Determining Toll of Freight Transport Based on Pavement Damage Costs in Pakistan

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Abstract: - The effect of freight vehicles, on the requirement for the road maintenance is considerable. It is clearly necessary, for road maintenance purposes, to know the value of the actual axle loading since minor underestimation can shorten the expected/design life of a pavement. In this study, marginal pavement damage cost (MPDC) was estimated for National Highways of Pakistan. For model estimation, cost data were obtained from the MR&R strategies. Total traffic load (ESALs) was calculated using AADT and WIM data. Statistical model was estimated using OLS regression techniques. Lastly, a comparison is carried out between current road use toll and actual damage incurred by different truck classes to pavement for N-5. Marginal PDC was estimated to be Rs. 0.59/ ESAL km - (2016 fixed rupees) per share of the load in 2016. PDC as Rs. 0.475 / ESAL- km (2016 fixed rupees) (80% share of the load in the cost of damage to the pier) for the national highway system. It was revealed from the comparison of the current toll and the cost of actual damages, that it is appropriate to charge vehicles based on PDC. Moreover, rate of fines and tolls on the national highway system must be based on the damage (ESALs) resulting from each vehicle class. With the initiation of CPEC, it is expected that the local transport industry will not be able to cope with the challenge of increase in demand with the present fleet. Hence, it is essential to update and enforce the axle load management regulations in accordance with the international standards. Moreover, human resource and infrastructure development are also issues to be considered for fully utilizing the benefits of CPEC for the national economy.

Key-Words: - pavement damage; Pakistan; freight transportation; highways; Pakistan

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1 Introduction

An efficient and well-maintained transportation system serves as the backbone for all economic activities [1]. Efficient transportation systems move goods and people throughout local, regional, state, national and international economies in a safe, timely, and reliable manner [2].

Freight is defined as any good, product, or raw material carried by a commercial means of transportation – including air, highway, rail, water, and pipeline [3].

Freight transportation, as defined by the Government Office of Science (2019) in the UK is, “the carriage of goods between an origin and a destination for commercial reasons because goods available at one geographical location are required at another location for processing, sorting or consumption”. It has classified the freight transportation to 3 approaches, as listed below:

1. Origin and destination: It has two types, domestic and international freight transport. Where the domestic is the freight movement within one country and the international transport will contain a freight movement between two countries or more.
2. Mode of appearance: It has two types, bulk, and non-bulk freight transport. The bulk is the movement of large volume of cargo using special mode, equipment, and terminals. However, the non-bulk freight is when the cargo is moved using unit load containers or packaged products for easy handling and following standard trailers.
3. Mode of transport: either by road, rail, pipeline, air or other.

Freight transportation services are needed to deliver raw and intermediate materials to producers and to deliver final products to retailers and final customers. Figure 1 illustrates the vital link performed by freight transportation in supply chains and economic performance. The design and provision of freight transportation services are complex tasks which require a wide variety of expertise, infrastructure, and technologies. They are required due to the size, ranging from one piece to bulk, and nature of the shipments, ranging from edible products to complex equipment [4].

Improvements in freight transportation efficiency, reliability and level of service have numerous economic benefits for production efficiency, optimization of distribution networks and product choice and cost to consumers. As improvements are made in the transportation infrastructure, producers can centralize their production operations and site their operations in lower-cost areas. This is because the uncertainties concerning the movement of goods to customers are reduced. Improvements in transportation infrastructure also allow a more efficient design of the distribution network. The cost of inventories can be reduced as the needed hedge against transportation uncertainties is reduced. This also allows firms to change their inventories quickly in response to customers' changing needs or desires. It all ultimately leads to lower cost and greater product variety for customers.

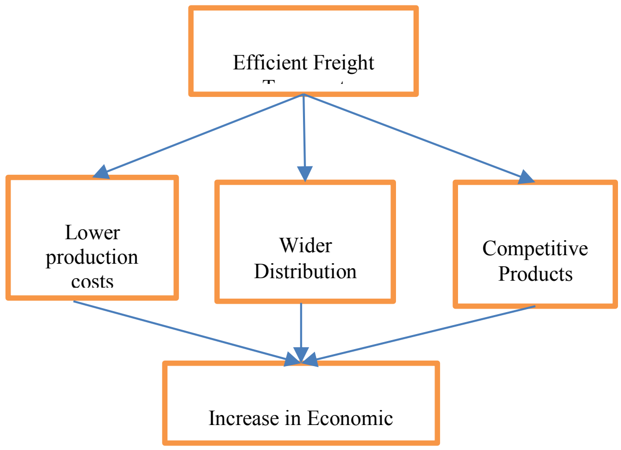

Figure 1: Role of freight transport in economics [5]

Freight transportation appears to have been dominantly the focus of geographers dealing with maritime and rail transport. It was so because traditionally these were the modes expressing most of the scale and scope of freight distribution [6]. More recently, developments in intermodal transportation, logistics, international trade and the emergence of e-commerce have transformed the freight transportation sector. Consequently, there seems to be a significant paradigm shift in the investigation of transport, commercial and retail geography [7]. Some of the results of this new paradigm shift have resulted in growth in the freight transport industry, which is expected to grow by a factor of 4.3 from 2010 to 2050. Moreover, it is expected that most of the international freight transport will be between the developing countries (by 2050) [8].

The maritime transport is the traditional dominant mode of bulk transportation. Hence, the trade patterns and industrial locations are highly influenced by it [9]. This is one of the reasons for the initiation of projects related to international trade routes which provide the opportunity for neighbouring countries to utilize the maritime facilities, along with land transport, for a better outreach to the international market.

The transport industry itself has become more closely integrated, implying that it may be fallacious to investigate freight transport modes separately. For instance, changes in the maritime container industry have significant impacts on the rail and trucking industry [10]. These changes received renewed attention from economists, social scientists, and geographers, placing the issue of freight distribution as a central concern in economic and transport geography [11]. Another issue of concern is the greenhouse gas emissions (GHGs) from international trade which have been reported to contribute to 33 percent of the trade related emissions and 75 percent of the emissions from major manufacturing industries [12].

