Briefing Note 010/11

GUIDANCE NOTE

Best Operational and Maintenance Practices for City Bus Fleets to Maximize Fuel Economy

ENERGY EFFICIENT CITIES INITIATIVE

Helping Cities Meet Their Energy Challenges of the New Century

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EXECUTIVE SUMMARY

In most large cities in developing countries, buses continue to be the public transport option of choice, carrying a large share of urban travelers. However, transit bus companies in these countries are often cash-strapped. In many cases, the operating cost per bus kilometer exceeds revenues and bus fares are often kept low irrespective of the cost of providing service. Many cities are dominated by old and fuel-intensive buses with high operating costs. Transit systems are also often plagued by overcrowded and undependable service, congested roadways and chaotic operating environments. Across the board, city officials in developing countries are under strong pressure to improve the efficiency and enhance the attractiveness of bus transportation.

Fuel makes up a relatively large fraction of total bus operating costs, especially when labor costs are low, as in many developing countries. Fuel costs can be reduced by improving the driving style of bus drivers and through sound maintenance practices. A safe and economical driving style can reduce variable costs, decrease down time due to repair work and maintenance, mitigate negative environmental impacts and improve road safety. Similarly, well-maintained buses that are properly tuned and adjusted tend to be cleaner, safer and consume less fuel than poorly maintained vehicles.

This Guidance Note[1] provides detailed and practical recommendations on how city bus operations managers and their technical staff can plan and implement such enhancements to their fleets through Operations and Maintenance (O&M) practices without significant capital investments. By implementing such recommendations, municipal officials and bus operators can increase the efficiency and fuel economy of their bus systems and reduce their cities' energy consumption, congestion and pollution.

Work on this Guidance Note started with a global literature review to assess state-of-the-art bus O&M practices in a number of countries, with a focus on enhancing fuel economy. Interviews were conducted with maintenance managers of transit organizations in eight cities in four countries. The information from those interviews, in combination with data from the literature review, were used develop the Guidance Note's recommended plan of action to achieve measurable fuel economy improvements displayed in Table 1.

1 This Guidance Note summarizes a larger report published by the Energy Sector Management Assistance Program (ESMAP) entitled "Transit Bus Operational and Maintenance Practices" (ESMAP 2011). For more information, visit www.esmap.org.

The recommended action plan focuses on five principles:

1. **Management commitment and ownership**
2. **Data collection and analysis**
3. **Maintenance directed at low fuel economy buses**
4. **Training directed at low-performing drivers**
5. **Employee communications and rewards**

From these principles, a series of 16 specific actions were developed covering management functions, data collection and analysis, special maintenance for fuel economy, maintenance quality assurance/quality control (QA/QC) functions, driver training and employee rewards. Many of these actions (such as driver training for fuel-efficient driving) have been widely adopted, while others are uncommon (such as, targeted maintenance for low fuel economy buses).

A validation of the recommended actions was carried out through field testing conducted in three cities in southern India: Hyderabad, Vijayawada and Mysore. The field testing results were incorporated into this analysis.

Implementation of the actions showed significant fuel economy improvements at the test sites. Newer diesel buses (4 to 7 years old) appeared to obtain about 4 to 5 percent improvement in fuel economy, while older diesel buses (7 to 14 years old) appeared to obtain about 7 to 8 percent fuel economy improvement. Driver training showed a fuel economy improvement in the 5 to 10 percent range, with the greatest benefit coming from on-road training rather than classroom instruction.

Due to the many different issues affecting fuel economy, it is difficult to make definitive statements in the absence of a careful controlled study, but the limited data suggests that the combination of driver training and organizational focus on fuel economy could provide fuel economy benefits in the 7 to 15 percent range for organizations where fuel economy has not previously been a focus.

The O&M practices recommended here were found to be most cost effective with a minimum fleet size of 100 buses in a city with an existing maintenance facility and low labor costs.

Overall, the testing showed that the recommended approach could be implemented without significant changes in operating structures, capital investment or upfront preparation. However, energy-efficient O&M practices must be carefully planned and must be appropriate to the size, resources, and "culture" of each city bus company in order to be successful.

INTRODUCTION

The transport sector plays an increasingly significant role in global energy requirements, accounting for 23 percent of all world energy consumption. A single energy source, petroleum, still accounts for the vast majority—95 percent—of the energy used by the sector (IPCC 2007). As a result, the oil price volatility of recent years has created considerable pressures on transport systems, particularly in the developing world.

This pressure, plus the explosion of urbanization and private vehicle ownership, has created strong incentives for city officials in developing countries to improve the efficiency and enhance the attractiveness of public transportation. Energy consumption for transport per individual is four times higher in cities such as Houston or Chicago, where the majority of trips are made by private car, compared to cities such as Warsaw or Hong Kong, where public transport, walking and cycling are predominant.[2] In most large cities in developing countries, buses continue to be the public transport option of choice, carrying a large share of urban travelers, often at relatively low cost.

However, transit bus companies in many developing countries are cash-strapped (Kojima 2001). Many cities are dominated by often old and fuel-intensive buses with high operating costs. At the same time, many bus transit systems are plagued by inefficiency, overcrowded and undependable service, congested roadways that slow down buses, and chaotic operating environments. As a result, the share of travel represented by bus transit has declined (IEA 2002).

In many cities, the operating cost per bus kilometer exceeds revenues, and bus fares are often kept low irrespective of the cost of providing service. For example, in India, most publicly owned bus systems in large cities generally cover about 70 to 90 percent of operating costs (Pucher, Korattyswaroopam and Ittyerah 2004). In Jakarta, Indonesia, the provincial government has regulated public transportation fares, keeping them just high enough to prevent bus companies from operating at a loss.[3]

Fuel makes up a relatively large fraction of total bus operating costs, especially when labor and bus costs are low, as in many developing countries (Jacobs, Maunder and Fouracre 1981). In the case of informal small-scale operations using rehabilitated or locally fabricated buses, the share of fuel cost is 20 to 30 percent.[4] In India, the fuel costs for buses in the state of Andhra Pradesh were 37 percent of total expenditures in 2009 (APSRTC 2011).

2 http://www.uitp.org/advocacy/public_transport.cfm#read

3 http://www.thejakartaglobe.com/opinion/cheap-jakarta-bus-fares-at-what-price/436368

4 http://www.worldbank.org/transport/roads/rdt_docs/annex1.pdf

Fuel costs can be reduced by improving the driving style of bus drivers, and through sound maintenance practices. A safe and economical driving style can reduce variable costs (fuels, repairs, maintenance, tires), decrease down time due to repair work and maintenance, mitigate negative environmental impacts, and improve road safety. Similarly, well-maintained buses that are properly tuned and adjusted tend to be cleaner, safer and consume less fuel than poorly maintained vehicles (UNEP 2009).

This Guidance Note provides detailed and practical recommendations on how city bus operations managers and their technical staff can plan and implement such enhancements to their fleets through O&M practices without significant capital investments.

SCOPE AND METHODOLOGY

Work on this Guidance Note started with a global literature review to assess state-of-the-art bus O&M practices with a focus on enhancing fuel economy. Interviews were conducted with maintenance managers of transit organizations in eight cities in four countries: Brazil, China, India, and the United States.[5] The information from those interviews, in combination with data from the literature review, were used develop the recommended action plan to achieve measurable fuel economy improvements in this Guidance Note. A validation of the recommended actions was carried out through field testing conducted in three cities in southern India: Hyderabad, Vijayawada and Mysore. The field testing results were incorporated into this analysis.

