The High Cost of Low Emissions Standards for Bus-based Public Transport Operators in India: Evidence from Bangalore

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ABSTRACT

To support the adoption of stricter fuel emissions standards, the Indian Central government has mandated that all new buses purchased by public transport authorities in select cities be compliant with the latest Bharat Stage 4 (BS-IV) emissions standard. While the BS-IV buses available in the Indian market are less-polluting than BS-III or lower buses, they have also proven to be less fuel-efficient. An analysis of the fuel efficiency data from the Bangalore Metropolitan Transport Corporation's (BMTC) 6,472-strong bus fleet from August 2012 through January 2013 indicates that non-BS-IV buses have an average weighted fuel efficiency of 4.01 km/L, whereas BS-IV compliant buses have an average weighted fuel efficiency of 3.52 km/L. Given that BMTC estimates that its buses travel a combined 1.295 million kilometres daily, a decrease in fuel efficiency from more efficient pre-BS-IV buses to less efficient BS-IV compliant buses has significant financial implications for BMTC's bus operations. The analysis presented in this paper shows that if BMTC were to upgrade its entire fleet to the BS-IV standard, the agency will require an additional ₹446-514 million ($7.47-8.61 million US) annually in fuel costs alone. This paper also explores the reasons for the reduction in fuel efficiency of BS-IV buses, suggests possible interventions, and identifies some potential unintended consequences.

INTRODUCTION

Air quality statistics of Indian cities make for grim reading. In 2010, air quality data produced by the Central Pollution Control Board showed that 99% of Indian cities and towns had at least one major pollutant that exceeded the nation's annual average ambient air quality standards. Among the 190 urbanized regions monitored, 90 had "critical" levels of particulate matter (PM_{10}) (ie. 1.5 times or greater than the prescribed limits) (*1*). Nitrogen oxides (NO_x) have also emerged as a growing problem, with 11% of monitored cities showing high or critical levels, up from 1.9% in 2008 (*2*).

Having recognized the urgent need to reduce urban air pollution levels, the Indian Central government has pursued two major interventions in the transport sector. First, it has instituted a set of vehicle emissions standards, known as the 'Bharat Stage' standards, which have become stricter over time. The latest iteration, Bharat Stage IV (BS-IV), has been in effect in 15 cities since 2010. And second, it has used national spending programs such as the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) to increase the scale and usage of public transport by providing cities with funding for the procurement of buses.

Despite the convergent goals of these two strategies, the manner in which stricter vehicular emission standards are being implemented suggest that they may be in conflict, particularly given the existing regime for funding and subsidizing public transport in India. To boost adoption of the BS-IV standard, the Central government has mandated that all new buses purchased by public transport authorities in select cities must be BS-IV compliant (*3*). While the BS-IV buses available in the Indian market are less-polluting than BS-III or lower buses, they have also proven to be less fuel-efficient and therefore more expensive to operate. At the same time there is significant pressure for urban public transport operators, which are by and large state-owned enterprises, to be profitable. The current financing regime for public transport in India lacks dedicated sources for subsidies. Public transport operators must compete with a large number of claimants for limited financial resources through annual budgetary appropriations (*4*). The costs of achieving reductions in air pollutant emissions, via the increased costs of operating lower emissions vehicles, are borne entirely by the operators themselves.

This paper examines the increased fuel-related financial costs if Bangalore's entire public transport bus fleet were to be converted to the BS-IV standard. In the first section, following an overview of existing studies on this subject, we establish the background on vehicle emissions standards in India, discuss technologies available to bus operators, and provide an overview of the public transport fleet in Bangalore. In the second, we discuss the methodology used to calculate the future fuel use and financial implications of bus fleet conversion to the BS-IV standard and present the results. Finally, we explore the likely causes of lower fuel efficiency for BS-IV buses, suggest possible interventions, and conclude by identifying potential unintended consequences.