Considering the growing importance of global commodity chains, recent developments in the field of distribution and logistics can be considered a 'missing link' between geographies of production and consumption and between economic and transportation geography. The development of global distribution systems goes on a par with environmental and energy concerns [13]. Furthermore, the advanced process of internationalization of markets and production has revitalized the importance of freight transport. It has added new factors into the considerations of transportation planners, which include intermodal connectivity, seasonality of local markets, demographic parameters, economic parameters, and technological developments [14].

In this context, a strong link was found between the logistic performance index and global competitiveness in a review study which covered longitudinal data across the globe. In this regard, European countries are reported to have the highest logistic indices and, consequently, global competitiveness in trade [15]. Due to these reasons, the transport infrastructure is constantly being upgraded in European countries, however, special attention is required to be paid on increasing the efficiency and environmental sustainability of these projects rather than mere expansion of physical structures [16].

One of the primary factors which links the logistic performance with competitiveness is the cost of transportation which manifests in terms of freight charges and paid by the customer [17]. Furthermore, the quality of transport and logistic services is an important factor, as well as, the capacity [18], and condition of the existing infrastructure and the regulation law of these services in the country [19]. Moreover, speed [19], reliability [20] and flexibility [21] are major factors especially when the time is one of the constrains, although customer requirement need to be taken in consideration [20]. Also, transit time [19, 20, 21, 22], required delivery time, number of transhipment points [18], service frequency and possibility of damage are some factors that will affect the choice of transportation mode [18, 20, 21]. Vehicle operation cost and the accident rate may also impact the decision while choosing the transportation modes [19]. Furthermore, monitoring the operation and the impact on environment may affect the decision while selecting the more appropriate mode for freight transportation [20]. With the technology development, the track-trace became an important service for the supplier and customer to follow the shipment movement [21].

The focus of this study is mainly on the trucking mode. However, the technologies and infrastructure for this industry is also affected by the changes in other modes as explained above. A summary of the current road freight operational problems and constraints are discussed below:

- **Cost of roads**: The road freight transport system is totally dependent on the availability of road space, and roads of suitable condition for transporting goods. One of the major causes of concern in the road freight system is the fact that it is evident that heavy goods vehicles do not currently contribute adequately to compensate for the wear, damage, and externalities caused on the roads [23].
- **Availability and prices of fuel**: There is an impending shortage of fuel worldwide, due to current manufacturing trends and economics. In addition, the implications of the present electricity shortages are very negative for road freight transport [24]. As diesel is also used for power generation on small scale in many industries worldwide. The electric vehicles and those operating on alternative fuels are gaining their market share, but their large-scale implementation is still a distant reality [25].
- **Personnel and staffing**: One of the severe pressures being experienced by the road freight industry is the skills shortage and lack of adequately trained and competent personnel in a wide range of disciplines. The technical training structures are inadequate and do not ensure the supply of competent technicians in the automotive trades. Management training for managers in road transport is ineffective. There is also a growing concern about the ineffectiveness of the driver training systems and institutions. That gap results in a failure to supply an adequate number of trained mature age (25 - 40 years old) drivers who are the typical candidates for employment as drivers [26]. Efforts have been made to automize different freight transport operations, but its outreach in the low-income developing countries is at a very low level [27].
- **Externalities**: The externalities associated with road freight transport include traffic congestion in the main city centres, and rising heavy vehicle accident rates in cities, and on the main national road corridors [28]. These externalities are partly caused by, though not limited to, the competition for road space and inadequate control of operating standards in the trucking industry. These factors are being minimized through the regularization and taxation of heavy vehicles' operations in the congestion zones [29]. Other factors include driving hours, driver training, and control of speeds and loads. Heavy goods vehicle exhaust emissions are a major cause of air pollution in cities [30], and traffic jams and congested roads further aggravate this situation.

For the well- operative country, infrastructure plays an important role. During the year 2016-17, the share of Transport and Communication, was 13.27 percent to the total GDP of service sector. Over the past ten years, road traffic both passenger and freight has grown significantly faster than the national economy. Currently, it is accounting for 91 percent of national passenger traffic and 96 percent of freight [31]. The competitive commission of Pakistan in 2018, published report on road and infrastructure stating that Pakistan stands 21st position for the size of its road network, the total length of roads in the country stands 264,401 thousand km that includes 12,131 Km long National Highway and Motorway network [32] . Highways in Pakistan are generally in poor condition. According to World Economic Forum, Pakistan ranks at 77th at the road network quality [33].

The answer to the question of how Pakistan can maintain steady medium term economic growth has continued to be at the forefront of the development agenda for the country's policy makers for a while. Part of the answer lies in making the best use of the country's infrastructure stock and improving it for continuous future use. This is recognized by the Government of Pakistan's 2011 Framework for Economic Growth, which seeks to place the country on a sustained high economic growth path by reducing the cost of doing business, improving the investment climate, and strengthening institutions [34].

The transport sector constitutes 10 percent of Pakistan's gross domestic product (GDP) and provides 6 percent of the employment in the country

[35]. The sector plays an important role as an enabler of other sectors in the economy via facilitating agglomerations, contributing to both domestic and international trade, and helping facilitate spatial transformation. However, this sector fails to provide efficient service to the users, especially the due to patterns in transport and trade logistics which generate significant inefficiencies going as high as 4–6 percent of nation's annual GDP [36]. Consequently, this becomes a major constraint in the path of economic development of the country.

Railways used to be the predominant mode of transportation in Pakistan some decades ago (figure 2). Its market share shrunk steadily as government-owned Pakistan Railways (PR) did little to improve its efficiency while a dynamic road sector emerged, integrated by a myriad of privately-owned units competing intensely in a largely unregulated environment. At its peak between 1955-1960, railways handled 73 percent of freight traffic; it was reported to handle less than four percent of the total freight traffic in 2015 [37]. It is planned to increase this share to 20% by the year 2025 [38].

