Analysis of critical issues in retrofitting of ICE vehicles

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Abstract. Vehicle population is increasing at an alarming rate causing cities, and towns to suffer air pollution due to inefficient engines. Every year millions of vehicles are being manufactured and scrapped. Disposal or scrapping of vehicles before their useful life is not a good option. All the parts and systems of a vehicle wear out at different rates. By employing this technology of retrofit for the next 10 to 15 years, the owners will be able to contribute to society by decreasing input energy for massive automobile industries. Based on the life span of automobile parts a range of age has been found in this research at which retrofit can be carried out. In this research, cost analysis of vehicles has been carried out which shows a decrease in performance with increased maintenance, repair, and replacement cost. A mathematical model has been created for performance and cost. The minima of this mathematical model are known as retrofit age. It has been shown in this research that the time has come to adopt this technology, due to inadequate recycling of automobile parts, limited processing plants, and limited scraps yard. For this study, Honda Activa 5G, Bajaj pulsar 500, and Maruti Baleno has been considered.

Keywords: Scrapping, Retrofit, Cost, Analysis

1. Introduction
Technology leads to many inventions. The automobile is one of the most important inventions. The present scenario depicts a rapid increase in vehicle population. Increased vehicle population occurs due to inadequate public transport, as a status symbol, to save time and provide a safe, comfortable ride, etc. NITI Aayog makes an effort to push up the Electric market by providing Rs 700 crore a year as subsidies to battery makers to overcome the biggest hurdle of high-cost batteries.

Growing up a population of vehicles lead to traffic congestion, severe air pollution, and other environmental effects [1]. Transition to e-mobility is focused due to severe air pollution, difficulties in oil imports, and the most important surplus solar energy to produce electricity for transportation. Due to the limited life span of vehicles, millions of cars are scrapped every year which demands huge lands for scrap yards and landfills [2].

Increased carbon emissions, finite oil resources emphasize transformation to electric and autonomous vehicles [3], [4]. Transition to retrofit and electric vehicles are due to zero emissions [5], [6]. In retrofitting, the addition of new technology to existing provides a striking balance between the cost of conversion, performance, range, and charging [7], [8]. Also, it saves a huge amount of energy required for recycling, production, and manufacturing of new components. Till 2030 electric vehicles will constitute 30\% of the total vehicle population.
Predicting engine useful life is tricky and depends on many factors. Studies have been done on electric kits [9] for conversion into electric vehicles but suggesting the exact age for retrofit is complicated. Plug-in hybrid electric vehicles offer a very promising alternative to conventional drivetrains [10]. In this paper striking balance between performance, depreciation, and maintenance cost is found to suggest retrofit age depending on the average run per day.

This paper is organized as follows; Section 2 describes the journey of a vehicle from its manufacture to scrap yard. Section 3 describes the longevity of vehicle parts and its classification into recyclable, reusable parts, etc. Section 4 talks about the retrofit procedure and its parts. Section 5 consists of the study of maintenance and depreciation cost of mopeds, motorbikes, and four-wheelers. The overall aim is to suggest useful life of vehicle and age after which retrofit can be accomplished based on its run per day.

2. Life Cycle Analysis

In India, the automobile industry is one of the fastest-growing industries [8]. As the annual sale increases, it leads to millions of vehicles adding to the vehicle population annually. With this number of vehicles to be scrapped at the end of useful life increases exponentially. This could increase with more stringent regulations coming into place concerning fuel and emission standards. Many of them get dismantled in local garages/mechanic shops. Infrastructure for vehicle dismantling in the country is woefully inadequate. It was found that ten states of Maharashtra, Tamil Nadu, Uttar Pradesh, Gujarat, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, Kerala, and Haryana accounts for nearly 75% of the vehicle population of India, and are ideal for the dismantling units. Coming up of these dismantling units will surely reduce the transportation cost of carrying old vehicles to scrap yard.