GLOBAL REVIEW OF GOOD PRACTICES

A global literature review on the effect of bus O&M practices on fuel economy reveals limited documentation, but offers examples of areas for improvement. A study from Singapore tracking the daily fuel economy of 24 buses over 3 months found that major maintenance—recommended servicing every 30,000 km—increased fuel economy by 3.2 percent (Ang and Deng 1990). Another significant finding was that the effects of maintenance decline with mileage accumulation after major service. In another study, nine bus companies in Jakarta participated in a comprehensive bus inspection/maintenance (I/M) and driver training program (UNEP 2009). While a 5 percent decrease in fuel consumption was achieved through maintenance practices, improved driving methods resulted in another 10 percent decrease in fuel consumption.

Similarly, the Andhra Pradesh State Road Transport Corporation (APSRTC) in India reported fuel economy for identical bus types in Hyderabad to be 10 to 12 percent higher than the values reported by Mumbai and Delhi (Sudhakararao 2010). Although there are differences in route congestion and weather conditions between these cities, much of the fuel economy benefits are attributable to bus O&M practices already in place. APSRTC has a long-standing program on O&M practices to improve city-wide bus fleet fuel economy. Data over 29 years (1980-2009) shows that fuel economy has improved from 4.1 km per

5 The interviews were conducted at the state owned Mumbai (BEST) and Delhi (DTC) bus transport corporations in India; two privately owned bus companies in Brazil (Julio Simoes in Sao Paulo and Bel Tour in Rio); Beijing Public Transport Holding (BPT) and the privately owned Beijing Xiang Long (BXL) in China; and the Washington DC and the State College Pennsylvania transport authorities in the United States.

liter (km/L) in 1981 to 5.2 km/L in 2010-11 (APSRTC 2010). Comparable buses in Delhi Transport Corporation (DTC) and Brihan Mumbai Electric Supply and Transport (BEST) report fuel efficiencies in the 4.2 to 4.5 km/L range (ESMAP 2011).

On the other hand, minor malfunctions in the air/fuel or spark management systems can increase fuel consumption and emissions significantly. A study conducted in Bangkok[6] shows, with over 90 percent[7] of all public transport handled by buses, that a periodic maintenance program for aging bus fleet resulted in a fuel economy gain of 9 percent and a significant drop in exhaust emissions—by at least 40 percent carbon monoxide, 20 percent hydrocarbons, 55 percent particulate matter, 15 percent black smoke, and 27 percent opacity.

Driving practices have 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 share common content. A key finding is that the benefits are obtained not through classroom instruction but from actual on-road training with a professional driving instructor. Driver training for safe and fuel-efficient driving was uniformly provided in the countries surveyed, and is a legal requirement in many countries.

The literature on bus maintenance practices has been summarized in meta-studies conducted by the US Transportation Research Board (Schiavone 2005). The key elements of a well-developed maintenance plan include the following steps:

- written maintenance plan that is updated regularly for all vehicles in the fleet;
- preventive maintenance checklists that are, at minimum, consistent with manufacturer requirements for buses under warranty;
- QA/QC checks on repairs conducted regularly by an internal team and periodically by an external audit team;
- data-based documentation that the existing plan adequately protects assets from deterioration over the buses's useful life; and
- detailed and permanent record keeping system that can track the maintenance history of each bus.

These steps are required by the government in many developed countries and are considered as a baseline for good maintenance. The literature also suggests the need for written standard operating procedures so that all repairs are performed according to procedure.

INTERVIEWS WITH TRANSIT ORGANIZATIONS

Major differences were found in the resources and level of effort to maximize fuel economy. Only two organizations of the eight surveyed (BXL and BPT in Beijing) tracked and maximized the fuel economy performance of individual buses and drivers, while a third (Simoes in Sao Paulo) employed a unique strategy of selling buses over four years old. Data collection practices and automated data acquisition

6 http://www.walshcarlines.com/pdf/Impact%20of%20Bus%20Maintenance%20on%20Emissions.pdf

7 http://www2.gtz.de/dokumente/bib/05-0524.pdf

system use is more varied and, surprisingly, many developing country fleets, like those interviewed in China and Brazil, employed state-of-the-art systems. The analytical capability possible with better data is, however, not always used for fuel economy analysis.

Interviews also revealed the key barriers to improving fuel economy. During the interviews with fleet managers at bus depots, everyone claimed that fuel economy was a high priority but more detailed questioning revealed other priorities. The key barriers were found to be the following:

1. Most maintenance organizations are measured by senior management for their ability to have a high percentage of buses in the field daily operating safely. Pulling buses from service for repair due to low fuel economy actually hurts the depot's operating performance metrics.

2. Maintenance managers rarely benchmark the fuel economy of their fleet against fuel economy achieved by other comparable fleets. Some managers were aware of the average fuel economy of some other fleets but believed the averages were "about the same" even with real differences actually observed. For example, fuel economy levels of 4.4 km/L and 4.8 km/L were regarded as similar even though the latter is 9 percent better than the first.

3. Bus fuel economy varies by route and is also strongly affected by driver performance. Most bus companies do not have any in-house analysis to normalize for route and driver effects, and cannot identify the low fuel economy buses except for extreme cases.

4. The data required to identify low fuel economy buses must be quite granular and have low error rates. This requires robust data collection systems with good data quality assurance, but few bus companies have made the effort to ensure high quality data inputs.

5. Many maintenance managers are convinced that good periodic maintenance automatically maximizes fuel economy. Targeted maintenance of low fuel economy buses may be seen in this context as having a small payoff when the focus of the organization is on periodic maintenance.

INCORPORATING CORE PRINCIPLES FOR FUEL EFFICIENCY

The global review of good practices revealed that the literature on bus O&M with a focus on fuel economy, especially in developing countries, was limited to a small number of papers. Accordingly, the review was expanded to include corporate strategies for enhancing energy efficiency so that the broad lessons from other businesses could be applied to bus maintenance organizations.

Two main findings from the review of corporate strategies showed that:

- energy efficiency is obtained from not just a simple technical fix; management and employees must focus on implementing the actions required; and
- improved efficiency will be realized over time as implementation of the actions becomes routine and accepted by all parts of the organization.

Energy efficiency has been embraced by many companies in every field. An analysis of global company strategies by the Pew Center for Climate Change identified a set of core principles based on over 70 case studies of corporations to increase efficiency (Prindle 2010). These include senior management focus, employee participation, detailed data collection and analysis, and communication of results. For bus operators, when these are combined with driver training and good maintenance practices, they create a culture of efficiency in the organization that can improve fleet average fuel economy while eliminating inefficient outliers from the fleet.

GUIDING PRINCIPLES FOR BUS O&M

Based on the lessons learned, background research, and interviews of city fleet operators, the following principles have been developed for O&M guidelines:

1. *Management commitment and ownership.* The technical support plan must be owned by the city transit agency so that its implementation is undertaken in a coordinated manner.
2. *Data collection and analysis.* Technical support interventions should be determined by benchmarks, targets and measurement of fuel economy indicators.

3. *Maintenance directed at low fuel economy buses.* Technical support interventions should be focused on the 10 percent of the fleet showing the lowest fuel economy, and underperforming buses should undergo proper O&M practices and quality assurance of repairs.
4. *Training directed at low-performing drivers.* On-road and classroom training with a trained instructor is required to improve overall driving quality.
5. *Employee communications and rewards.* The operator should periodically communicate efficiency results and give incentives to employees to create a culture of fuel economy.