Pakistan Railways (PR) faces severe competition from road transport and this competition has gotten worse because of governmental priority for investment in road over rail transport, as well as PR's inability to compete due to its poor governance. Between 1990-1991 and 2010-11, total rail track length decreased by 11 percent from 8,775 to 7,791 kilometres. Total freight and passengers carried decreased from 7.7 to 4.6 million tons (40 percent) and 84.9 to 58.9 million (31 percent), respectively. During 2005-2010, federal expenditure sanctioned for railways was Rs. 45.5 billion, compared to Rs. 155 billion for national highways (actual expenditure was significantly below the sanctioned amount) [39]. Moreover, only one third of the total rail network is used for core commercial purposes.

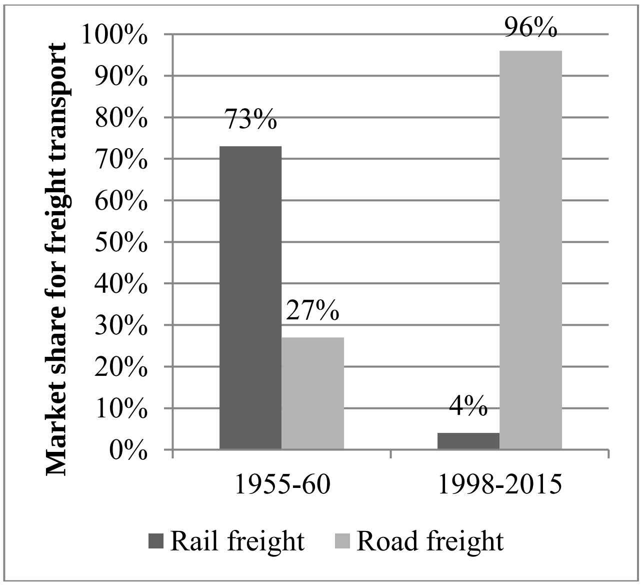

Figure 2: Decline in railway market share in freight transport

Roads have become the most important segment of transport sector in Pakistan with ever increasing reliance on road transportation. In 1947, reliance on roads was only 8%, however, the roads now carryover 96% of inland freight and 92% of passenger traffic and are undoubtedly the backbone of Pakistan's transport sector. From only around 50,000 km in 1947, Pakistan's current road network is now more than 260,000 km. This includes National Highway Authority (NHA) network of around 12,131 km, which despite being merely 4.6% of the overall road network takes 80% of Pakistan's commercial traffic [40].

Roads in Pakistan are in poor condition. The distresses like rutting and fatigue cracking have degraded the condition of the available road network making them unsafe and dangerous for the road users. Since road transportation complements the other modes of transportation, the poor condition of roads in Pakistan is affecting the country's economy. Currently Pakistan has almost 260,000 km of road network which is widely used and carries 91% passenger traffic and almost 96% of the freight traffic (Javed, 2005). Hence it is vital to keep the roads in good condition in order to facilitate smooth and safe traffic flow over the road facilities. Different reasons can be cited for the deteriorating condition of roads including violation of maximum permissible load carrying rules for transport vehicles and shortage of funds for maintenance activities. Unfortunately, the gap between the funds required and available for maintenance and rehabilitation activities has never been bridged since 1999-2000 [41].

In Pakistan, the roadways are usually made as flexible due to low cost as compared to rigid pavements. Flexible pavement experiences traffic loading and environmental factors (rain fall and temperature) that affect the performance of pavement and creates various distresses [42]. According to Pakistan Bureau of Statistics report, 2011 the total road network of Pakistan is 259,643 km, most of them in depleted conditions. According to NHA 67% of their road network is in poor condition with rutting being the most common form of roads distresses.

The National Highways and Motorways network constitutes 4.2 percent of the total road network and carries more than 90 percent of Pakistan's total traffic (96 percent of freight and 92 percent of passenger traffic). The majority of traffic moves along the north-south 1,760 kilometres of the N-5 Highway, which is Pakistan's longest highway and runs from Karachi to Torkham. The N-5 Highway carries 65 percent of intercity traffic and connects the key industrial centres in Punjab and neighbouring Afghanistan with international markets through the southern Karachi area ports. It serves over 80 percent of Pakistan's urban population and contributes to 80–85 percent of GDP [43].

Unfortunately, despite its great potential and demand, quality of the road infrastructure in Pakistan has severe capacity constraints that obstruct the facilitation and efficient movement of goods to their destination. Poor road maintenance is due to factors such as insufficient funding and overloading of vehicles. A 2004–05 survey of pavement condition on the federal network revealed that 37 percent of the road network was in poor to very poor condition [44]. The maintenance requirement of these roads is significant, and toll revenues and government expenditures fund roughly half of it. Provincial roads, which are the primary feeder roads for the National Highways network, are at the bottom of the road hierarchy system. As a result, the government gives more priority to National Highways' investment than provincial road investment. The federal budget shows a strong bias for road development work. From 1996–97 to 2010–11, total road length increased by 13 percent to a total of 259,758 kilometres, of which 180,866 kilometres were "high-type" (paved) roads during this period. Over the past couple of years, most low-type roads (unpaved) have been converted to high-type roads [45]. The NHA is responsible for the development, operations, maintenance, and the preservation of National Highway network.