PREVIOUS STUDIES

The literature on public transport and its relationship with emission standards has primarily assessed the cost-effectiveness of different technologies that achieve mandated emission standards. Schimek (2001) examined various forms of bus engine technologies, and concluded that retrofitting old diesel engines with new ones that comply with stricter emission standards to be the most cost-effective method of reducing emissions (*5*). Cohen et al. (2003) compared compressed natural gas, emission-controlled diesel, and conventional diesel buses, and found that emission-controlled diesel buses to be the most cost-effective (*6*). McKenzie et al. (2012) presented a life-cycle assessment of ultra-low sulfur diesel, hybrid diesel-electric, compressed natural gas, and hydrogen fuel-cell buses, and concluded that while alternative fuel buses reduce operating costs, they increase overall lifecycle costs (*7*).

Despite the number of papers that quantify public transport operating costs and the cost-effectiveness of various low-emission technologies, few have identified who must ultimately pay for these additional costs. The lack of literature on how low emission standards impact public transport operators in an environment where financial subsidies for operating costs are generally not available, such as in India, presents a significant gap in the literature.

POLLUTION STANDARDS AND FUEL TECHNOLOGY

In an effort to combat increasing levels of pollution, the Indian Central government announced in 1989 the creation of idle emissions limits for vehicles in the country (*8*). These limits were replaced with maximum permissible emission standards for petrol vehicles and diesel vehicles in 1991 and 1992 respectively. Since then, India has created a series of vehicular emissions specifications, based on the European Union's vehicular standards, known as Bharat Stage Standards. Since April 2010, Bharat Stage IV (BS-IV) standards have been in effect across 15 cities for all private vehicles and heavy-duty commercial vehicles, which include buses. The Bharat Stage V standard is likely to come into regulation in 2015 (*9*).

Indian manufacturers of heavy-duty diesel vehicles have generally utilized one of two engine technologies to achieve compliance with BS-IV emissions norms. One technology, Exhaust Gas Recirculation or EGR, focuses on reducing emissions from within the combustion chamber while the other, Selective Catalytic Reduction or SCR, focuses on post-treatment of exhaust gases (*10*).

In the EGR process, gases created from combustion are recycled into the engine again. Since NO_x are formed at high temperatures, the recirculation of cooled exhaust gases low in oxygen reduces the combustion temperature and lowers NO_x production. The exhaust gases are then sent through a filter, reducing the particulate matter emitted (*11*).

The SCR method, on the other hand, relies on optimized engine combustion which allows for better fuel efficiency and lower particulate matter generation. However, since higher combustion temperatures produce more NO_x, post-treatment of exhaust gases is required. This is accomplished by the introduction of a Diesel Exhaust Fluid (DEF), better known by its commercial name 'AdBlue', which reacts with the exhaust gases and converts nitrogen oxides into nitrogen and water vapour (*11*, *12*).

Though both technologies are effective at reducing pollution emissions, SCR technology has proven more popular in India. One reason is that SCR technology is generally more fuel-efficient, and therefore more cost-effective. Furthermore, high sulfuric content in diesel fuel can have a deleterious impact on EGR engines, reducing engine durability and reliability (*11*). The lack of consistent availability of low sulfur fuel in India has therefore prevented widespread adoption of EGR technology. For these reasons, SCR is the dominant BS-IV technology for public transport buses in India.

CITY CONTEXT: BANGALORE

Bangalore, India's third largest city is located in the South Indian state of Karnataka. With a population of 8.47 million in 2011, Bangalore is the second fastest growing major metropolis in India (*13*). Bangalore is perhaps best known as a hub of the information technology industry and is popularly known as the "Silicon Valley of India". Bangalore's annual per capita income of ₹110,400 ($1,816.30 USD) is the highest among metropolitan regions in India (*14*). Unsurprisingly then, private vehicle ownership has also increased dramatically in recent years (*15*). In the decade from 2001 to 2011, the proportion of Bangalore households owning a four-wheeled vehicle increased from 9.2% to 17.5%, while those owning two-wheelers increased from 32.8% to 44.3% (*16*).