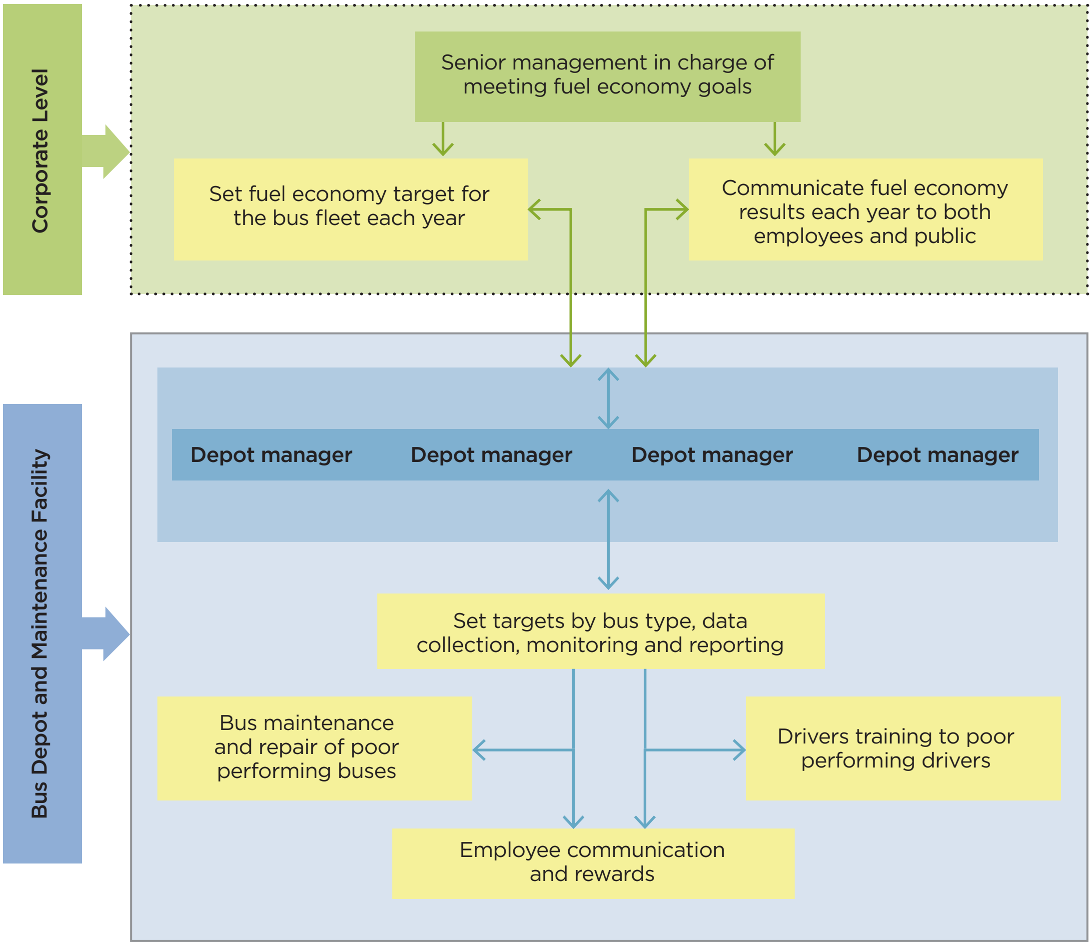
PROPOSED ORGANIZATIONAL STRUCTURE FOR BUS O&M

To successfully implement an energy-efficient O&M strategy requires time, patient advocacy, and overcoming significant organizational challenges, but such efforts yield fuel economy improvements and help the bottom line. Senior management responsible for city bus operations must lead and oversee the entire process, ensure alignment with existing working arrangements, and communicate the fuel economy results of the city bus fleet to employees.

The early stages are the most important to developing and implementing an energy-efficient O&M program. Of equal importance is the involvement of bus depot managers to assist in developing a technical support plan. The following recommended plan of action is directed towards both groups. At the corporate level, senior management will be responsible for setting and monitoring fuel economy targets and implementation strategies, for the associated investments, and for communicating the results achieved at the end of the year to employees. At the bus depot level, depot managers will be responsible for implementing the recommended practices and periodically rewarding best-performing drivers and mechanics. Depot managers also report fuel economy results achieved from each depot to the corporate level.

Figure 1 presents the recommended organizational structure for an effective implementation of the O&M guidelines. The proposed organizational structure for technical support planning and management must be adapted according to the local context.

FIGURE 1 | Proposed Organizational Structure for Technical Support Planning and Management



Source: Authors.

RECOMMENDED PLAN OF ACTION

The guiding principles and the findings from the literature review and interviews helped to develop a series of recommended actions to overcome the identified barriers and provide a systematic basis for improving fuel economy through O&M enhancements.

This 16-point action plan was designed to cover management functions, data collection and analysis, special maintenance for fuel economy, maintenance QA/QC functions, driver training and employee rewards. Each of these actions is based on best practices in bus maintenance organizations obtained from the literature review as well as from the interviews with the maintenance management of bus fleets. Table 1 summarizes the action plan. Many of these actions (such as driver training for fuel-efficient driving) have been widely adopted; other are uncommon (such as targeted maintenance for low fuel economy buses). Improving the fuel economy of the entire fleet is not a simple process and will require implementation of most, if not all, of the actions outlined here.

While not all of the elements of the proposed action plan have been implemented at any single location, many key elements have been incorporated independently at different locations. Three case studies, Edmonton (Box 4), Jakarta (Box 5), and Singapore (Ang and Deng 1990), show that fuel economy has improved by 5 percent to 15 percent even from partial implementations of the actions listed in Table 1.

PRINCIPLE I: MANAGEMENT COMMITMENT AND OWNERSHIP

Management efforts directed towards fuel economy are necessary and can yield benefits if they become an integral part of core management strategy. The following three actions by management are required.

Action 1: Appoint a Senior Executive to be in Charge of Fuel Economy

A senior executive should be made responsible for meeting fuel economy goals. This does not imply that this is the only task of the particular executive but it should be one major focus. The need for senior management involvement is a key finding of the Pew study (Prindle 2010). 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 a knowledge of O&M practices and understand the current data reporting and repair procedures; and

TABLE 1 | Summary of Actions for Instituting Transit Bus Maintenance Practices for Fuel Economy

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

8 Percent automatically normalizes for size. The list must be kept selective to be meaningful.

- the executive must have part of his/her bonuses linked directly to fuel economy goals set for the organization.

Action 2: Benchmark Fuel Economy and Set Goals

Benchmarking involves comparing properly computed fuel economy values for similar buses across different organizations. Typically, this will involve some data collection efforts as fuel economy results are generally not publicly available. Both government and urban bus transit associations can play a role in making such data available in a standard format. Benchmarking the existing fleet's fuel economy is the first step in determining where the current fleet is relative to its peers and to be able to set meaningful goals for future improvement.

In general, maintenance organizations monitor fuel economy closely and take corrective actions against buses and depots that report fuel economy that is much worse than average. Yet, the fuel economy function is integrated with other O&M functions and no organization was found with an executive whose responsibility was to maximize fuel economy, with one exception, BXL in Beijing. BXL has a special management group focused on fuel economy 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 fuel economy vehicles is typically directed towards those buses that are 15+percent worse than average (i.e., the outliers). Moreover, no organizations were found that actually set targets for fuel economy for either the short term (within one year) or long term.

Variables to be addressed for benchmarking. 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:

1. *Identical bus size with the same engine.* This is usually possible since bus sizes are standardized in most countries and only one to three engine suppliers compete within a national market.

2. *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.

3. *Fuel economy data collected for the same month.* This minimizes ambient temperature and air conditioner use related fuel economy variability.

Setting targets for the future. Targets for fuel economy are required to provide a clear goal to employees. 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. (When no comparable fleet data is available, the top runner method outlined below can be used). If the reference fleet has average fuel economy that is at least 5 percent worse than the best fleet in the benchmarking comparison, the best fleet's fuel economy is a reasonable target that can be attained over a two year period to allow time for these procedures to be established and implemented.