NHA has to secure the delivery of an efficient, reliable, safe and environmentally friendly National Highway network with a view to improving the quality of life in Pakistan. NHA looks after nearly all of Pakistan's major inter- provincial road links. The National Highways represent the main transport corridor linking ports to major population centres and to neighbouring countries via Afghanistan, China, India, and Iran. The National Highway network takes up 80% of traffic load presently comprising of 39 national highways, motorways, expressways & strategic highways. The current length stands at 12131 km. The network also includes around 5500 bridges and about 16000 culverts [46]. As mentioned earlier, National Highways are only 4.6% of the national Network and even though their condition is better but while comparing the entire countries network the condition is not good) and the road safety record is poor. The country's truck fleet is mostly made up of obsolete, underpowered, and polluting vehicles, and trucks are often grossly overloaded. Truck operating speeds on the main corridors are only 40 – 50 kph for container traffic, half of the truck speeds in Europe. For trucks carrying bulk cargoes, the journeys take 3- 4 times longer than in Europe [47].

Present patterns in transport and trade logistics in Pakistan generate inefficiencies that are costing Pakistan's economy roughly 4–6 percent of gross domestic product per year. Pakistan faces major inefficiencies and challenges in transport and logistics that increase the cost of doing business and hence reduce export competitiveness. These inefficiencies and challenges include:

(i) Poor highway conditions; underpowered, slow, and obsolete trucks; and the widespread overloading of trucks;

(ii) Low priority for freight rail services, despite its potential for being quite profitable relative to passenger services and relative to long-run freight hauls;

(iii) Long customs clearance times and long container dwell times at ports;

(iv) Long air freight dwell times and poor competition in the air freight market; and

(v) A rudimentary supply chain system that does not combine the strengths of transport modes into one integrated system.

The trucking sector carries 96 percent of the total freight traffic. While there are 216,119 registered trucks, the GoP estimates that only 200,500 of these (93 percent) operate on roads. 65-70 percent of the total truck fleet consists of single- or double-axle trucks. The trucking sector is characterized by the presence of a small fleet of owners who generally possess fewer than five vehicles [36]. The bulk of trucking companies are centred in the port city of Karachi, where one ethnic group dominates trucking. The trucking sector is highly competitive, characterized by low barriers to entry, many small operators, and low freight rates. To maintain high revenues, trucks are overloaded, which damages road quality and increases the demand for higher road investment. Lack of enforcement of regulations on safe operation, crew hours, truck modification, and trailer manufacture increase the risk of accidents. According to the GoP's Trucking Policy, by 2007, inefficiencies of the trucking sector were estimated at US$ 2.62 billion per year, consisting mainly of (i) US$ 1.04–1.57 billion per year in extra fuel costs and diesel subsidies, (ii) US$ 0.52–0.61 billion per year in additional road-user costs, and (iii) a US$ 0.44 billion per year contribution to the infrastructure deficit [36].

The current dominance of road transportation sector in freight transportation and its impacts on infrastructure and its expenditures, makes it critical to determine the toll collection of trucks based on their impact. This crucial aspect is missing from the current toll collection approach in Pakistan. Hence, this study approaches the goal of determining toll rates based on pavement damage costs. It also provides a comparison of the proposed approach with the current toll collection values to show the economic impact.

The remaining sections of the paper are organized as follows. Section 2 provides an overview about highway pavements. Section 3 provides the theoretical and computational framework and for the calculation of pavement damage costs and its comparison with the existing toll rates. Lastly, section 4 summarises the important findings and recommendations of this research.

2 Highway Pavements

The term "pavement" refers to a firm, long-lasting surface that is installed on a location to support automotive or pedestrian activities. Its primary function is to disperse the applied vehicle loads among several levels of the subgrade. To counter this, the pavement must be slip-resistant, comfortable to ride on, and quiet [48].

The purpose of highway pavement is to provide smooth surface over which vehicles can move safely from one place to another [49]. The two major types of pavements (flexible and rigid) have been mostly selected for the highway pavement to fulfil this function and they must be capable of transferring the wheel load to the sub grade such that its bearing capacity is not exceeded.

A true flexible pavement yields "elastically" to traffic loading (see figure 3). It is constructed with a bituminous-treated surface or a relatively thin surface of hot-mix asphalt (HMA) over one or more unbound base courses resting on a sub grade. Its strength is derived from the load-distributing characteristics of a layered system designed to ultimately protect each underlying layer including the sub grade from compressive shear failure [50].

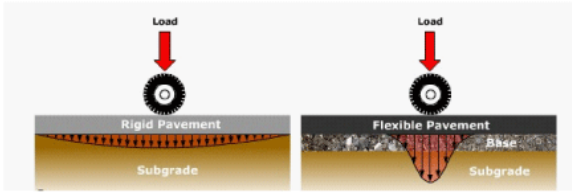

Figure 3. Typical stress distributions under a rigid and a flexible pavement

A flexible pavement typically consists of three or four layers, as shown in figure 4. For a four-layer flexible pavement, there is a surface course, base course, and subbase course constructed over a compacted, natural soil sub grade. When building a three-layer flexible pavement, the subbase layer is not used, and the base course is placed directly on the natural sub grade.

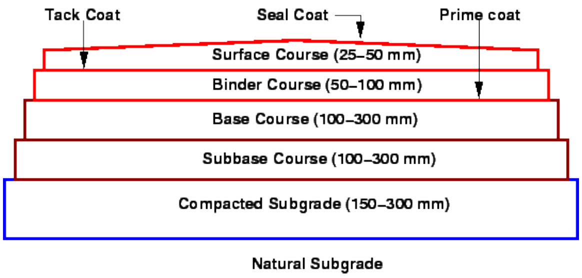

Figure 4. Typical cross section of a flexible pavement

In flexible pavements, the upper layer consists of asphalt concrete. Asphalt, also known as bitumen, is a sticky, black and highly viscous liquid, or semi-solid form of petroleum. Asphalt is a mixture of aggregates, binder, and filler, used for constructing and maintaining all kind of roads. Aggregates used for asphalt mixtures could be crushed rock, sand, and gravel. Different types of asphalt are:

1. Hot mix asphalt (HMA): Hot mixes are produced at a temperature between 150 and 190°C.
2. Warm mix asphalt (WMA): A typical Warm mix asphalt (WMA) is produced at a temperature around 20 - 40°C lower than an equivalent Hot Mix Asphalt (HMA).
3. Cold mix asphalt [51].