Bangalore's increasing population and vehicle ownership rates have contributed to its deteriorating air quality. Locally, the transport sector is a major source of air pollutants. In 2012, vehicles contributed 41% of particulate matter emissions and 67% of all NO_x emissions released (*17*). In particular, private vehicles such as two-wheelers and four-wheelers are responsible for a disproportionate share of air pollutant emissions when compared to their combined mode share of 25% for all trips (*18*). Two-wheelers alone contribute to more than 65% of hydrocarbons and 50% of carbon monoxide emitted by vehicular sources in Bangalore (*19*). Shifting users from emissions-intensive private modes like four-wheelers and two-wheelers to public transport therefore has an important role to play in reducing air pollution levels.

Within Bangalore, public transport is presently limited to bus services operated by the Bangalore Metropolitan Transport Corporation (BMTC). BMTC, a publicly owned entity, operates a fleet of 6472 buses across 2398 routes and serves approximately 4.9 million passenger trips daily (as of January 2013) (*20*). BMTC has historically performed extremely well, both in terms of revenues as well as in ridership. Ridership has grown consistently since 1997, and the rate of growth itself began to increase in the early to mid-2000s due to increases in service levels and the development of differentiated services to meet the needs of varying commuter segments (*21*). As a result, though public transport buses accounted for a mere 0.16% of vehicles on Bangalore's roads in 2011, they carried 42% of all motorized trips (*22*).

BANGALORE'S BUS FLEET: BHARAT STAGE COMPLIANCE & FUEL EFFICIENCY

BMTC currently operates a fleet of 6,472 buses. 129 (1.99%) of these buses, unique typologies that are unlikely to be replaced in a "like-for-like" manner, have been excluded from the analysis presented in this paper. Of the remaining 6,343 buses, 5,655 are "ordinary" non-air-conditioned (non-AC) buses, of which 765 (13.5%) are BS-IV compliant. BMTC also operates a 688-strong fleet of high-end air-conditioned (AC) buses, of which 100 (14.5%) are BS-IV compliant. In total, 865 (13.6%) of the 6,343 buses included in this analysis are BS-IV compliant. All of BMTC's BS-IV buses utilize SCR technology, which requires the post-treatment of exhaust with 'AdBlue' Diesel Exhaust Fluid (DEF). All future BS-IV buses procured by BMTC will be assumed to utilize SCR technology only.

In terms of manufacturers, BMTC's non-AC fleet is dominated by Ashok Leyland and Tata Motors, which together account for 92.9% (5255 of 5655 buses) of the total. The remaining 400 (7.1%) buses are manufactured by Eicher. BMTC's AC buses include those produced by Volvo, Marcopolo, and Corona (Figure 1).

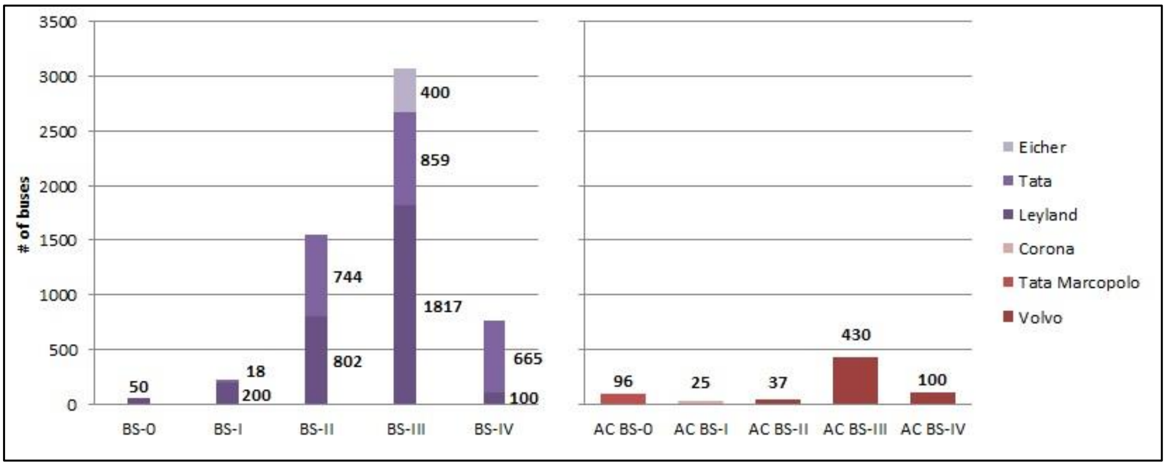

FIGURE 1: BMTC's bus fleet by make and BS-compliance (*23*)

