executive must have authority over driver and mechanic staff at all depots to install new procedures
- the executive must have the knowledge of maintenance practices and understand the current data reporting and repair procedures
- the executive must have part of his/her bonuses linked directly to fuel economy goals set for the organization.

Step 2: Benchmark fuel economy and set goals
Benchmarking and target setting have been identified by the Pew Study as a key first step to enabling a specific path to energy efficiency. Benchmarking the existing fleet's fuel economy is a key first step in determining where the current fleet is relative to its peers and to be able to set meaningful goals for future improvement. Benchmarking involves comparing properly computed fuel economy values for similar buses across different organizations. Typically, this will involve some data collection effort as fuel economy results are generally not publicly available.

<u>Variables to be addressed for benchmarking</u>
Bus fuel economy is a function of several variables including bus size (overall length and passenger capacity); engine horsepower, engine emissions certification, air-conditioner use and ambient temperature, as well as route specific drive cycle. The last item cannot be controlled for across cities so that there is an assumption that the average bus fuel economy across multiple routes will be similar. By selecting bus fleets from cities of similar size and congestion levels, the route variability can be minimized but not entirely eliminated. In addition the comparisons must be across:

- **Identical bus size with the same engine**. This is usually possible since bus sizes are standardized in most countries and only 1 to 3 engine suppliers compete within a national market.
- **Buses of similar age and emissions certification**. In most countries, the emissions certification level changes every few vehicle model years, so that age and certification level go together. It is important to benchmark fuel economy for engines with the same certification level as technology changes to meet emission standards will affect the comparison otherwise.
- **Fuel economy data collected for the same month**. This minimizes ambient temperature and air conditioner use related fuel economy variability.

<u>Setting targets for the future</u>
Once the reference fleet is benchmarked with respect to its fuel economy relative to comparable buses in other cities of similar size, it will be possible to set reasonable targets. If the reference fleet has average fuel economy (FE) that is at least 5 percent worse than the best fleet in the benchmarking comparison, the best fleet's FE is a reasonable target that can be attained over a two year period to allow time for these procedures to be put in place and implemented correctly.

If the reference fleet has the best FE, or is very close to the best (difference less than 4%), then an alternative method can be used to set targets. In any fleet, there is a distribution of FE from the worst to the best and typically, the available data suggests FE varies around the average by $\pm$ 10 to 15 percent, i.e., if the average is 4 km/L, the variation among buses will be from 3.5 to 4.5 km/L. The average FE of the top quartile of buses which in this example case could be 4.3 km/L is selected as the target for the fleet average in the future. This is referred to as the "top runner" method and the target is set at the level of the average fuel economy of the highest 25 percent of buses in the reference fleet.

Step 3: Communicate the results of FE programs to employees and the public
In general, fuel economy numbers for buses by bus or route are rarely made public, and the success or failure of efficiency programs not known outside management. The lack of information also extends to the executives who may be unaware of the fuel efficiency of similar buses in other cities both within the country and outside. The study team found that there were significant differences in fuel efficiency for identical models of buses across different cities (e,g., Washington and State College); while local congestion and weather may account for some of the differences, this was by no means obvious, and the reported fuel economy differences were sizeable (10 to 15%) across cities. The importance of communications is illustrated by the case of Toyota, one of the world's leading companies in the area of energy efficiency as described in the Box 1.

Communicating these differences to the public will lead to more open information flow and cause management to benchmark their organization against the best reported fuel economy. In addition it will sensitize policy makers to the impacts of fuel and technology choice, and motivate employees to compete informally with other cities.

Box 1: SETTING AND COMMUNICATING TARGETS TO EMPLOYEES

CASE STUDY – TOYOTA

Toyota is widely known for its efficiency in all aspects of production, and it is also one of the most energy efficient auto-manufacturers in the world. They have an empowered division called Energy Management Organization (EMO) which acts as a service organization to the production staff. The EMO has set up key energy performance indicators for all aspects of production and runs a competition called "Race for the Greenest". Once a month, shop captains and managers meet and participate in "race" where tiny cars are placed on a board and moved ahead based on the points earned in the previous month on energy use efficiency. The Race for the Greenest competition epitomizes Toyota's energy strategy. Energy performance indicators are reported regularly, and the process engages the whole organization from senior management to shop staff. There is a certain amount of fun in these monthly gatherings and it is not just about the performance numbers, it is about how employees see themselves and what they take pride in. The Toyota system creates a culture that is about engaging employee pride and ingenuity for collective gain.