2.1 Types of Pavements

2.1.1. Flexible pavements

Flexible pavements are built of asphalt or bituminous concrete and are intended to flex in response to traffic loads. These pavements are appropriate for low to medium traffic loads and are less expensive to install than rigid pavements [52].

2.1.2. Rigid pavements

Rigid pavements are designed to transmit weight equally across a vast area. They can withstand high traffic volumes and large loads and last longer than flexible pavements. They do, however, have a larger starting cost [53].

2.2 Problems in Flexible Pavements

However, the flexible pavements normally show defects like rutting failure and fatigue cracking causing the pavement to fail before its design life. Fillers in asphalt concrete are suspected to be a major contributor to these failures [54].

2.3 Pavement Design

Pavement design is an important process that involves selecting appropriate materials and building processes to provide long-lasting, safe, and cost-effective highways. Pavement design features include pavement type, thickness, drainage, subgrade, and foundation. The selection of pavement design features is influenced by various criteria, including traffic volume, climate, soil conditions, and budget. Proper pavement design may improve road performance and lifespan while lowering maintenance costs and increasing safety [55].

The factors considered in the AASHTO procedure for the design of flexible pavement are:

- Pavement performance.
- Traffic.
- Roadbed soils (subgrade material).
- Materials of construction.
- Environment.
- Drainage.
- Reliability [30].

According to the AASHTO design approach, the traffic load is calculated as the quantity of times a single-axle load of 18,000 pounds (80 kilonewtons, or KN) is applied to the pavement while being supported by two sets of dual tires. This is often known as the equivalent single-axle load (ESAL). The equivalency factors employed in this situation are dependent on the structural number (SN) and the terminal serviceability index to be utilized in the design. But only after the design time, which is the number of years the pavement will successfully continue to handle the traffic load without needing an overlay, can the total (ESAL) laid on the roadway throughout its design period be established. Flexible roadway paving is typically intended to last for 20 years, and traffic [56].

Flexible pavements usually consist of a bituminous surface underlaid with a layer of granular material and a layer of a suitable mixture of coarse and fine materials. Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of granular materials, and cohesion of fine materials. Flexible pavements are further divided into three subgroups: high type, intermediate type, and low type. High-type pavements have wearing surfaces that adequately support the expected traffic load without visible distress due to fatigue and are not susceptible to weather conditions. Intermediate-type pavements have wearing surfaces that range from surface treated to those with qualities just below that of high type pavements. Low-type pavements are used mainly for low-cost roads and have wearing surfaces that range from untreated to lose natural materials to surface treated earth [57].

2.3.1 Different layers of flexible pavement

Subgrade

The subgrade is usually the natural material located along the horizontal alignment of the pavement and serves as the foundation of the pavement structure.

Subbase Course

Located immediately above the subgrade, the subbase component consists of material of a superior quality to that which is generally used for subgrade construction.

Base Course

The base course lies immediately above the subbase. This course usually consists of granular materials such as crushed stone, crushed or uncrushed slag, crushed or uncrushed gravel, and sand [58].

Surface Course

The surface course is the upper course of the road pavement and is constructed immediately above the base course. The surface course in flexible pavements usually consists of a mixture of mineral aggregates and asphalt. It should be capable of withstanding high tire pressures and resist abrasive forces due to traffic [59]. Figure 5 illustrates the different layers of flexible pavement.

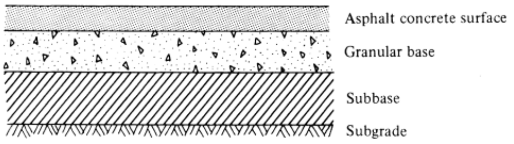

Figure 5. Different layers of flexible pavement

2.3.2 AASHTO Design Method for Flexible Pavement

AASHTO established an empirical method of pavement design in 1993. It was replaced with a mechanistic empirical design in 2004 [60]. However, the 1993 method is still in use in many countries (including Pakistan) due to its simplicity and availability of related parameters [61]. Since focus of this book is related to Pakistan hence, AASHTO 1993 method is discussed in more details. In this AASHTO design method, the traffic load is determined in terms of the number of repetitions of an 18,000-lb (80 kilonewtons (KN)) single-axle load applied to the pavement on two sets of dual tires. This is usually referred to as the equivalent single-axle load (ESAL). And is given by equation 1.

$$ESAL_i = f_d \times G_{rn} \times AADTi \times 365 \times N_i \times F_{Ei} \quad (1)$$

Where:

$ESAL_i$ = equivalent accumulated 18,000-lb (80 kN) single-axle load for the axle category i

f_d = design lane factor

G_{rn} = growth factor for a given growth rate r and design period n

AADTi = first year annual average daily traffic for axle category i

N_i = number of axles on each vehicle in category i

F_{Ei} = load equivalency factor for axle category I [62]

2.3.3. Pavement Thickness

Pavement thickness varies according to the kind of pavement, traffic volume, and soil conditions. Flexible pavements have a thickness of 4 to 6 inches, whereas rigid pavements have a thickness of 8 to 12 inches. Proper pavement thickness guarantees adequate traffic load support and prevents early failure due to cracking or rutting. Inadequate thickness might result in expensive repairs and upkeep [63].

2.3.4. Structural Number

Indicates the total structural requirement required to support the traffic loadings in the design. It's an arbitrary figure that represents the structural integrity of a pavement needed for a particular set of soil support (MR), total traffic represented in ESALs, terminal serviceability, and environmental factors [64].

3 Pavement Maintenance & Damage Costs

The effects of road management can be assessed in terms of the various impacts:

- Level of service (road condition)
- Socio economic impacts
- Road user costs
- Accident levels and costs
- Road administration costs [65, 66]

All above are very important aspects as far as road management is concerned. All problems start with the level of service (i.e. introduction of pavement distress in pavement life cycle). The level of service for which a road is designed, demands a particular quality of traffic flow on the road during peak hours.