Currently, end-of-life vehicles in India usually end-up in the informal sector, such as the scrap yards at Mayapuri, New Delhi, Shivajinagar Gujri, or Pudhupet, Chennai. Mostly dismantling happens crudely. Recovered auto components are either refurbished and sold in the second-hand market or the material resource is recovered from these components and sent for recycling.

The growing vehicle population demands a huge area for scrap yards, dismantling, and dumping off the waste. So, the burning issue is to maximize the utilization of the scrap with minimal wastage. Thus, Retrofitting seems to be the best option to increase the end life of the vehicle. The government also permits conversion into the hybrid electric vehicle by retrofitting to curb the rising pollution issue.

Manufacturing and dismantling of automobiles occur in industries itself [11]. The manufacturing of components and systems require different materials. For example, metal for the vehicle body, glass for windows, cloth and leather for interior, etc. Mostly a vehicle is composed of parts and materials that can be recycled. Raw materials along with recycled parts enter into the manufacturing industry, and the final product i.e., vehicles are produced, packaged, and distributed to car dealers. During its useful life, it goes through three to five owners, before it is scrapped.

Breakdown occurs at its end of life. Nearly 70% – 80% of a car can be recycled. Oil, gas, and coolants are drained, tires are removed and then sent to another processing plant. Usable materials are melted down to be used again. Ex: Metal, plastic, and glass. All the recycled parts and materials are sent back to manufacturing plants. These materials are used again for the manufacture of a new car. Thus, the cycle continues again. Some vehicles are directly scrapped. In scrap yards, ferrous and non-ferrous materials are separated using air and magnetic separators. Automotive shredder residue like glass, plastic is largely landfilled due to its heterogeneous and complex matrix.
Figure 1 shows how to end life vehicle passes through various stages from its manufacture till scrapping. From the last owner, it either gets scrapped directly or its auto parts are separated as reusable, recyclable parts in garages, mechanic shops, and sold as spare parts.

2.1 Factors That Contribute to Engine and Parts Longevity
The longevity of the engine and parts depends on multiple factors. Its useful life depends on how well it's manufactured and maintained. Auto part life differs from component to component. For example, a tire won't last as long as a typical exhaust pipe. Table 1 shows life for different auto parts in two-wheelers as well as four-wheelers which undergo frequent replacement.

Table 1. Parts which are often replaced.

| Parts which are often Replaced | Approximate Life                      |
|-------------------------------|--------------------------------------|
| Oil and oil filter            | 3 to 6 months (5000 to 8050 Km)      |
| Air Filter                    | 3 to 4 years (50000 to 80500 Km)     |
| Brake pads                    | 3 to 5 years (50000 to 113000 Km)    |
| Tires                         | 5 to 7 years (depends on use)        |
| Battery                       | 4 to 5 years                         |
| Bike chains and belts         | 6 years (120000 Km)                  |
| Sparkplug                     | 8 years                              |
| Auxiliary Lighting            | 5 to 7 years                         |

Replacement of part depends on the make and model of car, city, or place at which it is used, miles covered by it annually, and even climatic conditions of the place where it is used. Wear and tear also depend on how we drive the car i.e., driving style. For example; rough and aggressive driving causes brake pads to wear at a much faster rate. Parts like engine, muffler, radiator, starter have a longer life but are replaced due to weight issues in retrofit whereas the Brake calliper, alternator, fuel pump, water pump, fuses, engine sensor, clutch, etc. Need not to be replaced frequently.

Used parts and components are classified according to Recycling, refurbishing, and remanufacturing process:
Recycling-Purpose is to recover and reuse materials from returned products and parts or components.