If the reference fleet has the best fuel economy or is very close to the best (difference less than 4 percent), then an alternative method can be used to set targets. In any fleet, there is a distribution of fuel economy from the worst to the best and, typically, the available data suggests fuel economy varies around the average by 15 to 20 percent (i.e., if the average is 4 km/L, the variation among buses will be from 3.2 to 4.8 km/L). The average fuel economy of the top quartile of buses, which in this example case could be 4.6 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.

Action 3: Communicate the Results of Fuel Economy Programs to Employees and the Public

Communicating the results for fuel economy performance relative to targets to employees and the public at large is necessary so that failures in execution are not hidden and management continues to make an effort to meet targets. In general, fuel economy numbers for buses by bus or route are rarely made public, and the success or failure of efficiency programs is not known outside company management. The lack of information also extends to executives who may be unaware of the fuel economy of similar buses in other cities. Communicating these differences to the public at large 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. The importance of communications is illustrated by the case of Toyota,[9] one of the world's leading companies in the area of fuel economy (see Box 1).

PRINCIPLE II: DATA COLLECTION AND ANALYSIS

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. There is more variation in the data acquisition systems and types of analysis than in maintenance procedures across bus maintenance organizations. The use of commercial or purpose-developed software to manage and analyze the data is required and most organizations have software for maintenance support. Based on the survey of facilities, the following bus data collection and analysis related actions are recommended.

Action 4: Automate Data Acquisition and Analysis to the Maximum Extent

Data analysis. Automating the data collection system for fuel economy to be measured accurately is recommended but not essential to the success of the fuel economy program. Bus daily use data, and fuel consumption and maintenance records are often recorded manually and typed into databases, with errors from both the recording process and the data input process, resulting in less confidence in the data. With automatic data acquisition systems becoming relatively cheap and reliable, automation is a good step to ensure more complete and accurate data acquisition.

9 Further details are available at www.toyota.com/about/environmentreport2010.

BOX 1 **Setting and Communicating Targets to Employees**

CASE STUDY—TOYOTA

Toyota is one of the most energy-efficient auto manufacturers in the world. The company has an empowered division called the 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 a "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. The Toyota system creates a culture that engenders employee pride and ingenuity for collective gain. What sets Toyota apart from the average company are the added levels of data monitoring and reporting. Shops captains have access to energy use data at very disaggregate levels that enable 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 can 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.

Source: Prindle 2010.

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. At the most basic level, data is automatically gathered once the bus enters the garage. 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 level data to the computer system. Maintenance-related items, such as oil and coolant checks and part replacements, are entered manually. More advanced systems communicate with the vehicle continuously and the Automatic Vehicle Location system can track vehicles while obtaining real time system performance information. Such systems can spot breakdowns as they happen or predict the possible occurrence and reroute the vehicle back to the garage before serious damage occurs.

Data analysis software. Data analysis software is required to integrate all fleet maintenance activities, and is an essential counterpart to good data collection. The software can also be used to track fuel economy at the route and bus type level. Many programs are available commercially and automated maintenance management software has a proven track record of improving maintenance quality, lowering costs and increasing bus availability (Box 2).

The benefits of this action include:

- automated tracking of all fueling and repair events;
- automated scheduling of buses for maintenance and repair;
- parts ordering and inventory control to maximize parts availability, minimizing down time for repairs;
- identification of low fuel economy or low reliability buses for additional repairs; and
- automated generation of reports for senior management to provide near real time tracking of important fleet performance variables.

Action 5: Set Up Specific Data Quality Assurance Systems for Fuel Economy Variables

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. To improve fleet fuel economy, the 10 percent of buses with the lowest fuel economy must be selected for additional maintenance. Since fuel economy is computed from two variables, fuel use per day and miles per day, the error rate to ensure that at least

BOX 2 **Benefits of Maintenance Management Software**

Commercial maintenance management (MM) 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; and
- 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 costs. 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: US Department of Transportation Fact Sheets (undated).

9 of 10 buses selected are correctly identified requires each variable to have error rates of less than 1 percent maximum. It is imperative to have a QA procedure for data that holds errors to less than 1 percent of data recorded, and this is 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.

Action 6: Special Analysis for Fuel Efficiency Data

Many bus organizations rely on commercial fleet maintenance management systems that automatically flag under-performing buses while also signaling the need for periodic maintenance events, 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. Field interviews revealed 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. The software must be capable of identifying the lowest fuel economy buses after accounting for other variables affecting fuel economy. 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. The simple

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

Source: Authors.

averaging method to identify low fuel economy buses and drivers requires the following:

- determining the average fuel economy by route;
- determining the average fuel economy of each bus (and bus type if many different types of buses are used on the same route) and each driver;
- comparing the bus and driver specific fuel economy to the route average by bus type for the route that each bus and driver is assigned to; and
- selecting the 10 percent of buses with the lowest fuel economy relative to the route/bus type average.

This method requires that buses assigned to only one or two routes and drivers be assigned largely to the same bus every day. When the routes and drivers assigned to each bus are different every day, the separation of the individual bus, driver, and route effects cannot usually be accomplished by simple averages. A more sophisticated approach is required to adjust for bus type, route and driver effects. Multiple regression technique is an option to perform such analysis.[11]

Action 7: Use Data to Refine Periodic Maintenance Intervals

Refining maintenance intervals is a useful but not an essential step in maximizing fuel economy. 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. 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)[12] 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.

PRINCIPLE III: MAINTENANCE OF LOW FUEL EFFICIENT BUSES

Overview of two-step special maintenance program. The identification and repair of low fuel economy buses is as important as 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. Some simple steps need to be taken first at the depot and if these do not solve the problem, a second tier of more complex steps (at a central or more specialized repair facility) may be required. A general checklist applicable to most diesel and Compressed Natural Gas (CNG)-powered buses that should be incorporated

11 Fleet managers interested in this method can refer to Section 4.3.4 (ESMAP 2011).

12 MTBF is the average frequency with which a product fails, the average time between failures or the length of time a bus component is expected to work without failure. It is also an indicator of system reliability that is calculated from known failure rates of various system components.

into the program is provided below. A key recommendation is that repair procedures should be documented in writing and provided to all mechanics as a standard operating practice. This will ensure consistent repair procedures, and allow for future updates as required.

Action 8A: Tier I Checks Implemented at the Depot

The two-tier checklist 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. The 19 tier I repair checks (see Annex 1) 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, but some may not be applicable to specific technologies, such as automatic transmission equipped vehicles. 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. If no problems are found in the tier I repair set, the bus should be sent to the centralized or more capable facility ("pit maintenance") and the more detailed checks performed per Step 8B. Unless there is visible smoke, the detailed maintenance can be coordinated with the periodic maintenance date of removal from service.

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

The 14 checks compiled in Annex 2 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.

These checklists are indicative only and may not be comprehensive for some unique engine types. In general, it is anticipated 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.

Action 8C: Compare Pre-repair and Post-repair Fuel Economy 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.

Maintenance oversight and QA/QC. All maintenance organizations have a series of checks on mechanics' work as part of the QA/QC procedure on repairs performed. Mechanics are typically graded by seniority, with 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.

Action 9: Require Mechanics to Sign-off on Repairs

Mechanics should sign-off on the repairs they perform. This step 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. The following actions are required:

- The maintenance organization must maintain a log book for each bus documenting maintenance actions.
- After every maintenance action, the key repairs performed should be identified and the mechanic performing the repair must be identified.
- The mechanic must sign off on the repair or note any issues with the repair that could not be solved.

Mechanics not following procedures with resulting failures and low fuel economy should be retrained 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.