Motorway standards are much higher than that of an urban city road. Similarly, the impact of farm to market road will be much greater in the life of a farmer who can take his perishable products for sale than in case of an area which does not have a road. The road user cost impact is the direct benefit which is transferred to the user in case of a better road. Vehicle operating cost/road user cost will be less if road is in good condition, however, it will be much more than in real terms if road condition is poor. A better road reduces the risk of accident, and the social benefits are much greater [67].

The total road transport cost to economy is related to four components which are.

I. Road user/Vehicle Operating Cost; it accounts for about 50 % of the life cycle cost of any road system.

II. Cost of Construction; it accounts for about 15 % of the life cycle cost of any road system.

III. Cost of Maintenance; it accounts for about 25 % of the life cycle cost of any road system.

IV. Operational Cost; it accounts for about 10 % of the life cycle cost of any road system [68].

Maintenance reduces the rate of pavement deterioration, it lowers the cost of operating vehicles on the road by improving the running surface, and it keeps the road open on a continuous basis. Maintenance is also required to improve safety, but the paradoxically, this is sometimes problematic as it can lead to increased speeds which, in turn, result in increased numbers and severity of accidents.

Maintenance covers a wide range of activities, many of which lack the “glamour” associated with new works. Maintenance activity sometimes goes unnoticed; however, the long-term effects of maintenance are significant. Even with adequate maintenance, pavement will deteriorate over time. The rate of deterioration will depend on several factors including traffic loading, the pavement strength, climate, traffic data, and pavement serviceability. Eventually, the end of design life of pavement will be reached and there is a need for pavement reconstruction or up-gradation [69].

These are normally expensive activities and should, therefore, be postponed for as long as possible by carrying out effective and timely routine maintenance and periodical overlays. If the required cyclic maintenance and preventive as well as reactive maintenance are not carried out, drainage will become ineffective and surface defects will worsen, both of which result in water penetrating the structure of the pavement. For paved roads, the resulting distress requires that a higher level of maintenance is needed prematurely. Failure to carry out resurfacing maintenance at the appropriate time soon leads to the need to carry out strengthening overlays, which is at least two times as expensive as resealing. If this overlay is not carried out soon enough, major deterioration sets in and pavement rehabilitation/reconstruction will be required, which is at least four to five times more costly than overlay. It will be seen that deferring works results in rapid escalation of costs to the road administration.

3.1 Formulation of MR&R Strategies and PDC Estimation

The effect of axle loading and, particularly over loaded vehicles, on the requirement for the road maintenance is considerable. For example, a 10-ton axle causes about 2.5 times as much deterioration to pavement as an axle weighing 8 ton. It is clearly necessary, for road maintenance purpose, to know the value of the actual axle loading since minor underestimation can shorten the expected/designed life of a pavement.

The Equivalent Axle Load Factor (EALF) is defined as the damage per pass to a pavement by an axle load and its configuration (single, tandem, or tridem) relative to the damage per pass of a standard axle load, usually the 18-kips single-axle load [70]. The EALF represents the mixed traffic or mixed axle loads and axle configurations of different vehicle types in terms of a single design axle load. The traffic loads applied to any pavement structure determine the pavement's service life. The initial concept of EALF was given by the AASHO road test conducted in the late 1950s and early 1960s. The 18 kips single-axle load was selected as the standard axle load because it was the maximum legal load in most states of the United States of America at the time of the AASHO road test [71].

The test results from the AASHO road test were used to obtain an empirical equation to find EALF. These EALF were published in the AASHO American Association of State Highway and Transportation Officials (AASHTO) Interim Guide for Design of Pavement Structures in 1972 and in all subsequent editions of the AASHTO Design Guide [72, 73]. The EALF from the AASHO road tests represented that with an increase in axle load and axle load repetitions, the damage to pavement structure also increased. Therefore, the determination of equivalent axle load factors and the number of axle load repetitions is critical in the design of any pavement structure and forecasting the best estimate of future traffic loads on the pavement structure over a design period becomes necessary. The AASHTO EALFs are used to convert different axle configurations and traffic loads in a traffic stream on a pavement system to 18-kip equivalent single axle loads (ESALs). The traffic loads applied on a pavement structure are usually a combination of various axle loads and configurations, for example, a 2-axle truck has a configuration of a single-axle with single wheel at the front while at the rear, and the axle configuration can either be single-axle with single tires or single-axle with dual tires. Each axle load and axle configuration will result in damage to the pavement structure. This damage effect to the pavement can be calculated by converting it to any standard axle load and configuration, usually the 18-kips single axle load. The number of axle load repetitions for any axle configuration (single, tandem, or tridem) is multiplied by its EALF to obtain the equivalent damage based on 18-kips single-axle load. A sum of the equivalent damage of all axle loads, and variable axle configurations in a traffic stream over a design period is called the equivalent standard axle load (ESALs). Underestimating the ESALs will lead to early pavement failure than expected for the design period while overestimation of ESALs will cause over-designed pavement structures. The AASHTO EALF for the flexible pavement is dependent upon the load on the axle, the axle configuration, the terminal serviceability index, and the structural number for the flexible pavement.

In a study done by NHA, marginal pavement damage cost (MPDC) was estimated for National Highways of Pakistan. For model estimation, cost data were obtained from the MR&R strategies. Total traffic load (ESALs) was calculated using AADT and WIM data. Statistical model was estimated using

OLS regression techniques. Lastly, a comparison is carried out between current road use toll and actual damage incurred by different truck classes to pavement for N-5 [74].

3.2 Data Collection and Collation

For estimation of MPDC the first requirement is the collection of valid data. The data were collected from number of sources and were compiled in the form of a database. Different past published reports of National Transport Research Centre (NTRC) and NHA, NHA annual maintenance plans and traffic data from various Weigh in Motion (WIM) stations located on national highway network were collected and explored to extract the required information. The details of these data are explained one by one in the ensuing paragraphs.