What set Toyota apart from the average company is the added level of data monitoring and reporting. Shop captains have access to energy use data at very disaggregate levels that enables them to look deeply at energy use. Shop captains know they must pay attention to this information to meet their "key performance indicator" targets. If their monthly performance starts deviating significantly from the targets, they will request EMO staff for additional assistance. Individuals are encouraged to develop and submit kaizen (continuous improvement) ideas to the EMO system and the database is available to Toyota employees worldwide.

Note: Adapted with permission from Case Studies in Best Practices in Energy Efficiency, Pew Center on Global Climate Change 2010.

3.2 Data collection and analysis

3.2.1 Importance of data collection
Developing any type of fuel economy program must rely on a robust tracking and measurement system. Hence collection of bus travel, route, fuel use, other fluid (oil, coolant) use and maintenance data at the most granular level – daily for each bus and driver – is essential. In general, most large bus operators do collect such data but at somewhat different levels of detail. In many bus fleets, maintenance tends to be performed at two different levels. Routine checks, oil and coolant addition and minor adjustments are made at the depots, while more major repairs are conducted at a centralized facility. In many instances, the data from routine checks and daily inspections/additions are not part of the database.

There is more variation in the data acquisition systems and types of analysis across bus maintenance organizations. The use of commercial or purpose developed software to manage and analyze the data is required and most organizations do have software for maintenance support.

Step 4: Automated data acquisition and analysis to the maximum extent
Historically, bus daily use data, fuel consumption and maintenance records were recorded manually and types into databases, with errors from both the recording process and the data input process resulting in less confidence in the data. While many developing country bus fleets and smaller bus fleets around the world still use manual data acquisition systems, the trend to automatic data acquisition is now occurring on a global basis. In most developed countries, fully automated data acquisition systems are now being used as part of the "Smart garage" system of bus maintenance management. The literature on maintenance documents the benefits of automated data acquisition systems. At the most basic level, the bus entering the garage sets up automatic data acquisition. The bus is recognized by the system through a bar code, and the bus electronic control system automatically downloads the daily travel and speeds, as well as any system problems through on-board diagnostics. The fuel filler system also reports the fuel fill data to the computer system. Only maintenance related items such as oil addition, coolant addition or part replacement is manually input, and these data are needed only occasionally.

With automatic data acquisition systems becoming relatively cheap and reliable, automation is a good step to ensure more complete and accurate data acquisition. First, modern heavy duty bus engines incorporate engines with electronic control to meet emission standards starting from the Euro III level, so that much of the data is already available for almost no cost except for the bus to central computer electronic link interface. Second, transit agencies report that fuel dispensing management systems can be installed at a cost of about $15,000 per garage. Third, bar code readers installed in the garage doorways are low cost at a few hundred dollars per installation. Some systems can also report data on the condition of vehicle components such as brakes, electrical systems and ventilation/air-conditioning systems to a central Mobile Data Terminal for use and analysis.

Data analysis software to integrate all fleet maintenance activities are available commercially and are essential counterpart to good data collection. The software can also be used to track fuel economy at the route and bus type level. Automated maintenance management software has a proven track record of improving maintenance quality, lowering costs and increasing bus availability.[3] Box 2 presents the results documented by users of fleet management software.

