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EFFECT OF ROAD ROUGHNESS AND VEHICULAR SPEED ON EMISSIONS USING HDM-4

Jitender Singh[1], Pardeep[2]

[1]student, Sat Priya Group of Institutions, Rohtak. India.

[2]HOD Sat Priya Group of Institutions, Rohtak, India.

*Corresponding Author

E-mail Id:-jitusingh503@gmail.com

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ABSTRACT

Almost every urban centre, not only in India, but throughout the world is facing the problem of poor air quality. Air pollution due to vehicle exhaust is a significant contributor to overall air pollution. Through tailpipe, vehicles emit various harmful chemical compounds as a direct result of combustion process. Since vehicular emissions are ground level sources, they have direct impact on health of human being. Traffic jams, long queues on signalized intersections and poor road conditions affect the steady pattern of flow which results into higher fuel consumption and consequently high vehicular emissions are observed. Savings in fuel consumption and curbing the related emissions is need of the present hour. Deteriorated roads results in higher fuel consumption and are responsible for higher emissions, therefore appropriate maintenance of roads is among the potential methods to reduce vehicles emissions.

In this study, a total of 5 alternatives including base case are created in the HDM- 4 software. Through base case, effect of road roughness and vehicular speed on emissions is estimated for vehicles cars and trucks. For cars, fuel consumption and emissions first increases, then decreases and finally increases on account of increase in roughness. This behavior of fuel consumption and emissions curve with respect to road roughness is explained in 3 zones. For trucks, fuel consumption and emissions always increases on account of increase in roughness. However rate of increase in fuel consumption and emissions is higher for higher values of roughness. Benefits of optimum maintenance and rehabilitation strategy for roads are evaluated in terms of savings in fuel consumption and reduction in vehicle emissions for the present study. Comparison of base case and optimum maintenance case for life term (20 years) yields savings of 4.4% in fuel consumption and 4.23% reductions in CO2 emissions.

Keywords- vehicular emissions, HDM-4 software, rehabilitation strategy, economic evaluation

1. INTRODUCTION

India is second-largest country by population in the world. It has rapidly growing economy and transportation sector is a vital element. A sound transportation system not only offers greater personal mobility but also supports the industrial and commercial base of a country, facilitates the flows of external and internal trade and also allows for effective physical communications. Within developing countries like India transport infrastructure is often seen as the key to unlock economic growth.

On the other hand, because of this economic growth, the number of vehicles on Indian roads in the past has increased tremendously and this growth is expected to grow in the future also. This increase in number of vehicles is responsible for another set of problems including lack of space, reduction in natural resources, environmental pollution, etc. Vehicle emissions, in the form of conventional pollutants (CO, NOx, PM, HC etc...) and greenhouse gases (CO2, CH4 etc...), can have adverse impacts such as premature mortality, lower crop yields, environmental damage, and global warming. These problems, in turn, can set back the economy.

2. OVERVIEW OF EMISSION STANDARDS IN INDIA

Starting with Supreme Court of India interventions in the late 1980s, the country started moving towards mitigating the public health impacts of vehicle and fuel emissions. The initial steps consisted of eliminating lead in petrol, switching to compressed natural gas (CNG) for auto rickshaws and buses in Delhi and subsequently other cities, and establishing Euro 1/1-equivalent emission standards known as India-1 standards for new vehicles.

India has progressively lowered its permissible vehicular emission limits for new four-wheeler vehicles following the path laid by the European Union (EU). The Auto Fuel Policy of 2003 laid down a road map for vehicular emission and fuel quality standards. This road map has been largely implemented. In 2010, Bharat IV fuel quality standards and vehicle emission standards for four-wheeled vehicles were implemented in 13 major cities, while Bharat III standards took effect in the rest of the country.

Bharat Stage (BS) emissions standards are emissions standards instituted by the Government of India (GOI) that regulate the output of certain major air pollutants (such as hydrocarbons (HC), nitrogen oxides (NO), carbon monoxide (CO), sulfur oxides (SO), particulate matter (PM) by vehicles and other equipment using internal combustion engines. They are equivalent to the European emissions standards. The National Fuel Policy commenced on October 6, 2003, is a phased program for implementing the EU emission standards in India by 2010. As of January 2013. Bharat IV standards had been expanded to about ten more cities. For two and three- wheelers, India followed an independent path and regulated emissions in a different manner than Europe and China. This first phase of emission reductions from all on- road vehicular sources shows great progress.

DESCRIPTION OF HDM-4

The Highway Development and Management (HDM) model, originally developed by the World Bank, is widely used as a planning and programming tool for the highway expenditure and maintenance activities. HDM-4 is a computer model that simulates physical and economic conditions over the period of the analysis for the series of alternative/ alternatives and scenarios specified by the user. It is designed to make comparative cost estimates and economic evaluations of different construction and maintenance options.