An analysis of fuel efficiency data for BMTC's fleet from August 2012 to January 2013 shows significant differences in the fuel performance of buses complying with differing BS-norms. For the non-AC fleet, BS-IV buses exhibit the lowest fuel efficiency numbers, achieving an average of 3.63 km/L, compared to the fleet-wide average of 4.17 km/L. Variations in fuel efficiency exist between BS-IV buses from different manufacturers as well. Ashok Leyland BS-IV buses, for example, achieve a fuel efficiency of 4.07 km/L whereas Tata Motors BS-IV buses achieve only 3.56 km/L. There is a clear trend of decreasing fuel efficiency for buses complying with stricter BS-norms (Figure 1). For AC buses, however, this trend is reversed; BS-IV AC buses have the highest fuel efficiency of the entire fleet (Figure 2). Given that non-AC buses account for a majority of the fleet, and will continue to do so in the near-to-medium term future, the overall effect of fleet conversion to the BS-IV standard will be a reduction in fleet-wide fuel efficiency.

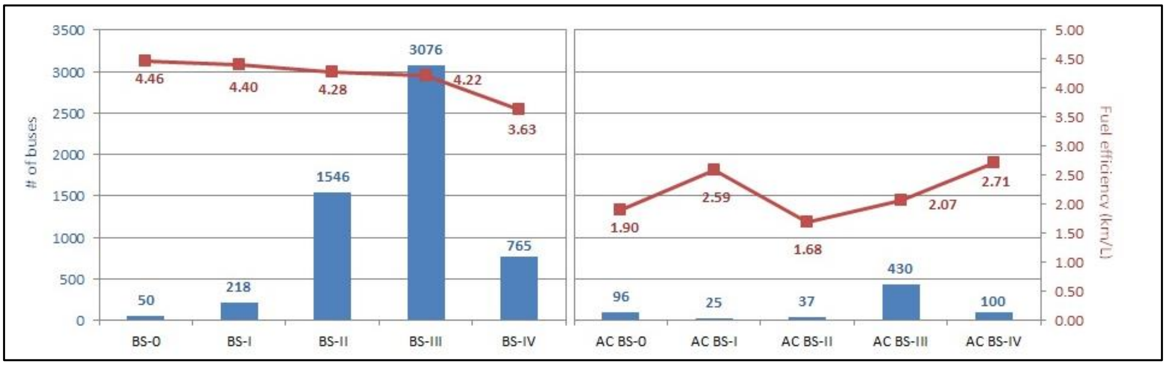

FIGURE 2: BMTC's bus fleet by number and fuel efficiency (*23*)

ESTIMATING THE FUEL COST IMPLICATIONS OF FLEET CONVERSION TO BS-IV NORMS

Methodology

Estimating the increased fuel-related costs for BMTC of operating a BS-IV only fleet is a function of two factors. First is the cost of increased fuel use due to a reduction in fleet-wide fuel efficiency. And second is the cost associated with an increase in use of DEF, as necessitated by the use of SCR BS-IV technology which, as discussed previously, will likely remain the dominant BS-IV technology employed by BMTC (Formula 1).

FORMULA 1: Fuel costs resulting from BS-IV conversion

$$Fuel\ cost\ implications\ of\ BS4\ conversion = (A \times B) + (C \times D)$$

whereby:
A is the change in fuel use between pre- and post-BS4 conversion
B is the estimated future fuel price
C is the change in diesel exhaust fluid use between pre- and post-BS4 conversion
D is the estimated future diesel exhaust fluid price

Estimated Future Increased Fuel Use (A)

The overall change in fuel use depends on two factors: the increase in fuel use from converting non-AC non-BS-IV buses to non-AC BS-IV buses, and the decrease in fuel use from converting AC non-BS-IV buses to AC BS-IV buses. To calculate the net impact, the estimated future post-conversion fuel use is subtracted from the current pre-conversion fuel use. Determining overall fuel use of pre- and post-conversion of the fleet to BS-IV is based on (Formula 2):