3.2.1 Weigh-in-Motion (WIM) Station Data

Data of four WIM stations named Sangjani, Eminabad, Peshawar and Rashakai located on N-5 were collected for the year 2012 by a post-graduate student in NUST. The same data has been used for initial analysis for this study. The raw data contained the information on truck GVW, truck class, no. of axles, axle weight, date and time, vehicle ID, and axle spacing. The data at each WIM station were sorted into thirteen truck classes including buses and wagons (Table 1).

Table 1: Gross Vehicle Weight (GVW) of trucks operating on national highways

Truck Class	GVW (Tons)	Stering Axle (Tons)	Single Axle 1 (Tons)	Single Axle 2 (Tons)	Single Axle 3 (Tons)	Tandem Axle 1 (Tons)	Tandem Axle 2 (Tons)	Tridem Axle (Tons)
3	17.16	5.17	11.99	-	-	-	-	-
4	17.16	5.17	11.99	-	-	-	-	-
5	31.12	7.08	12.13	11.99	-	-	-	-
6	40.98	7.08	-	-	-	33.90	-	-
7	48.22	5.59	-	-	-	-	-	42.63
8	36.95	5.59	12.59	9.25	9.52	-	-	-
9	44.41	5.59	9.52	-	-	29.30	-	-
10	45.52	5.59	12.89	-	-	27.04	-	-
11	49.84	3.99	-	-	-	23.33	22.52	-
12	42.51	3.99	9.62	6.38	-	22.52	-	-
13	42.56	3.99	7.52	7.72	-	23.33	-	-
14	42.56	3.99	9.57	-	-	-	-	32.00
15	79.3	5.61	9.89	-	-	32.42	31.38	-

The data were used to determine the percentage of each truck class present in the truck stream. The total truck count observed was greatest at Sangjani WIM station followed by Eminabad, Rashakai and Peshawar. The proportions calculated for each class of truck at all WIM stations are summarized in the Table 2. It can be observed that the truck class-three and -four has the highest contribution in traffic stream while all other truck classes contribute very low percentages in the truck traffic stream.

Table 2: WIM station data

Truck class	WIM Station				Average (%)
	Sangjani	Eminabad	Peshawar	Rashakai	

	No. of Trucks	%	No. of Trucks	%	No. of Trucks	%	No. of Trucks	%	
3	4411	20.01	1382	15.47	436	25.95	783	42.10	25.9
4	4411	20.01	1382	15.47	436	25.95	783	42.10	25.9
5	5116	23.21	1711	19.15	42	2.50	94	5.05	12.5
6	5116	23.21	1711	19.15	42	2.50	94	5.05	12.5
7	652	2.96	439	4.91	166	9.88	25	1.34	4.8
8	652	2.96	439	4.91	166	9.88	25	1.34	4.8
9	652	2.96	439	4.91	166	9.88	25	1.34	4.8
10	652	2.96	439	4.91	166	9.88	25	1.34	4.8
11	35	0.16	100	1.12	7	0.42	-	-	0.4
12	35	0.16	100	1.12	7	0.42	-	-	0.4
13	35	0.16	100	1.12	7	0.42	-	-	0.4
14	35	0.16	100	1.12	7	0.42	-	-	0.4
15	238	1.08	594	6.64	32	1.9	6	0.32	2.4
Total	22040	100	8936	100	1680	100	1860	100	100

3.2.2 Average Annual Daily Traffic (AADT)

AADT data were obtained from NHA for the year 2015. NHA has divided national highway network into total of 709 sections. The data extracted for each section comprised AADT, length of the segment in kilometres, surface type and road class. The AADT data for the study of toll plazas are given in table 3 according to the vehicle classes.

Table 3. Classified AADT

Year 2015	Class-5	Class-6	Class-7	Class-8	Class-9	Class-10	Total
January	23350	98787	334	6535	99	33	129138
February	23203	76989	144	7060	58	30	107484
March	36772	100485	425	8114	1057	960	147813
April	48349	111115	761	10829	110	339	171503
May	56505	118373	738	10967	1019	758	188360
June	58493	127978	330	10001	1172	109	198083
July	38625	68130	206	8602	835	47	116445
August	32399	97624	314	8865	227	111	139540
September	23493	91912	233	5230	146	36	121050
October	27794	92462	224	6075	253	37	126845
November	30747	100471	155	7729	89	174	139365
December	24045	90441	169	5338	89	61	120143
Average	35315	97897	336	7945	430	225	142147

The classes of trucks are defined as follows:

- Class-1: Car, Pickup
- Class-2: Mazda T-3500(or less), Shehzore, Hilus
- Class-3: Tractor+Trolly
- Class-4: Bus

- Class-5: 2 Axle Truck (6 wheeler)
- Class-6: 3 Axle Truck (10 wheeler)
- Class-7,8,9,10: Multi Axle Truck (14,18,22 wheeler)

AADT data were sorted into six traffic groups: (1) very high traffic, (2) high traffic, (3) medium traffic, (4) medium to light traffic, (5) light traffic and (6) very light traffic. The details of six traffic groups are provided in Table 4.

Table 4: Grouping of pavements based on AADT

Traffic Group	AADT Range	Number of Road Segments	Average AADT
Very High Traffic	AADT>25,000	25	40,956
High Traffic	18,000< AADT <25,000	29	21,625
Medium Traffic	12,000 <AADT <18,000	97	15,166
Medium to Light Traffic	8,000<AADT <12,000	146	10,717
Light Traffic	4,000< AADT <8,000	313	6,995
Very Light Traffic	AADT<4000	99	3,730

3.2.3 Treatment Costs

NHA uses different types of rehabilitation and maintenance treatments for its highway system. The most notable of these treatments are functional overlay 30 mm thick, 50 mm thick, functional overlay 50 mm thick with deep patching and cold milling, structural overlay 100 and 120 mm thick, structural overlay 120 mm thick with deep patching, thin surface treatment, crack sealing and patching. The treatment costs for commonly used treatments obtained from NHA in 2013 constant rupees per lane-kilometre (12 feet wide lane) are presented in Table 5.