Action 10: Institute Random and Periodic Checks of Repairs

Supervisory mechanics or the Chief Mechanic should institute a series of random and periodic checks on repair quality, including the following specific actions:

- Supervisory mechanics should focus on repairs of chronic failures to improve performance by checking the repair after the mechanic has finished, ensuring adherence to standard operating procedure. This could also result in changes if better procedures can be developed.
- Supervisory mechanics should conduct regular checks of all mechanics, but surprise checks may also reveal mechanics who may be taking unspecified short cuts.

- Mechanics with higher than average repeat failure rates should be checked more frequently.

Action 11: Develop an Independent QA/QC Team

An external QA/QC team should check mechanic performance and repair quality to ensure uniformity in procedures among depots. This team should review the repair procedures used, the frequency of repeat failures and the internal QA/QC procedure employed by the supervisory mechanic. As such, the independent team reviews procedures, not repairs. The outside team has been found to be helpful in preventing internal collusion between mechanics in a depot and also in making procedures consistent across the various repair depots in a large organization (Box 3). Such teams also help knowledge transfer as some mechanics may have found specific repair methods 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.

Action 12: Update Procedures and Periodically Retrain Mechanics

Mechanic skills need to be updated periodically. Both vehicle and diagnostic technology continues to change with the advent of electronic controls, which are only now being offered in many developing countries. Sending mechanics to special retraining classes not only helps mechanics adapt to changing requirements, but also provides an opportunity for informal exchange of best practices in the industry. Procedures for repair also need to be periodically reviewed and updated to reflect industry best practices.

BOX 3 **Benefits of Independent QA/QC Teams**

In the United States, the Washington Metropolitan Area Transit Authority (WMATA) operates a fleet of about 1,500 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 MTBF 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.

Source: General Manager (J.Hiott), Bus Maintenance Operations, Central Baldensburg Facility, WMATA.

BOX 4 **Impact of Bus Drivers' Training on Fuel Economy in Edmonton, Canada**

The Fuel Sense driver training program was implemented in 2000 for Edmonton City Transit. All the drivers were trained over a period of 10 months. A comprehensive review in 2003 found that fuel economy had improved by 5.5 percent, and the drivers exhibited very good retention of the driving techniques from year to year. The start-up costs were US$60,000 and annual costs were estimated at US$45,000. One of the key lessons learned in Fuel Smart was how easily the entire process can be transferred, and how the improvements, though simple, needed to be brought together in a practical way. Other lessons learned were the need to coordinate training with workloads so that drivers are not tired when they come to training. A separate but important lesson was the need to communicate results regularly. Drivers benefit from follow-up communications and are more motivated to continue lessons if they are appraised of the results. Management also needs to be kept informed to support the growth of the program and its applications to new areas.

Source: Transport Canada 2004.

PRINCIPLE IV: TRAINING OF LOW-PERFORMING DRIVERS

Drivers' behavior is an important component of fuel economy on the road, and driver training has been implemented by a number of 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 economy driving can also be easily incorporated into courses that teach safe driving. Of course, all driver training courses stress safety as the highest priority and there is no suggestion that safety must be compromised for fuel economy. As a result, the need for such training with periodic retraining is recommended to ensure the drivers maintain best practices (Boxes 4 and 5).

Action 13: Core Principles of Fuel Efficient Driving

Fuel efficient driving is a technique that any driver can use and must be taught to all drivers. The basic steps of 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; and
- anticipating traffic ahead to minimize hard braking and acceleration.

Driver training programs have been established commercially and the use of a human trainer and a training video is common. Periodic retraining is required to ensure that drivers do not slip back into inefficient practices.

There are a number of commercial and government-sponsored courses that teach fuel-efficient driving or eco-driving for heavy duty vehicles. These courses

BOX 5 **Bus Inspection/Maintenance and Drivers Training in Jakarta, Indonesia**

In Jakarta, nine bus companies developed their own internal I/M program. The program checked the vehicle for engine malfunctions and excessive smoke and measured exhaust opacity.

In order to be successful, the program also contained a large educational program. The education aimed at raising awareness among technicians on how to conduct a proper I/M program. The education also included instruction to bus drivers on safe and fuel saving driving practices.

Over 13,000 buses were tested in 2001 and 2002, with 89 technicians and 1372 drivers trained. Measures identified through the inspection program that could be easily fixed were cleaning air filters, adjusting fuel injection timing and injection nozzle pressure and calibrating the fuel injection pump. In some cases, air filters and fuel injection nozzles had to be replaced.

This program achieved a 30 percent reduction of diesel soot and a 5 percent decrease in fuel consumption through improved maintenance practices. An additional 10 percent decrease in fuel consumption was attained through improved driving methods. Approximately a third of the vehicles failed the inspection but over 80 percent of them could be repaired with only minor additional cost.

The Jakarta program started out with just two bus companies on a voluntary basis but, by the end of the program, it grew to nine bus companies as the economic benefits became more apparent.

Source: UNEP 2009.

have been developed for city driving and courses for transit bus drivers also teach aspects of bus rider safety and public safety. For example, the United Kingdom's Safe and Fuel Efficient Driving (SAFED)program[13] incorporates all of the key features required in a good driver training program.[14] 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 (Boxes 4 and 5). 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 habits and show the driver how to correct them.

Action 14: Retraining the Worst Performing Drivers

It is important to identify and send the worst 10 percent of a depot's drivers in terms of fuel economy for retraining. The recognition of poor drivers based on

13 www.freightbestpractice.org.uk/fuel-efficient-drivers-handbook.

14 Annex 7 provides an overview of some popular programs; the SAFED classroom topics covered and Driver Handbook contents are listed in Annex 7.3 (ESMAP 2011).

data analysis (as described in Action 6) and their retraining can lead to significant improvements in fuel economy. Drivers who do not improve their driving even after repeated counseling can be 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.

PRINCIPLE V: EMPLOYEE COMMUNICATIONS AND REWARDS

Motivating employees is a key part of any strategy to create a culture of fuel economy 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. It is recommended 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 fuel economy goals and targets as suggested in Action 1. Rewards should also be instituted at the depot level, and at the individual level per steps 15 and 16 described below.

Action 15: Communicate Fuel Economy Data

The weekly or monthly average of the fuel economy performance of the top 10 drivers at each depot must be posted at a visible location where all employees can see this information. In addition, the average fuel economy by bus type and depot should also be posted across all depots so that each depot's employees can be aware of their relative performance. In-house communications in the form of posters at a highly visible location have been found to be very effective by the Andhra Pradesh State Transport Corporation in India. Providing information to employees on fuel economy performance by publicly posting this data is key to motivating individuals to perform well. A second and closely related aspect requires both managers and employees to maintain 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 actions towards fuel economy.

Action 16: Mechanic and Driver Awards

Awards for mechanics are recommended for the depot with the best fuel economy performance. Good maintenance is a 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. Given this, the depot mechanics can be jointly 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 successful implementation of this step relies on proper setting of fuel economy goals at the bus type or depot specific levels.

Drivers should be rewarded for good performance in both safety and fuel economy. 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, often because it has been difficult to separate driver performance from that of the bus (model, age) and route (see

BOX 6 **Difficulty of Implementing Rewards for Fuel Economy Performance**

Transit bus operators have tried to institute awards for fuel economy performance with mixed success. In some agencies, the awards had to be withdrawn as they caused resentment 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 agencies where such awards have been accepted and are popular, the data on fuel economy is adjusted to the route level. More importantly, data is openly available, and drivers can see their own performance relative to other drivers on similar routes. This illustrates the synergy between the different steps recommended—open communications, ensuring data quality and performing more advanced data analysis make it possible to fairly reward employees and create a culture of employee pride in fuel economy performance.

Source: Interviews with bus fleet managers.