FORMULA 2: Calculating fleet-wide daily fuel consumption

$$Fleet\ wide\ daily\ fuel\ consumption = \sum \left\{ \frac{E}{F} \times G \right\}$$

whereby:
E is the daily utilization of each bus make (kilometres travelled/bus/day)
F is the fuel efficiency of each bus make (kilometres travelled/L)
G is the number of buses of each bus make

Given that the fleet conversion to the BS-IV standard has not yet occurred, a flexible approximation of the future bus fleet composition is required. Since BS-IV buses produced by different manufacturers exhibit different fuel efficiencies, the make-up of the fleet will have a large impact on the overall amount of fuel use. Three scenarios of potential future fleet composition are used in this analysis:

Fleet Composition Scenario 1 All Ashok Leyland non-AC buses are converted to Ashok Leyland non-AC BS-IV Buses, all Tata Motors non-AC buses are converted to Tata Motors non-AC BS-IV Buses, and Eicher non-AC buses are split equally between the two manufactures.

Fleet Composition Scenario 2 The entire non-AC bus fleet is split equally between Ashok Leyland BS-IV and Tata BS-IV buses.

Fleet Composition Scenario 3 The Central Government's JNNURM program provided funding between 2010 and 2012 for the procurement of buses. Since these buses are still relatively new, they are unlikely to be replaced for the best part of the next decade. Therefore, in this scenario, only non-JNNURM non-AC buses are converted to the BS-IV standard, with the total number of BS-IV buses split as in Scenario 1.

In all three scenarios, all AC buses are converted to Volvo AC BS-IV buses.

Estimated Future Fuel Price (B)

Three price points for diesel fuel are used. Given the increasing cost of fuel in India, as diesel subsidies are gradually rolled back (*24*), it is estimated that the present-day retail price for diesel will be at the low end for future diesel price (₹52.64/L). The recent dramatic increase in diesel price for bulk diesel consumers, which include public transport operators, suggests that bulk diesel prices represent the high end of future fuel prices (₹62.29/L) (*25*). The average mid-point between these two prices, ₹57.46/L, is also used.

Change in Diesel Exhaust Fluid Use (C)

Along with additional diesel fuel consumption, there will also be an increase in the use of DEF following fleet conversion to BS-IV. AdBlue, a trademarked name for DEF, is currently used on BMTC's fleet of 865 BS-IV vehicles (765 non-AC BS-IV vehicles and 100 AC BS-IV vehicles) at the rate of 5% of diesel consumption, as recommended by engine manufacturers. That is, 5L of DEF is used for every 100L of diesel consumption. Given that there are 6343 buses in the BMTC fleet, the consumption of DEF will increase significantly if all vehicles are converted to the BS-IV standard. Diesel exhaust fluid is used only in BS-IV vehicles and not in BS-3 or lower vehicles. The net change in DEF use is therefore the fleet-wide daily DEF consumption post-conversion to BS-IV (the result of Formula 2 multiplied by 5%) minus BMTC's existing DEF usage.

Estimated Diesel Exhaust Fluid Price (D)

The lack of historical price trends for DEF precludes meaningful projections of future prices. Therefore the average price that BMTC currently pays for its diesel exhaust fluid, ₹44.72/L (US$ 0.74/L), is used.

Data Source

The analysis for the fleet conversion to BS-IV emissions standard uses fuel economy data provided by the Bangalore Metropolitan Transport Corporation (BMTC), gathered over a 6-month period from August 2012 to January 2013. Data was arranged by BMTC zones (North, East, South, West), and further split by bus vehicle type (Non-AC vs AC), bus vehicle BS-compliance, and vehicle manufacturer.

RESULTS

Additional Diesel Fuel Use Costs

Table 1 shows BMTC's estimated additional annual fuel use if the fleet is all BS-IV.