Box 2: MAINTENANCE MANAGEMENT SOFTWARE BENEFITS

Commercial maintenance management software is now widely used by bus fleets and truck fleets in the US and Europe. Several surveys have been undertaken to understand the benefits of implementing such software, and studies of transit fleets reported 70 percent of responding fleets were very pleased with the benefits. Other studies of bus and truck fleets have also found similar results. A survey conducted by the Aberdeen Group found demonstrated cost savings by 80 percent of organizations that switched to fleet management systems. In addition, the research revealed

- 13 percent improvement in vehicle utilization due to reduced breakdown rates
- 11 percent reduction in maintenance costs
- 12 percent increase in service organization profitability
- improvements in driver compliance with defect reporting

However, there are few reports of specific fuel economy improvements as most MM software is geared towards reducing breakdowns and reducing service cost. The State of Utah reported a 2.5 percent decrease in fuel consumption but specific fuel economy figures or total miles driven were not reported.

Source: See footnote 3.

[3] US Department of Transportation. Maintenance Management Systems Fact Sheet: Transit Overview, available at www.pcb.its.dot.gov

Step 5: Set up specific data quality assurance systems for FE
Error checking the data is a key requirement for a robust system, but many locations do not have specific data QA/QC procedures related to fuel economy, unless fleet management software automatically signals data errors. As a result, managers do not trust daily outputs and rely only on monthly indicators where the data errors are evened out.

The plan to be followed for improving fleet fuel efficiency is that the ten percent of buses with the lowest fuel economy be selected for additional maintenance. Since fuel economy is computed form two variables, fuel use per day and miles per day, the error rate to ensure that at least 9 of 10 buses selected are correctly selected requires each variable to have error rates less than one percent maximum. It is imperative to have a QA procedure for data that holds errors to less than 1% of data recorded, and this particularly true for manual data acquisition systems. The data fields required for the analysis and preferred and maximum error rates are presented in Table 2. The preferred error rates are those commonly used by maintenance management software sold commercially.

Table 2: Data quality assurance on fuel efficiency variables

Variable	Description	Check	Preferred Error Rate	Maximum Error Rate
Bus Number	Unique bus identifier	Corresponds to in-service bus	0	<0.1%
Odometer In and Out	Odometer reading when bus leaves garage and re-enters garage after shift	Odometer out = previous day in. In-out within specified limits	<0.1%	<1%
Fuel Added	Gallons/ Liters of fuel added to fill tank	< tank size, limit against daily travel	<0.1%	<1%
Driver Name or Number	Driver identifier	Corresponds to driver reporting for shift	0	<0.1%
Bus Route number	Route identifier	Valid route number	0	<0.1%
Breakdown Indicator	Indicates if Bus did not complete shift per schedule	Validate from time re-entering garage	0	0
Fill indicator	Indicates if tank was filled to maximum	No check	0	0
Time stamp	In/out date and time	Validate against standard shift times	0	0

Step 6: Special analysis for FE data
Many bus maintenance organizations rely on commercial fleet maintenance management systems that automatically flag mal-performing buses while also signaling the need for a periodic maintenance event, printing out the specific maintenance actions required and tracking the maintenance plan. A number of fleet management software suppliers offer maintenance management solutions that can also be customized to some extent to meet the fleet's requirements. Others rely on specialized in-house programs to provide similar functions. The study team's check and interviews found that **most programs only report average fuel economy** by bus, and only a few flag those that fall outside of a relatively wide band of acceptable fuel economy values. It is well known that bus fuel economy depends on the bus type, route characteristics, driver and bus passenger load, which is why a relatively wide range of fuel economy falls in the "acceptable" range. Because the routes and drivers are not randomly assigned to each bus, the separation of the individual bus, driver, and route effects cannot be accomplished by simple averages. While many methods can be used, a simple mathematical regression will solve this problem and the regression equation can be specified as

$$\textit{Fuel Consumption (FE)} = A + Bi*(\textit{route } i) + Cj*(\textit{bus } j) + Dk*(\textit{driver } k)$$

Where A is the constant term and B, C and D are dummy variables; Bi the co-efficient that corrects fuel economy for route effects (one for every route), Cj the co-efficient that corrects for the bus effect (one for each bus) and Dk the coefficient that corrects for driver effects (one for each driver in a given bus type, as drivers may switch buses).