Box 6). To successfully provide driver awards for fuel economy, the following are required:

- drivers' performance ratings must be adjusted based on the route and bus;
- the adjusted performance for all drivers must be publicly posted; and
- the adjustment factors and their fairness can be evaluated by the drivers so that they will accept them over time.

The simple averaging method[15] by route is useful if buses and drivers are typically allocated to the same routes most of the time. Clearly, statistical fluctuations in fuel economy leads to some uncertainty in the estimates of fuel economy ranking, and to avoid problems, the top 10 percent of drivers should be recognized and rewarded.

15 It is defined as the simple average of fuel economy across all records over a given time period. For example, bus no. 10 has 44 records in the database, the simple average fuel economy is the average across all 44 records.

RESULTS FROM FIELD TESTING

Validation testing of these recommendations took place over 10 weeks, starting at the end of January 2011. As a result of the short time frame, testing was not possible against the longer range recommendations in actions 4, 7 and 12; actions 15 and 16 (employee rewards for fuel economy) were already in place at APSRTC. Field testing was done in three Indian cities: Hyderabad and Vijayawada with APSRTC, and Mysore with Karnataka State Road Transport Corporation (KSRTC).

Overall, the testing showed that the recommended approach could be implemented without significant changes in operating structures, capital investment, or upfront preparation. The data on bus fuel economy, though manually collected, was of reasonably good quality and permitted the identification of low fuel economy buses and drivers. At each depot, approximately 10 buses were identified each month as low fuel economy buses, relative to the same bus technology types operating on the same routes. In addition, approximately 20 drivers were identified as low fuel economy drivers although the selection of drivers appears to have been based on low absolute fuel economy without adjustments for route variations. The buses identified were sent for special diagnostics and repair as recommended in action 8; low fuel economy drivers were sent for retraining on good driving practices.

Data was collected from three APSRTC bus depots[16] between January and March 2011, totaling about 60 buses and 120 drivers. Pre- and post-repair performance of buses and pre- and post-training performance of drivers was monitored to estimate fuel economy benefits. Mechanics at facilities were competent in performing the required diagnostics and repairs, and they successfully followed the recommended sequence of repairs recommended in (see Annexes 1 and 2). The fuel economy results from the data collected over a limited time period for the repaired subset of buses and the retrained subset of drivers in APSRTC showed considerable variability in the level of improvement in fuel economy observed, which was to be expected since the problems differ from bus to bus and driver to driver.

16 Bharkatpura (BKPT) depot in Hyderabad; Governorpet1 (GVPT1) and Governorpet2 (GVPT2) depots in Vijayawada.

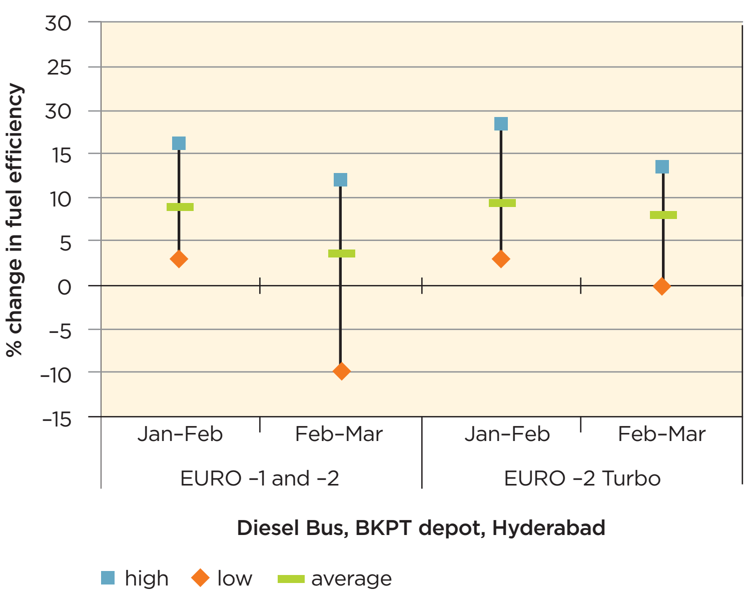
TEST RESULTS FROM BUS MAINTENANCE AND REPAIR

The average data on fuel economy showed positive and significant fuel economy improvements. Figure 2 shows the data by type of bus technology on the observed improvements from repair buses in the Bharkatpura bus depot in Hyderabad city; the average fuel economy benefits vary from about 6 to 9 percent.[17] The benefit of repairing low-performing buses in terms of fuel economy appears to be a function of vehicle age. Newer diesel buses (4 to 7 years old) appear to obtain about 4 to 5 percent improvement in fuel economy based on the buses that were tested in Mysore (ESMAP 2011). Older diesel buses (7 to 14 year old) appear to obtain a benefit of 7 to 8 percent fuel economy improvement based on the data from Hyderabad.

TEST RESULTS FROM DRIVER TRAINING

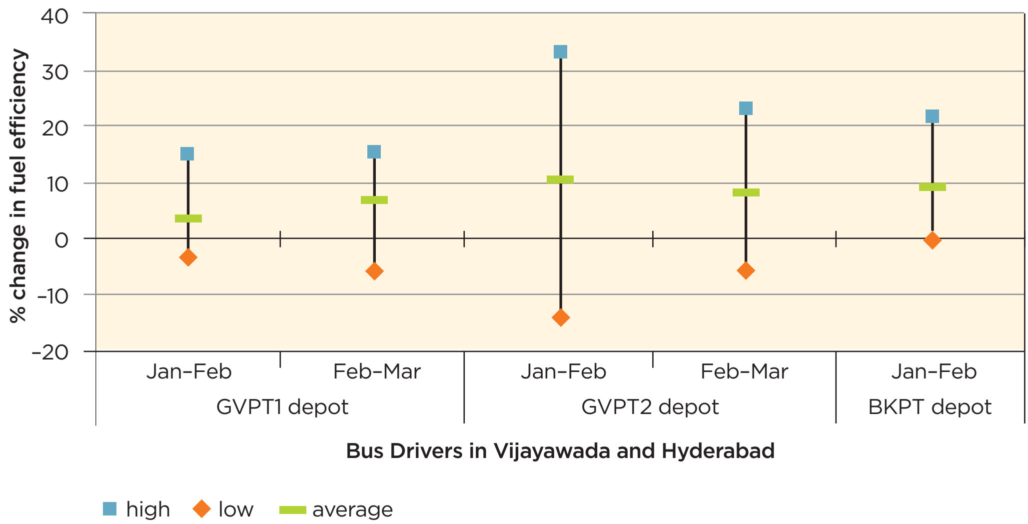
Driver training programs incorporate most international best practices for fuel-efficient driving, and the on-road training, in particular, appeared to be very well suited to help drivers facing local driving conditions. During the field validation, drivers were identified on the basis of low absolute fuel economy, not on route-adjusted fuel economy. Even better results could be obtained by changing driver selection to be on a route-adjusted fuel economy basis. Drivers are highly motivated by the public display of driver specific fuel economy information, and the award for good fuel economy performance inculcates driver pride in their performance even though the monetary value of the award is small. Figure 3 shows the

FIGURE 2 | Percent Fuel Economy Improvements from Repair of Buses at the Bharkatpura Depot in Hyderabad



17 Results presented here are buses that were tested in APSRTC depots only. Details of the test results with KSRTC buses are presented in the detailed study report (ESMAP 2011).

FIGURE 3 | Percent Fuel Economy Improvement of City Bus Drivers from Training in Hyderabad and Vijayawada



benefits from driver training in Hyderabad and Vijayawada, with an average fuel economy improvement in the 5 to 10 percent range.