TABLE 1: Overall annual fuel consumption impact

	Additional fuel consumption from non-AC BS-IV fleet (L)	**Reduced fuel consumption from AC BS-IV fleet (L)**	**Overall additional fuel use (L)**
Scenario 1: Leyland to Leyland, Tata to Tata, Eicher split	8,884,693.93	-5,726,314.98	3,158,378.94
Scenario 2: Ordinary Fleet Split between Leyland and Tata	9,306,829.55	-5,726,314.98	3,580,514.56
Scenario 3: All non-JNNURM buses converted to BS-IV, split as Scenario 1	8,684,274.31	-5,726,314.98	2,957,959.33

From the overall fuel consumption impacts, the costs of additional fuel usage are calculated. The overall fuel-only financial impacts of converting BMTC's buses to BS-IV norms can be seen in Table 2.

TABLE 2: Overall annual fuel financial impact

		Fuel price		
	Overall Additional Fuel Use (L)	***Low (₹52.64/L)***	***Mid (₹57.46/L)***	***High (₹62.29/L)***
Scenario 1	3,158,378.94	166,257,067.56	181,496,245.96	196,735,424.36
Scenario 2	3,580,514.56	188,478,286.60	205,754,269.36	223,030,252.13
Scenario 3	2,957,959.33	155,706,979.12	169,979,132.89	184,251,286.65

Depending on the fleet composition scenario and the future price of diesel, the additional diesel fuel consumption is estimated to cost between ₹155.7 million to ₹223 million annually ($2.64-3.78 million USD).

Additional Diesel Exhaust Fluid (DEF) Costs

Table 3 shows the overall additional DEF use while Table 4 shows the overall financial impacts of additional DEF use.

TABLE 3: Overall annual DEF consumption impact

	Total annual DEF consumption (L)	**Additional DEF consumption (L)**
Pre-conversion to BS-IV		
Existing BS-IV Fleet (865 buses)	288,000	Not applicable
Post-conversion to BS-IV (incl. AC)		
Scenario 1	6,793,857.29	6,505,857.29
Scenario 2	6,814,964.07	6,529,964.07
Scenario 3	6,783,836.31	6,495,836.31

TABLE 4: Overall annual DEF financial impact

	Total DEF costs (₹)	Current DEF costs (₹)	Aditional DEF costs (₹)
Scenario 1	303,821,298.09	12,879,360.00	290,941,938.09
Scenario 2	304,765,193.34	12,879,360.00	291,885,833.34
Scenario 3	303,373,159.84	12,879,360.00	290,493,799.84

Overall Fuel and DEF costs

Combining the additional costs of the diesel exhaust fluid and diesel fuel provides the overall additional costs. The overall additional fuel and DEF related costs of operating a fully BS-IV fleet would cost BMTC, at its present scale of operation, approximately ₹446.2 to 514.9 million rupees annually ($7.47-8.61 million USD) (see Table 5). This is equivalent to 3.33% of its annual turnover (*26*).

TABLE 5: Overall financial impacts of fuel and DEF

	Fuel price		
	Low (₹52.64/L)	*Mid (₹57.465/L)*	*High (₹62.29/L)*
	Total additional costs (₹)		
Scenario 1	457,199,005.66	472,438,184.06	487,677,362.46
Scenario 2	480,364,119.94	497,640,102.70	514,916,085.47
Scenario 3	446,200,778.96	460,472,932.73	474,745,086.49

This range also likely represents the lower-end of the overall fuel cost implication in future years for two major reasons. Firstly, the analysis presented utilizes the current market price for AdBlue, the diesel exhaust fluid (DEF) that must be utilized in BS-IV buses. However, increased demand for AdBlue as more BS-IV buses are added to the fleet and anticipated limitations in the ability of suppliers to match this demand means that the price for this input may increase in the medium term. Secondly, BMTC is also in the process of augmenting its overall fleet size, which is expected to increase from nearly 6,500 buses to 8,000 buses in the next 2 years (*27*). As overall fleet size increases, the overall fuel cost implication will increase as well.

MITIGATING INCREASED COSTS DUE TO FLEET CONVERSION TO BS-IV NORMS

Exploring the Reasons for Lower Fuel Efficiency in BS-IV buses

There are three potential explanations for why BS-IV buses, as operated by BMTC, exhibit lower fuel efficiency than older buses with lower emission standards: (I) BS-IV technology is inherently fuel inefficient, (II) newer BS-IV buses use higher horsepower engines, and (III) newer BS-IV buses are heavier.