3. LITERATURE REVIEW

Study by White & Velinsky, in year 1979

White and Velinsky investigated the effect of road roughness on rolling resistance through field studies. A mechanistic pavement roughness model was developed based on field data collected. These models were applied to predict the vehicle energy losses from both the tire and suspension system. Sensitive analysis through the roughness model revealed that vehicle rolling losses increased with the increase of pavement roughness.

Study by Bester, in year 1984

Bester through experimental studies found the impact of pavement type and roughness on rolling resistance. He used an experimental method to measure the rolling resistance of passenger cars and trucks on eight different surfaces: asphalt, concrete , surface treatment , and unsurfaced. His study revealed that pavement type (asphalt vs. concrete) had only a small effect on rolling resistance. The roughness has an effect on the rolling resistance as smoother roads have lower rolling resistance values.

Study by Lucas & Laganier, in year 1990

Lu simulated the rolling resistance responses of a quarter car model with spectral density functions and investigated the influence of pavement roughness on the car rolling resistance. Results showed that the rolling resistance increased significantly with the increase of pavement roughness: pavement with bad surface condition may increase the vehicle rolling resistance by about 40%.

Lucas and Laganier evaluated the roughness effect on fuel consumption with three studies: laboratory studies, test track studies and open road studies. Pavement roughness was simulated with a vibration bench in the laboratory study. Results showed that roughness is an important factor for vehicle fuel consumption. Lucas et al plotted a graph between extra fuel consumption and unevenness level, the conclusion of which is-extra fuel consumption is ranging from 0 to 0.4 L per 100 Km for evenness rating from excellent to poor.

HDM-4 evaluates 'n' number of alternatives simultaneously in one analysis. Taking the advantage of this concept, total 5 alternatives including Base case are created for this study. Base case represents do-nothing or very little maintenance case. One more advantageous aspect of HDM-4 analysis is that, it does the life- cycle analysis. So, in the base case, road is getting deteriorated for the life term of pavement and the corresponding change in speed, fuel consumption and emissions is predicted by the software. In this way roughness and speed impact on emissions is analysed through base case outputs. Out of defined alternatives, one will be selected as optimum alternative based on economic indicators estimated by HDM-4. Then comparison between optimum alternative (economically and technical viable case) and base give will highlight the reductions in vehicle emissions and savings in fuel consumption when optimum alternative is opted.

Study by Sandberg, in year 1990

Sandberg conducted vehicle fuel economy studies on 20 different road surfaces that had different textures. These surfaces ranged from standard asphalt mixtures to chip seals and unpaved roads. Texture and roughness were measured using a laser profilometer attached to a passenger car. Sandberg concluded that fuel consumption could vary by 11 percent from the smoothest to roughest road.

Study by Delanne, in year 1994

Delanne through field experiments investigated the effect of pavement roughness on light vehicle fuel consumption. Ten different roadway sections were tested in France and vehicle rolling resistances were measured with hydraulic bench test. Test results showed that the increase of pavement roughness can increase the vehicle fuel consumption significantly: by up to 6%.

Study by Amos, in year 2006

Amos collected fuel data on a 22-mile interstate loop with a dump truck at 60mph. Data was collected before and after the pavement resurfacing. The IRI before and after resurfacing was 130 in/mile and 60 in/mile respectively. Results from fuel data showed that a 2.46% fuel saving was found for the dump truck before and after the roadway was resurfaced.

Study by Chatti & Zaabar, in year 2012

Five different vehicles were used in this study to assess fuel consumption relative to pavement type, vehicle speed, road roughness, and surface texture. Only flat and smooth pavement sections were used in order to determine the direct effect of pavement surface texture and type on fuel consumption. Five different locations in Michigan were selected for testing with a medium car, SUV, van, light truck and (articulated) heavy truck. Fuel consumption was measured as testing was conducted in winter (wet conditions) and summer (dry conditions) and at three speeds (35, 45 and 55 mph). Five sections each of asphalt concrete (AC) and portland cement concrete (PCC) pavements were identified for testing, although it is not stated what type of PCC pavements (jointed plain concrete pavement, continuously reinforced concrete pavement, etc.) were included. Raw profile and texture data were collected by the Michigan Department of Transportation. The IRI on these pavements ranged between 0.8 and 6.0 m/km for AC pavements and 0.8 and 2.5 m/km for PCC pavements, while the texture ranged from 0.23 mm to 1.96 on the AC pavements and 0.23 to 2.7 mm on PCC pavements.

Using an analysis of covariance (ANCOVA), the authors estimated the effect of roughness on fuel consumption, as well as the effect of surface texture on fuel consumption. A regression and lack of fit analysis were conducted to determine the effect of surface texture on fuel consumption. The authors summarized that grade and IRI were each statistically significant and although surface texture was found to be statistically significant at 35 mph, it was not statistically significant at 45 and 55 mph.

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