Due to the many different issues affecting fuel economy, it is difficult to make definitive statements in the absence of a careful controlled study, but the limited data suggests that the combination of driver training and organizational focus on fuel economy could provide fuel economy benefits in the 7 to 15 percent range for organizations where fuel economy has not previously been a focus.

SCALING UP OF TEST RESULTS TO THE CITY BUS FLEET

The fuel economy benefits of bus maintenance and driver training were extrapolated for the entire bus fleet of Hyderabad—3,290 vehicles in total—using baseline fuel economy data obtained before the start of testing (ESMAP 2011). For maintenance, results were extrapolated on the assumption that all buses performing 2 percent or more below average and would be eventually repaired over the course of one year. The results indicated that the fleet-wide benefit from repair of older buses would be 3 percent while the benefit of repair of newer buses would be 2.1 percent. The fleet-wide benefits of driver training were estimated, using a similar method, to be 2.7 percent (Box 7).

COST-BENEFIT ANALYSIS

The degree of benefit obtained at the fleet level from implementing a strong fuel economy program depends greatly on certain factors:

- age composition of the bus fleet;
- technology of bus maintenance;

BOX 7 **Results from Field Testing**

The 16-point action given in Table 1 was applied by the city transit managers in APSRTC and KSRTC. While APSRTC implemented the actions at the Hyderabad and Vijayawada bus depots, KSRTC deployed them at the Mysore bus depots. Comparing the fuel economy data before and after and repair of the 10 percent most underperforming buses and training of the 10 percent poorest performing drivers revealed the following results:

- Maintenance practices: Euro 2 diesel buses (4-7 years old) appear to obtain an average benefit of about 4-5 percent improvement in fuel economy based on buses that were tested in Mysore. Euro 0/1 diesel buses (7-14 years old) appear to obtain a benefit of 7-8 percent improvement based on the test results from Hyderabad. Surprisingly, even the new CNG buses (<3 years old) at Vijayawada showed a fuel economy benefit of about 5 percent, which could be due to ignition system defects.
- Driver training: The benefits accrued from drivers training are quite consistent and show an average fuel economy improvement of 6-8 percent. A key finding is that the benefits are obtained not through classroom training but from actual on-road training with a professional driving instructor.
- Extrapolating the repair and drivers' training results over the course of a year on city buses in Hyderabad was expected to result in a combined fuel economy improvement of 4.8 percent for newer buses and 5.7 percent for buses older than 4 years.
- Monthly fuel cost savings: The monthly fuel savings per percent improvement in fuel economy was estimated at US$1,120 for a depot of 100 buses. Given the results above, if maintenance and driver training were to combine to give an overall 5 percent fuel economy improvement, APSRTC would save US$0.18 million per month in Hyderabad alone.

Source: ESMAP 2011.

- pre-existing organizational emphasis on fuel economy; and
- characteristics of the routes in the city.

To control for this, the costs and benefits of putting the recommended plan of action in place were estimated for a city of 10 depots, with each depot housing 100 buses, using cost data collected from APSRTC. Table 3 presents the benefit to cost (B/C) ratio of implementing of most of the 16 recommended actions for different depot fleet sizes.

For a typical depot with 100 buses, the monthly cost for implementing all recommended measures was estimated at US$2,767. With the estimated range of improvement at 4.8 percent in newer buses to 5.7 percent in older buses, the fuel savings alone would range from US$5,376 to US$6,384 per month respectively, making the program very cost effective, with a B/C ratio of 1.94 to 2.31. This does not include the value of co-benefits associated with reduced vehicle emissions and safety.

TABLE 3 | Cost-Benefit Analysis: Estimated Monthly Values in US$, March 2011 (from APSRTC data)

COST BREAKDOWN AND BENEFIT FROM FUEL SAVINGS	NUMBER OF BUSES			
	50	100	150	200
Fixed Costs				
Senior Executive	178	178	178	178
Data Analyst	667	667	667	667
Computer/Software	56	56	56	56
Periodic Audit	111	111	111	111
Step Variable Cost				
Special mechanic/Helper	667	667	1,333	1,333
Amortization—Spare Bus	356	356	356	711
Mechanic Retraining	67	67	133	133
Variable Cost				
Driver Training	333	667	1,000	1,333
TOTAL COST	2,433	2,767	3,833	4,522
Benefit				
Fuel Saved Newer Buses (Liters) [4.8 percent]	64	128	192	256
BENEFIT (Newer Buses—savings in fuel cost)	2,688	5,376	8,064	10,752
B/C Ratio—Newer Buses	**1.10**	**1.94**	**2.10**	**2.38**
Fuel Saved Older Buses (Liters) [5.7 percent]	76	152	228	304
BENEFIT (Older Buses—savings in fuel cost)	3,192	6,384	9,576	12,768
B/C Ratio—Older Buses	**1.31**	**2.31**	**2.50**	**2.82**

Source: Authors.

CONDITIONS OF APPLICABILITY

It is important to be specific to the conditions under which this approach is most effective. The B/C ratio becomes smaller as the number of buses at a depot decreases. This is due to the fixed costs of a spare bus and a specialized mechanic and helper for fuel economy related repairs. The results of the B/C cost ratio analysis suggests that the program is near break-even (i.e., a B/C ratio close to 1) when the number of buses at a depot is around 50. Since these costs are computed for India, where labor costs are quite low, the analysis suggests that the program be implemented when the minimum number of buses exceeds 70 to 100, depending on local labor cost and fuel cost, to ensure a favorable B/C ratio. Such an O&M program may not be cost effective in a developed country setting where labor costs are high.

The following other conditions would also be a pre-requisite for implementation of the recommended approach:

- an existing maintenance facility that conducts most periodic maintenance and can conduct the majority of common repairs in-house;
- access to a more specialized repair facility capable of engine and fuel injection system rebuild that can be either in-house or supplier based, to realize the full fuel economy potential of the program;
- the capability to train drivers in fuel-efficient driving at either an in-house or at a commercial driving school; and

- an age composition of the bus fleet such that a significant fraction of the fleet is older than five years.[18]

While the above conditions may suggest limited applicability, traditional city bus operators in developing countries normally have fleets ranging from about 30 to 1,000 vehicles; the majority of fleets probably consist of between 300 and 600 buses (Iles 2005). Many medium to large cities in the developing world have bus fleets of several hundred to several thousand buses, and buses are usually retained for 12 to 15 years. In most of the cities in Asia, Middle East and North Africa, a large share of urban public transport services are provided by medium or large size (private and state-owned) bus operators. Such organizations also usually have the capability of conducting all periodic maintenance at depots, even if the depot level maintenance facility is contractor-run. Access to more intensive repair and engine rebuild is typically available at either a centralized workshop or at the dealerships of the bus manufacturer. Driver training for safety is also common and a legal requirement in many countries. Training schools are usually available, although a fuel economy component may need to be added.

In some countries, especially in Latin America, urban bus services are contracted out to numerous small operators who service one or two routes with a small number (1 to 10) of buses. In such cases, removing a bus from a revenue generating route to check for fuel economy is not cost effective and may involve penalties for not providing the frequency of service required under the contract. Unless small contractor fleets are pooled, some of the recommendations in this report may not be applicable to such small fleets, although driver training would still be warranted.

18. The analysis reveals smaller benefits in fuel economy for newer buses (ESMAP 2011).


PSR
Phone

CONCLUSION AND RECOMMENDATIONS

In many cities around the developing world, buses are the most common form of urban transit and vehicle fleets are a significant investment for transit organizations. Due to the popularity of bus transit, authorities continue to try to develop efficient, clean and affordable urban bus systems that can maintain or even improve total mobility, even as incomes grow and cities expand.