Refurbishing- Replacement of dated parts or components by ones with a higher level of technology

Remanufacturing- It aims to recover the quality and technology of parts and components so that they are as good as that of new parts and components. Table II shows the classification of used parts and components based on the principle of 3R.

| Recycling     | Refurbishing  | Remanufacturing |
|---------------|---------------|-----------------|
| Engine        | Hood          | Hood            |
| Battery       | Wire          | Wire            |
| Transmission  | Engine oil    | Engine oil      |
|               | Gear oil      | Gear oil        |
|               | Coolant       | Coolant         |
|               | Catalytic Converter | Bumper     |
|               | Door          | Suspension      |
|               | Trunk         | Wheel           |
|               | Vehicle Body  | Vehicle Body    |
|               | Seat          | Window and Doors|
|               | Window        | Seats           |

3. Retrofitting of Conventional Vehicle to Electric Vehicle

Retrofit technology is an alteration process of an internal combustion engine by batteries. It involves choosing the vehicle, sizing a motor, and the type of batteries. In other words, it is a green mobility solution involving the conversion of a conventional engine powered vehicle into an electric-powered vehicle with more functionalities to be compatible with the latest environmental demands. An electric vehicle utilizes electric motors and motor controllers instead of an internal combustion engine and hence for retrofitting of engine-powered vehicles to electric vehicle powertrain is different. The gasoline engine, exhaust system, gas tank, and clutch assembly are no longer needed and hence removed from the conventional vehicle during the conversion process. There is no need to change the existing manual transmission system as it is bolted to an electric motor. A battery box is installed in the vehicle. Standardization of the electric kits makes it quite easier to retrofit. According to the size of the vehicle, the number of batteries and the type of motor is decided. The electric controller takes power from batteries and delivers it to the motor. Table 3 shows the major systems of IC Engine which are replaced in retrofitting.

| System to be dissembled     | Power systems to be installed |
|------------------------------|-------------------------------|
| Engine                       | Electric motor                |
| Fuel tank                    | Battery                       |
| Exhaust system and fuel injection system | Wirings and Controller |

Retrofitting needs to be studied in various propulsion systems, tractors, aircraft, railway engines, and ships can be thought of being retrofitted. However bigger vehicles will need more critical, technical,
and economic analysis. It is often found that retrofitting is associated with a lot of redesigning which needs to be addressed properly. For small vehicles redesigning may be on a trial-and-error basis.

4. Discussion
Switching directly to electric vehicles seems to be a costlier affair. Electrical battery charging systems, infrastructure, and wireless charging are still in the developing phase. The use of retrofit will surely provide a striking balance between performance, cost, and efficiency. The optimal range of retrofit age is when the depreciation, maintenance, and replacement cost increase along with dissatisfactory operation. Based on data collected we plotted graphs of maintenance, repair, and replacement cost vs life of car for moped, motorcycle, and four-wheeler to spot the retrofit age. Depreciation cost, maintenance cost was collected from various dealers. Various service centers were visited to collect data on maintenance costs. Feedback from the insurance agency was taken regarding the depreciation value of vehicles.

Similarly, figure 2, figure 3, and figure 4 as per the driving range for moped show our analysis regarding the expected retrofit age of the vehicle. Considering the driving range, the graph of maintenance cost vs. the life of vehicles is plotted. From this, the expected age for retrofitting of less used (20 km run per day), the medium used (40 km run per day), and heavy used (60 km run per day) moped is predicted from the graph. The less-used moped is recommended to be retrofitted at the age of 6.5 years, the medium used moped at the age of 6 years, and heavily used moped at the age of 7 years.
Similarly, figure 6, figure 7, and figure 8 as per the driving range for the motorbike show our analysis regarding the expected retrofit age of the vehicle. The retrofitting is to be done at the age between 8 to 9 years of a less used bike, for medium used bike in between 7 to 8 years, and the heavily used bike, it is approximately between 6.5 to 7 years.