The lowest or most negative values of the coefficient identify the lowest fuel economy routes, buses and drivers. The advantage of the regression method is that all three effects are considered together for the ranking of routes, buses and drivers. The coefficients **can be thought of as a ranking system**, so that a bus with a high Cj coefficient can be considered as having better than average FE after correcting for the route and driver effects, while a bus with a low coefficient is lower than average FE after the route and driver corrections. In this context it should be recognized that the regression can recognize a bus as a low FE bus even if its absolute FE is close to the average, as it may be operated on a route which is not crowded and other buses on that route are showing much higher fuel economy than the depot average. If buses are generally dedicated to single routes, and typically use the same drivers, then the simpler method of averaging FE first by route, and then by bus and by driver can be utilized, as this method can produce equivalent results to the regression.

Box 3 describes the data needed for the regression analysis. The regression methodology has been used by Ang and Deng[4] to model bus fuel economy and the effect of maintenance and mileage.

Box 3: IMPLEMENTING THE REGRESSION ANALYSIS

A regression analysis can be conducted through the use of most common spreadsheet programs such as Excel. The data needed are the **daily records** for each bus that have the following variables: 1) Date/time 2) Bus number 3) Route number 4) Driver Number 5) Odometer out 6) Odometer in 7) Fuel Dispensed.

The steps are to first check the data as detailed in step 5, eliminate the records failing the quality check and then determine fuel economy using the formula for each set of daily records.

Fuel economy = (Odometer in – Odometer out)/ Fuel Dispensed

The regression is then defined with the fuel economy computed as the dependent variable (Y) and the independent variables are specified as the Bus number (X1), the driver number (X2) and the Route Number (X3). The regression input must also specify that X1, X2 and X3 are dummy variables signifying that they are labels for the bus, driver and route. One bus close to the fleet average fuel economy can be specified as the reference. Instructions in the spreadsheet will usually guide the user on how to run the regression. The regression output will provide the average fuel economy of the reference bus and a number for each bus, driver and route. If the number is positive, then the particular bus, driver or route experiences better fuel economy than the reference bus while negative numbers indicate worse fuel economy. Hence, the regression provides immediate analysis for which buses and drivers are performing poorly.

Source: See footnote 4.

Step 7: Use the data to refine periodic maintenance intervals

In general, maintenance organizations adopt manufacturer recommended maintenance intervals but rarely modify them to suit local conditions. The data can be used to extend some maintenance intervals while shortening others, or make the maintenance a function of bus age, with more periodic inspections for older buses. Many organizations like Washington Metropolitan Area Transit Authority (WMATA) do refine intervals for parts that fail more frequently than normal, but rarely use data to modify standard maintenance intervals. Warranty requirements may make these intervals inflexible for the first 5 years typically, but intervals on older buses can be adjusted.

One method for determining maintenance intervals is to examine the mean time between failures (MTBF) for older buses and determine which components are failing at a rate faster than their service intervals. Those with low mean time between failures can be serviced more frequently. Conversely, manufacturers usually over-specify maintenance to provide a cushion against unexpected failures and it is possible that MTBF data will indicate some components need less frequent service, saving some maintenance costs.

[4] Ang, B.W. and Deng, C.C. The effects of Maintenance on the Fuel Efficiency of Public Buses. Journal of Energy, March 1990.

3.3 Bus maintenance for good FE

3.3.1 Overview of two-step special maintenance program

The identification and repair of low fuel economy buses is second only to driver training in maximizing fleet fuel economy. Once a bus has been identified as a low fuel economy unit, a plan must be incorporated to ensure its performance returns to average or better. This GN recognizes that some simple steps need to be taken first at the depot and if these do not work, a second tier of more complex steps (at a central or more specialized repair facility) needs to be taken. The specific method to conduct the inspection and repair are bus make and model dependent and cannot be specified here. However, the study team has provided a general check list applicable to most diesel and CNG powered buses that should be incorporated into the program. A key recommendation from our interviews and literature review is that **repair procedures should be documented in writing and provided to all mechanics**. This will ensure consistent repair procedures, and allow for future updates as required.