However, in most cities, public transit has to be subsidized to make it affordable, and the financial problems of most governments worldwide are causing significant changes in transit systems. In the past 20 years, transit systems in many cities have changed from a government owned enterprise to a financially constrained municipal enterprise with emphasis on cost control, innovation and competition. Usually, the financial position of bus fleet operators is weak and may not allow rapid bus replacement to upgrade the fleet to new and more fuel-efficient vehicles. And in developing countries, the cost of fuel is a relatively large fraction of total operating costs, particularly when labour costs are low.

As this Guidance Note demonstrates, there are ways of improving fleet-wide fuel economy, safety, and the overall efficiency of transit systems at relatively low cost. Good O&M practices are necessary to achieve optimal fuel economy and low emissions and can reduce significant expenditures on fuel, freeing up resources for improved services. Effective implementation of drivers' training programs has shown to improve fuel economy by 5 to 10 percent, with the greatest benefits obtained through actual on-road training with a professional driving inspector. The identification and repair of low fuel economy buses is second only to driver training in maximizing fleet fuel economy. The combination of driver training, bus maintenance and organizational focus could provide fuel economy benefits in the 7 to 15 percent range for organizations where fuel economy has not been a priority.

The O&M practices recommended here were found to be cost effective with a minimum fleet size of about 70 to 100 buses in a city with an existing maintenance facility and low labor costs. Energy-efficient O&M practices must be carefully planned and must be appropriate to the size, resources, and "culture" of each city bus company to be successful.

While virtually every bus operator uses a basic checklist to conduct O&M practices, many smaller operators simply do not have the time or staff to develop instructions for other essential maintenance and repair activities. Fortunately, the transit community has a great deal of collective knowledge concerning practices, and the community can freely exchange this knowledge without the competitive pressures typically found in other industries.

This Guidance Note is one step in the direction of giving city bus operators equal access to that collective knowledge. This note is targeted at two levels of users: 1) managers responsible for implementing O&M practices at bus depots or maintenance workshops; and 2) senior management of transport corporations, who are responsible for making the strategic investment decisions required to enhance fuel economy gains. Active and continuing support by senior management, as well as driver training and motivation, is critical to the success of energy-efficient O&M efforts.

If transit companies are to see gains in efficiency over the long term, however, a number of changes need to take place. Operating companies should value fuel economy as a performance indicator at least as highly as fleet utilization. Targets should be set for fuel economy performance, and senior executives must be accountable for meeting those targets. Depot managers and mechanics must know that performing the extra maintenance needed to make a poorly performing vehicle more fuel efficient will not hurt them in their jobs. Data collection must be made systematic to monitor fuel economy, and combined with a transparent system of assessing performance. Finally, the route-specific variability of fuel economy must be taken into account. Fuel economy monitoring systems should account for this variability, and gains should be measured across time rather than across routes. Rewards could be for fuel economy improvements rather than absolute performance metrics.

Governments could play a key role by requiring publicly owned bus operating companies to take the lead in implementing the sort of recommendations laid out in this Guidance Note, and showing the way for private operators. National-level rewards for fuel economy would give due recognition and visibility that would motivate companies to adopt the best O&M practices. Similar action by associations of bus companies would also go a long way in motivating action in this regard. Governments could also set up high-quality driver training facilities that would serve the needs of multiple operators. This would be particularly useful in countries where midsize operating companies dominate and no single company has the resources to invest in such training infrastructure.

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ANNEX 1

Tier I Checks for Implementation at the Local Bus Depot to Improve Fuel Economy

COMPONENT	CHECK	PASS/ FAIL CRITERION AND REPAIR
Tires/ Wheels	1. Check tire inflation 2. Check for free rolling of wheels 3. Wheel bearing lubrication	1. Pressure meets specification or add air 2. Wheels rotated easily by hand or check brakes (see below) 3. 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 calliper boot and wear adjuster cap 7. Check for brake retraction after pedal release	4. Excessive free play requires brake pedal linkage adjustment 5. Gap must be visible or liners reinstalled 6. Wear adjuster should not be at setting limit, or replace liner 7. 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	8. Lack of visible lubricant and/or noise in joints and bearings signify need for lubrication 9. Visible driveline and gearbox vibration indicates need to tighten mounts
Accelerator/ Clutch pedal	10. Check clutch pedal linkages 11. Check Accelerator linkages	10. Excessive play requires linkage adjustment 11. Excessive play requires linkage adjustment
	12. Check accelerator return spring	12. 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	13. Visible dirt on air cleaner, replace 14. Check for any foreign objects or broken catalyst in pipe. 15. Electronics check for diagnostic codes indicating any failure 16. Smoke opacity over 20 percent indicates engine problem, send to central maintenance facility
Air conditioner-related	17. Check tension in compressor belt drive 18. Check for refrigerant pressure 19. Check for compressor damage	17. Tighten belts as required or replace if worn significantly. 18. Low pressure indicates refrigerant leaks and leaks should be identified and fixed. 19. Replace or repair as required

Source: Authors.

ANNEX 2

Tier II Checks for Implementation at the Central Bus Maintenance Facility to Improve Fuel Economy

COMPONENT	CHECK	PASS/ FAIL CRITERION AND REPAIR
Wheels	1. Check wheel alignment 2. Check tire camber	1. Set to manufacturer specification 2. Set to manufacturer specification
Clutch	3. Check condition of clutch facings 4. Check clutch release bearing	3. Replace clutch facing if worn 4. Replace bearing if worn/ failed
Fuel System (Diesel/ CNG)	5. Check fuel lines and tanks for leakage	5. 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	6. Set timing and stop to manufacturer specifications 7. Low pressure indicates pump rebuild 8. Asymmetric spray indicates need for injector cleaning or replacement 9. Turbo rotor must rotate freely or else replace bearings 10. Low compression requires head gasket, ring check or engine rebuild 11. Torque head bolts to manufacturer specification, replace cracked head 12. Replace worn rings 13. 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	6A. Set to manufacturer specifications 7A. Output pressure must be within specifications or replace 8A. Replace broken wires and fouled spark plugs 9A. Turbo rotor must rotate freely or else replace bearings 10A. Low compression requires head gasket, ring check or engine rebuild 11A. Torque head bolts to manufacturer specification, replace cracked head 12A. Replace worn rings 13A. Radiator or hose leaks should be patched
Exhaust System	14. Inspect exhaust brake valve if used	14. Valve not opening freely should be cleaned or replaced

Source: Authors.

ACRONYMS AND ABBREVIATIONS

APSRTC	Andhra Pradesh State Road Transport Corporation
ASRTU	Association of State Road Transport Undertakings
B/C	Benefit to Cost
BEST	Brihan Mumbai Electric Supply and Transport
BKPT	Bharkatpura Depot
BPT	Beijing Public Transport Holding
BXL	Beijing Xiang Long
CNG	Compressed Natural Gas
DTC	Delhi Transport Corporation
EMO	Energy Management Organization
EURO 1 & 2	Heavy Duty Engine Emission Certification Levels for the European Union (higher numbers indicate increasing stringency)
ESMAP	Energy Sector Management Assistance Program
GVPT1 & 2	Governorpet 1 & 2 Depots
IEA	International Energy Agency
IFC	International Finance Corporation
I/M	Inspection/Maintenance
IPCC	Intergovernmental Panel on Climate Change
km	Kilometer
KSRTC	Karnataka State Road Transport Corporation
L	Liters
MM	Maintenance Management
MTBF	Mean Time Between Failures
O&M	Operations and Maintenance
QA/QC	Quality Assurance/Quality Control
RPM	Revolutions per Minute
SAFED	Safe and Fuel Efficient Driving
UNEP	United Nations Environment Programme
WMATA	Washington Metropolitan Area Transit Authority

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