Technologically, Exhaust Gas Recirculation (EGR)-based BS-IV engines are indeed less fuel efficient due to the nature of the fuel combustion process. However, as discussed earlier, EGR engines are uncommon in India and are likely to remain so until the wide spread availability of low-sulfur diesel is established. Selective Catalytic Reduction (SCR) is the dominant BS-IV engine technology at present and for the foreseeable future. SCR technology, however, relies on the post-treatment of exhaust gases and is therefore unlikely, by itself, to result in lower fuel efficiency.

The case for higher horsepower engines and heavier buses being the culprit is much stronger. The relationship between higher horsepower engines, heavier vehicles and lower fuel efficiency is well established (*28*, *29*). A comparison of BMTC buses of different BS-norms by engine horsepower and vehicle weight also clearly shows that BS-IV buses utilize more powerful engines and are heavier as well (Figure 3). It is likely that these two aspects explain the majority of the difference in fuel efficiency for buses of different BS-norms.

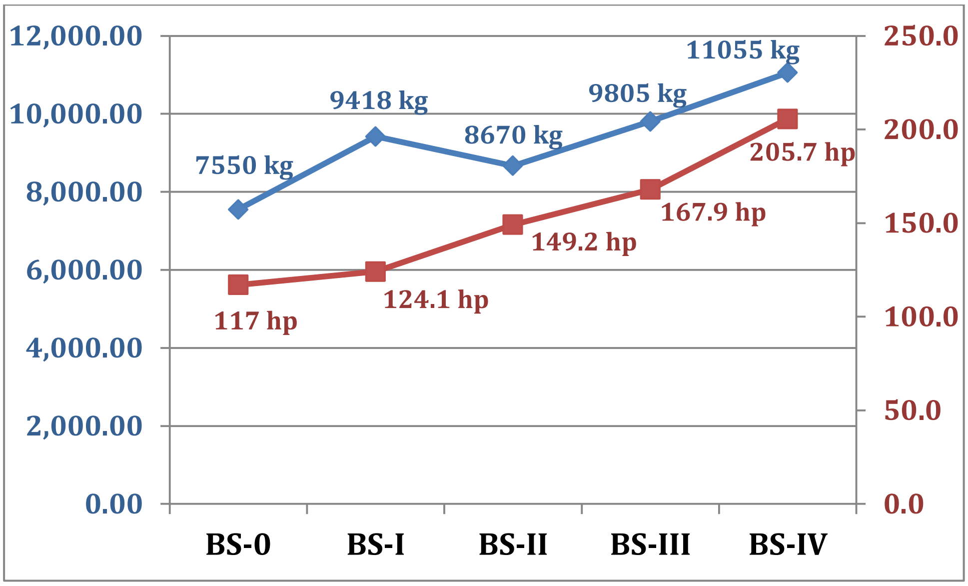

FIGURE 3: BMTC bus horsepower and weight by BS norm (*23*)

Nevertheless, the ability of agencies such as BMTC to address these issues is limited. The main constraint is the commercial unavailability of lower horsepower BS-IV engines. This is largely due to the nature of the bus manufacturing industry in India. Historically, buses in India have been built on truck chassis. This is because the demand for trucks, which carry a significant portion of long distance freight in India, has always been significantly higher than that for buses. Although there is a growing industry in bus-specific chassis manufacturing, it is still of insufficient size to influence the decisions of engine manufacturers, who cater largely to the truck market which demands more powerful engines (*S. Chengali, Cummins India, personal communication with authors, July 22, 2013*). In other words, agencies like BMTC are forced to buy higher horsepower BS-IV engines for their buses (*CG. Anand, BMTC, personal communication with authors, July 25, 2013*).