Step 8 A: Tier I Checks Implemented at the Depot

The two tier check list requires that low fuel economy buses be subjected to the first tier of inspection (and repair if necessary) at the depot and its fuel economy rechecked. If this does not solve the problem, then a second tier of more complex inspection and repair should be performed at the central maintenance facility. The first tier repairs do not require a maintenance hoist or inspection pit and can be easily performed by junior or mid-level mechanics. The set of first steps have been compiled from the actual checks recommended by manufacturers and involves those that can be easily performed when the bus arrives at a depot, requiring few special tools. In general, these checks will eliminate easily correctable defects that can hurt fuel economy by creating an extra load on the engine through additional friction. Sixteen specific checks are suggested in Table 3, but some may not be applicable to specific technologies such as automatic transmission equipped vehicles.

Table 3: Tier I - Checks for implementation at the local bus depot

Component	Check	Pass/ fail criterion and repair
Tires/ Wheels	1. Check tire inflation 2. Check for free rolling of wheels 3. Wheel bearing lubrication	Pressure meets specification, or add air Wheels rotated easily by hand or check brakes (see below) No grinding noise in bearings or lubricate as required.
Brakes	4. Check for free play of brake pedals 5. Check gap between brake liners and drum/disc 6. Check caliper boot and wear adjuster cap 7. Check for brake retraction after pedal release	Excessive free play requires brake pedal linkage adjustment Gap must be visible or liners reinstalled Wear adjuster should not be at setting limit, or replace liner Liners move away from rotor on brake release, or else check for brake hydraulic/air line defects
Driveshaft/ Axles	8. Check lubrication of driveshaft joints, axle bearings and differential 9. Examine tightness of driveline and gearbox mounts	Lack of visible lubricant and/or noise in joints and bearings signify need for lubrication Visible driveline and gearbox vibration indicates need to tighten mounts
Accelerator/ Clutch pedal	10. Check clutch pedal linkages 11. Check Accelerator linkages 12. Check accelerator return spring	Excessive play requires linkage adjustment Excessive play requires linkage adjustment Accelerator snaps back on release or else replace spring
Engine related	13. Check air cleaner for clogging 14. Check exhaust pipe for blockage 15. Check on-board diagnostics if applicable 16. Check for visible smoke on snap acceleration	Visible dirt on air cleaner, replace Check for any foreign objects or broken catalyst in pipe. Electronics check for diagnostic codes indicating any failure Smoke opacity over 20% indicates engine problem, send to central maintenance facility.

If no problems are found in the tier I repair set, the bus should be sent to the centralized or more detailed facility ("pit maintenance") and the more detailed checks performed per the list below. Unless there is visible smoke, the detailed maintenance can be coordinated with the periodic maintenance date of removal from service.

Step 8B: Tier II Checks at the Central Maintenance Facility

The 14 checks compiled in Table 4 from manufacturer recommended checklists should be implemented with trained mechanics. The specific method to carry out the above generic inspection items is unique to each engine/bus combination but all of the above are standard items for maintenance, and the methods documented in maintenance manuals.

Table 4: Tier II - Checks for implementation at the central bus maintenance facility

Component	Check	Pass/Fail Criterion and Repair
Wheels	1. Check wheel alignment 2. Check tire camber	Set to manufacturer specification Set to manufacturer specification
Clutch	3. Check condition of clutch facings 4. Check clutch release bearing	Replace clutch facing if worn Replace bearing if worn/ failed
Fuel System (Diesel/ CNG)	5. Check fuel lines and tanks for leakage	Check for fuel drops on floor under bus (diesel) or use gas detector (CNG). Replace lines or tank as required
Engine (Diesel)	6. Check Fuel Injection pump timing and maximum fuel stop 7. Check FI pump pressure 8. Pull and check fuel injectors for leakage or clogged spray holes 9. Check turbocharger bearings (if turbocharged) 10. Check cylinder compression 11. Inspect cylinder head for cracks, bolt tightness 12. Check piston rings if oil consumption is high 13. Check for engine coolant loss/ overheating	Set timing and stop to manufacturer specifications Low pressure indicates pump rebuild Asymmetric spray indicates need for injector cleaning or replacement Turbo rotor must rotate freely or else replace bearings Low compression requires head gasket, ring check or engine rebuild Torque head bolts to manufacturer spec., replace cracked head Replace worn rings Radiator or hose leaks should be patched.
Engine (CNG)	6A. Check air-fuel mixer settings 7A Check gas pressure regulator 8A. Check ignition system wires and spark plugs for misfire 9A. Check turbocharger bearings (if turbocharged) 10A. Check cylinder compression 11A. Inspect cylinder head for cracks, bolt tightness 12A. Check piston rings if oil consumption is high 13A. Check for engine coolant loss/overheating	Set to manufacturer specifications Output pressure must be within specifications or replace Replace broken wires and fouled spark plugs Turbo rotor must rotate freely or else replace bearings Low compression requires head gasket, ring check or engine rebuild Torque head bolts to manufacturer spec., replace cracked head Replace worn rings Radiator or hose leaks should be patched.
Exhaust System	14. Inspect exhaust brake valve if used.	Valve not opening freely should be cleaned or replaced