Similarly, figure 6, figure 7, and figure 8 as per the driving range for the motorbike show our analysis regarding the expected retrofit age of the vehicle. The retrofitting is to be done at the age between 8 to 9 years of a less used bike, for medium used bike in between 7 to 8 years, and the heavily used bike, it is approximately between 6.5 to 7 years.
Similarly, figure 10, figure 11, and figure 12 as per the driving range for four-wheeler show our analysis regarding the expected retrofit age of the vehicle. Similarly, the graph is plotted as per the driving range for four-wheeler Retrofitting age of less used four-wheeler is predicted between the age of 9 to 10 years, 8 to 9 years for the medium used and 7.5 to 8 years for a heavily used four-wheeler. Table 4 shows the suggested retrofit age for various vehicles under consideration.

Table 4. Results.

| Category of vehicle | Retrofit Age (in years) | Run (in km) after which retrofit is to be done |
|---------------------|-------------------------|---------------------------------------------|
| Mopeds              |                         |                                             |
| Having a daily run of 20 km/day | 6-7                     | 55,000                                      |
| Having a daily run of 40 km/day  | 6                       | 85,000                                      |
| Having a daily run of 70 km/day and above | 5                     | 1,00,000                                    |
| Motor cycle         |                         |                                             |
| Having a daily run of 20 km/day | 8                      | 60,000                                      |
| Having a daily run of 40 km/day  | 7                       | 1,00,000                                    |
| Having a daily run of 60 km/day and above | 6.5                    | 1,50,000                                    |
| Four-wheeler        |                         |                                             |
| Having a daily run of 20 km/day | 9                      | 65,000                                      |
| Having a daily run of 40 km/day  | 8                       | 1,15,000                                    |
| Having a daily run of 60 km/day  | 7.5                     | 1,60,000                                    |

After the initial period of useful life, many parts, components or system of an automobile begins to wear and tear and need replacement. Life of component varies from part to part and depends on a multitude of things like make, manufacture, the model of the car, areas of use (terrain areas or smooth flat road), driving style (rough, etc.), miles it covers annually and how well it is maintained and taken care of. By using an existing vehicle with this alteration technology, we not only extend the life cycle of that unit but save huge energy input of recycling, new parts production, and new manufacturing. Along with the increased sophistication of telemetry and the internet of things, retrofit seems to be most beneficial for fleet owners. The running cost of IC vehicles is twice as much as retrofitted
vehicles. Zero-emission i.e., avoids severe air contaminations. Also, engine and maintenance cost in retrofitting is nil. No need for regular service check-up provides better, smooth, and noiseless ride.

5. Conclusion
In this study, solutions about problems that occur due to increased vehicle populations that give rise to air pollution, scrapping, use of pollutants, and condemned IC engines are given. The life cycle of the vehicle, from manufacturing to scrapping and dismantling, has been analysed. Different materials for its manufacturing were classified into recyclable, reusable parts, remanufacturing, and refurbishing. It has been found that the use of recycled materials has a positive effect on energy conservation and emission reduction. Ease of modelling, simulation, and analysis of Electric vehicles help to rectify and improve efficiency performance at its early stage. Cost analysis of mopeds, motorcycles, and cars has been carried out, to find the best age for retrofitting. Extensive data has been collected from various sources such as service centers, dealers, second-hand vehicle markets, insurance companies, etc. to conclude. Depreciated values of vehicle and maintenance costs were mainly considered for this analysis. The recommended retrofit age for a moped is 5 to 7 years, and the motorcycle is in between 6 to 8 years, depending on usage. For cars, the retrofitting age is found to be between 7 to 9 years. It has been found that the Adoption of this technology has become essential due to inadequate landfills for disposals, lack of processing plants, increased input energy for manufacturing, and to avoid discarding of parts before its useful life. Thus, the life of the IC engine is extended with an increase in performance, efficiency zero emissions, and green mobility solution. To boost demand in the automobile sector, the government is considering a ‘scrapage policy’, to get unfit vehicles off the roads, and thus increase the demand for retrofitted and new vehicles. Future transportation is in retrofitted vehicles and then hybrid electric vehicles. Pure electric vehicles will also slowly move into the market.

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