The issue of vehicle weight is related to improvements in bus body quality and design. Newer buses use a structural configuration that necessitates increased weight. The use of features like increased glass coverage to provide bigger windows as well as structural elements to provide more spacious interiors and reduce collision impacts explain in large part the increased weight of newer buses. These elements play a significant role in improving the comfort and safety of commuters. While some reductions in vehicle weight could be achieved through better design and the use of advanced materials, the overall impact is unlikely to be very significant (*GS Rangarajan, I-MAC India Coach Builders, personal communication with authors, July 26, 2013*).

It should be noted however, that even if BMTC and similar agencies are able to procure lighter buses with lower horsepower engines and eliminate the reductions in fuel efficiency, there still remains the added cost of DEF for an all BS-IV fleet. As shown in the previous section, the additional cost of increased DEF use alone would cost the agency approximately ₹290.4 to 291.8 million ($4.78 to 4.79 million USD) annually at present scale of operations.

Suggested Interventions

There are two suggested ways in which the increased fuel-related costs of lower-efficiency BS-IV buses can be mitigated. The first is to nudge market players involved in bus manufacturing to produce vehicles that use lower horsepower engines and have lower overall weight. However, it is likely difficult for individual agencies such as BMTC to influence the production decisions of manufacturers, especially those whose business is largely geared towards the production of trucks. The Indian Central Government, on the other hand, can play an influential role in this matter by leveraging national spending programs such as JNNURM. For instance, India's finance minister recently announced the intention to support the procurement of 10,000 buses for select Indian cities through JNNURM (*30*). This follows on from a similar program in 2009-2012 that financed the procurement of 14,000 buses for 61 Indian cities (*30*). Orders of this magnitude are sufficient to serve as 'market makers' for engine and bus body manufacturers. By ensuring the that financing takes into account the issue of fuel efficiency, manufacturers can be encouraged to produce vehicles that more closely match the needs of public transport operators.

If convincing manufacturers to produce buses that closely match the needs of urban bus public transport operators proves to be ineffectual, state and local governments should seriously revisit the issue of subsidies for urban public transport operators. Subsidies can be tied to the uptake of BS-IV vehicles in the operator's fleet and can thus be limited to the issue of the additional cost of operating BS-IV buses. The subsidy can thus be directly linked to the issue of reducing air pollutant emissions from public transport vehicles, and need not be a general subsidy to cover other operational deficits, which is more politically contentious.

CONCLUSIONS

Depending on future fuel prices and the composition of the fleet by manufacturer, the additional annual fuel-related costs of operating an all BS-IV fleet for BMTC, at its present scale, is estimated to be between ₹446.2 to 514.9 million rupees annually ($7.47-8.61 million USD). This is a significant amount, equivalent to approximately 3.33% of BMTC's entire annual turnover (*25*). As discussed previously, this amount also likely represents a lower-bound of the overall fuel cost implication in future years. It is also worth noting that fuel and DEF costs are only one component of the total financial costs of fleet conversion to the BS-IV standard. BS-IV buses also cost more to procure and, anecdotal evidence suggests, cost more to maintain. The overall financial cost of purchasing, operating, and maintaining the BMTC's fleet at a BS-IV standard, therefore, is likely to be significantly more substantial.

The fact that BS-IV buses produce lower emissions, and thus contribute to improving the overall urban air quality scenario in Indian cities, is not disputed. However there is a real and recurring cost to achieving these gains in air quality. If the burden of these costs is to be borne by public transport operators alone, it raises the prospect of a potential paradox regarding the effectiveness of this strategy as a means of reducing air pollution and improving air quality. If the financial cost of upgrading its fleet to the BS-IV standard is so burdensome for a public transport provider that it necessitates the scaling back of overall service levels, particularly given the pressure to be profitable and the absence of operational subsidies, the resultant shift of passengers from public to private transport may quickly undo any air quality gains made.

It should be remembered that the biggest contribution of public transport towards reducing air pollution is by providing a service which is of a scale and quality that encourages people to shift away from more pollution-intensive private modes. The reductions in air pollution that can be achieved by shifting people from private to public transport will likely far outweigh the reductions that will be achieved by improving the efficiency of public transport vehicles themselves. While the goal of improving the emissions standards of public transport vehicles is a worthy one, care should be taken to ensure that achieving this goal does not come at the cost of reducing the quality, scale, and affordability of public transport service itself.

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