Tables 3 and 4 are provided to set up a checklist and may not be comprehensive for some unique engine types. In general, the study team anticipates that the tier I and tier II checklists will bring all buses into compliance with fuel economy requirements. However, local conditions may also impose special problems such as salt corrosion in snowy locations, or engine overheating in very hot locations. The list should be modified using the knowledge of local mechanics as appropriate.

Step 8C: Compare pre- and post-repair FE data
Once the buses go through the repairs in step 8A and /or 8B, the next month's data will provide information on the post repair fuel economy value. The fuel economy value should be compared to the pre-repair value and the percent improvement used as the indicator for fleet benefits.

3.3.2 Maintenance oversight and QA/QC
All maintenance organizations have a series of checks on mechanics work as part of the quality assurance and quality control procedure on repairs performed. Mechanics are typically graded by seniority with junior mechanics trained by senior mechanics, and the Chief or Supervisory mechanic checking the work of all mechanics on a regular or intermittent basis. The use of an independent team to check the work of all mechanics is less common but also used, especially for large fleets. Based on the data obtained from interviews, the following suggestions for maintenance QA/QC appear to be very useful in the field.

Step 9: Institute both random and periodic checks of repairs
Supervisory mechanics could focus on repairs of chronic failures to improve performance by regular checks of all mechanics, but surprise checks may also reveal mechanics who may be taking un-specified short cuts to complete the repairs quickly.

Step 10: Require mechanics to sign-off on the repairs they perform
This is very useful to track repair of chronic defects that recur in the field. In this case, individual mechanics associated with repeat failures can be identified and their repair practices monitored carefully. Mechanics that do not follow procedures with resulting failures and low fuel economy can be re-trained or disciplined, as appropriate. In small organizations, it may be possible to informally identify which mechanic serviced which bus, but even here, the sign-off requirement could make mechanics more careful.

Step 11: Develop an independent QA/QC team
The use of an outside QA/QC team for checking mechanic performance and repair quality has been found to be helpful in preventing internal collusion between mechanics in a depot and also in making procedures more uniform across the various repair depots in a large organization. Such teams also help knowledge transfer as some mechanics may have found specific repair or part improvements that help reduce chronic or periodic problems, and the independent team can also act as a consolidator of the knowledge base for the organization. Box 4 presents the case of WMATA to demonstrate need for an independent system wide audit team to ensure the procedures are strictly followed.

Box 4: BENEFITS OF HAVING AN INDPENDENT QA/QA TEAM

THE WASHINGTON TRANSIT AUTHORITY EXPERIENCE

The Washington Metro Area Transit Authority (WMATA) operates a fleet of about 1500 buses across several counties and has multiple garage facilities that operate and service different makes and models of buses, including CNG, diesel and clean diesel buses. Over the last few years, WMATA has made a large effort to standardize maintenance procedures across different facilities by having written detailed step-by-step procedures that identify the checks, repairs and tools to be used, which are referred to as Standard Operating Procedures. Historically, they have found that individual garages develop their own methods to deal with problem repairs which may not necessarily reflect the best practice. By having an independent system wide audit team, WMATA has been able to standardize procedures across the entire maintenance system and ensure that procedures are strictly followed. The result is that maintenance costs have been reduced while mean time between failures has been improving for a given technology type (some new technologies have higher failure rates which affects the behavior of the average rate). A side benefit has been that mechanics moving from one location to another find identical tools, procedures and practices in place.

Step 12: Update procedures and re-train mechanics periodically
Both vehicle and diagnostic technology continues to change with the advent of electronic controls, which are only now being offered in developing country environments. Sending mechanics to special re-training classes is more

important now with the changing requirements, but attending centralized classes also affords informal exchange of best practices in the industry. This is normal procedure for all large fleets interviewed in this study. Procedures for repair also need to be periodically reviewed and updated to reflect industry best practices as well.

3.4 Driver training

3.4.1 Need for fuel efficient driving practice

The driver's behavior is an important component of fuel economy attained on the road, and driver training has been widely implemented by most urban transit authorities. The near universal use of driver training is currently driven by legal requirements to ensure safety for the general public, but fuel efficient driving is also incorporated into courses that teach safe driving. As a result this GN merely emphasizes the need for such training with periodic re-training to ensure the driver maintains best practices.

There are a number of commercial and government sponsored courses that teach fuel efficient driving for heavy duty vehicles. These courses have been developed for city driving and courses for transit bus drivers also teach aspects of bus rider safety and public safety. The main aspects of the course are a short classroom review of the steps for safety and fuel efficiency, followed by a simulator driving course (if a simulator is available) or instructional video, followed by on-road training with a professional instructor, who monitors driver behavior. The **on-road driver training is the most important component** of the course as most drivers are generally aware of good driving practices but may have developed many inefficient habits that they may not even be aware of, which typically include clutch riding, pumping the accelerator pedal and improper gear shift. The professional instructor can spot these bad habits and show the driver how to correct them.

Step 13: Core Principles of Fuel Efficient Driving

Fuel efficient driving is a technique that any driver can use. The basic steps to fuel efficient driving are:

- cutting out unnecessary idling
- staying within the speed limit and maintaining engine RPM at optimum levels
- accelerating and braking gently
- using vehicle momentum to maintain cruise speed
- avoiding pumping the accelerator pedal
- anticipating traffic ahead to minimize hard braking and acceleration.

The quality of the driver training program and its effect on driver behavior towards fuel efficiency is typically a function of the quality of the on-road instructor, class room material (see Box 5).

Box 5: THE BENEFITS OF ECO-DRIVING

Training drivers in fuel efficient driving methods has been popular for over 20 years but the benefits claimed by proponents is often not based on scientific research, and many of the claims of 15 percent (or more) fuel economy benefits are unsubstantiated. A scientific study by Monash University in Australia operating heavy duty vehicles on a test track with specific speed profiles for driving was conducted employing a control group of untrained drivers as well. The study found that those who received classroom only training did not improve, but those who had both classroom and on road training were able to reduce fuel consumption by 27 percent, on average. Even here, there were large variations among drivers so that the result was not statistically significant at the 95% confidence level, but were significant at the 90% confidence level. However, the number of gear changes and brake applications were substantially reduced and the changes were significant at the 95% confidence level. Drivers were retested after 6 and 12 weeks, and the fuel economy benefits were retained for the trained group over that period. Importantly, the study found the size of the benefit in fuel economy to be constant over the period, and the savings did not require an increase in travelling time or any decrease in average speed over the course. The study cautioned that the magnitude of the reduction observed on the test track would not likely be replicated in actual service.

Source: Symmons, M.A. and Rose, G. Ecodrive Training Delivers Substantial Savings for Heavy Vehicle Drivers, Proceedings of the Fifth International Symposium on Human Factors in Driving, 2008

As an example of a well regarded program the United Kingdom's Safe and Fuel Efficient Driving (SAFED) program incorporates all of the key features required in a good driver training program and can serve as a guide to what elements should be incorporated.

Step 14: Retraining the worst drivers
The recognition of poor drivers based on data analysis (as described in Step 6) and their re-training can lead to significant improvements in fuel economy. Some of the best run organizations recognize and send the poorest 10 percent of their drivers in terms of fuel economy for counseling and re-training. Drivers who do not improve their driving even after repeated counseling are often subject to disciplinary action or discharge. These types of actions are required to motivate all drivers to take the program seriously, and are also recommended for incorporation into a driver education program.

3.5 Employee rewards

3.5.1 Employee motivators
Motivating employees is a key part of any strategy to create a culture of fuel efficiency and examples in industry have shown that management and employee motivation, not technology, explains much of the difference between fuel efficient and fuel inefficient operations. A second and closely related aspect requires both managers and employees to have good awareness of how well they are doing relative to others in the group. This type of information sets up friendly competition for employee participation in implementing the recommended steps towards fuel efficiency.

Currently, information provided to employees is focused on safety ratings and the number of buses fielded each day, or total bus revenue kilometers, and employees or entire depots are rewarded for safety performance and revenue performance. The study team found only a few instances where there are employee rewards for fuel economy, and those awards are for good drivers. In those instances, there appears to be a lot of motivation on the part of drivers to win the award. It is suggested that awards be provided at three distinct levels. At the system-wide level, the executive in charge of fuel economy can be rewarded for meeting system goals and targets for fuel economy as suggested in Step 1. The study team also suggests rewards at the depot level, and at the individual level.

Step 15: Depot level awards
Good maintenance is a second key aspect of fuel economy performance but it is difficult to reward individual mechanics for fuel economy performance as they will perform repairs on many buses that may be randomly assigned to them, after the buses have had a breakdown or have been selected for additional maintenance. Since bus assignment is not within their control, the depot mechanics can be rewarded for meeting fuel economy goals and failure rate goals that are specific to the make/model of the buses housed and serviced at the particular depot. Note that this involves setting FE goals at the bus type or depot specific levels (see Step 2).

Step 16: Individual driver awards
The driver can have a large effect on vehicle fuel economy through the use of Eco-driving. Currently, drivers are rewarded by many transit systems for safe driving by having an accident free and consumer complaint free record, but rewards for fuel economy performance are relatively rare. Drivers can also be recognized for good performance in both safety and fuel economy metrics. Determining fuel economy performance at the driver level is complicated by the fact that absolute fuel economy depends on bus model, its age and condition, the route and the driver (see Box 6).

Hence, the key issues for providing driver awards (as illustrated by Beijing Xiang Long (BXL) Bus Company for fuel economy are:

- the route and bus adjustment be made for each driver's performance,
- the adjusted performance for all drivers be publicly posted,
- the adjustment factors and their fairness can be evaluated by the drivers so that they will accept its fairness over time (or have it changed to reflect factors that only drivers may be aware of.

The regression method of data analysis provides the bus and route specific adjustment factors that can be used as an initial estimate and potentially refined to meet driver complaints if any. Clearly, the statistical method has some uncertainty in the estimates of fuel economy ranking, and to avoid problems the top 10 percent of drivers should be recognized and rewarded.

Box 6: THE DIFFICULTY IN IMPLEMENTING REWARDS FOR FUEL ECONOMY PERFORMANCE

Transit bus operators have tried to institute awards for fuel economy performance with mixed success. In some agencies such as Bel Tour in Brazil, the awards had to be withdrawn as they caused resentment and unrest among drivers and mechanics. Since fuel economy is also bus and route dependent, the drivers and mechanics believed that winners of the award unfairly benefitted from having the best buses or the least demanding routes, and these perceptions had a basis in fact. Few transit agencies subject the fuel economy data to the level of analyses required to untangle these effects, and the data were also not subjected to rigorous quality checks.

In the agencies where such awards have been accepted and are popular, the data on fuel economy is stratified to the bus type and route level. More importantly, the data are available to the drivers and they can see the own performance relative to other drivers on similar routes and become comfortable with the quality of data. This illustrates the synergy between the different steps recommended in this GN – without the efforts on open communications, ensuring data quality and performing more advanced data analysis, it becomes impossible to fairly reward employees and create a culture of employee pride in fuel economy performance.