Table 5: Rehabilitation and maintenance treatment costs

Sr. No.	Treatment Type	Treatment Cost (Million per Lane-km)
1	Functional Overlay 30 mm thick	3.46
2	Functional Overlay 50 mm thick	4.95
3	Functional Overlay 50 mm thick (with Deep Patching)	5.05
4	Functional Overlay 50 mm thick (with Cold Milling)	6.28
5	Structural Overlay 100 mm thick	8.82
6	Structural Overlay 120 mm thick	10.27
7	Structural Overlay 120 mm thick (with Deep Patching)	10.42
8	Existing Surface Treatment with/TST	3.3
9	Reconstruction 25 cm WBM Base / 13 cm AC	17.09
10	Reconstruction 25 cm WBM Base / 16 cm AC	19.13
11	Reconstruction 25 cm WBM Base / 5 cm AC	9.66
12	Reconstruction 25 cm Aggregate Base / 13 cm AC	15.71
13	Reconstruction 30 cm Aggregate Base / 13 cm AC	16.08
14	Reconstruction 20 cm WBM / TST	9.23
15	Reconstruction 20 cm WBM / DST	8.98
16	Patching	1.7
17	Crack Sealing	1.7

3.2.4 Treatment Service Lives

Reliable estimates of treatment service lives of commonly used treatments are not available from NHA. Treatment service life is an important input for MR&R strategy formulation. Questionnaire survey technique was used to get experts opinion on service lives of commonly used treatments. The nature of the recent work was highlighted in the questionnaire and opinion on minimum, maximum and average service life of the commonly used treatments by NHA was asked. The opinions given by the experts were observed critically and the averages of service lives were used in the study. The minimum, maximum and average service lives of treatments used in the study obtained through experts' opinion are summarized in the Table 6.

Table 6: Service life for different pavement treatments

Sr. No.	Treatment type	Service life (years)		
		Minimum	Maximum	Average
1.	Functional Overlay 30 mm thick	3	7	4
2.	Functional Overlay 50 mm thick	3	7	5
3.	Functional Overlay 50 mm thick (Deep Patching)	4	7	6
4.	Functional Overlay 50 mm thick (Cold Milling)	5	7	6
5.	Structural Overlay 100 mm thick	4	7	6
6.	Structural Overlay 120 mm thick	4	8	6
7.	Structural Overlay 120 mm thick (Deep Patching)	6	10	8
8.	Existing Surface Treatment/TST	1	3	2.5
9.	Structural Overlay 12 cm thick	6	10	8

3.2.5 ESAL Calculation for Truck Classes using WIM Data

The ESALs were calculated for each truck class using the average axle weights (Table 7). The ESALs were calculated for each of the axle for a specific truck class using AASHTO's fourth power law as shown in equation (2).

$$ESAL = \left[\frac{Axle\ load}{Standard\ axle\ load}\right]^4 \qquad (2)$$

The standard axle load of 18,000 pounds (8.19 tons), 34,000 pounds (15.47 tons) and 48,000 pounds (21.84 tons) were used for the estimation of ESALs [75]. The average ESALs calculated for different truck configuration are presented in the Table 7.

Table 7: ESAL for different classes of trucks [76]

Sr. No.	Axle type							Average truck ESAL
	Steering	Single-1	Single-2	Single-3	Tandem-1	Tandem-2	Tridem	
3	0.159	4.612	-	-	-	-	-	4.771
4	0.159	4.612	-	-	-	-	-	4.771
5	0.561	4.831	4.612	-	-	-	-	10.004
6	0.561	-	-	-	23.151	-	-	23.712
7	0.218	-	-	-	-	-	14.574	29.366
8	0.218	5.607	1.634	1.833	-	-	-	9.291
9	0.218	1.833	-	-	12.919	-	-	14.970
10	0.218	6.160	-	-	9.371	-	-	15.750
11	0.057	-	-	-	5.193	4.509	-	5.250
12	0.057	1.911	0.370	-	4.509	-	-	6.846
13	0.057	0.714	0.793	-	5.193	-	-	6.756

14	0.057	1.872	-	-	-	-	4.627	11.183
15	0.221	21.35	-	-	19.365	16.998	-	21.721

The summation of ESALs calculated for each axle of a truck class gives the average ESAL of that truck class. It can be noticed that truck class three and four are generating lowest ESAL value of 4.771 while truck class six and seven are producing much higher values of ESAL (23.712 and 29.366 respectively). Truck class eleven, twelve and thirteen has lesser no of ESALs whereas truck class fifteen is also producing higher value of ESAL that is 21.721.

3.3 Comparison of ESALs with Past Studies in Pakistan

In the past, various studies were carried out that calculated ESALs for different configurations of trucks in Pakistan. NTRC (1982), ACE (1988), RR&MTI (1989), NESPAK (1993) and NHA (1995) are major studies carried out in the past for ESAL estimation [78]. A comparison of ESALs estimated in past studies is provided in Table 8. The marked difference in ESAL calculated in different past studies may be attributed to quality of data and methodology used for ESAL estimation.

Table 8: Comparison of ESALs between different local studies

Truck Configuration	Majeed [77] NTRC	ACE (1988)	RR&MTI (1989)	NESPAK (1993)	NHA (1995)	Present Study
2-Axle Single	3.30	4.96	6.33	7.4	6.49	4.77
3-Axle Single	-	-	-	-	16.62	10.01
3-Axle R.Tandem	-	7.63	24.82	26.72	18.48	23.71
4-Axle Single	-	9.77	9.68	-	19.00	9.291
4-Axle R.Tandem	11.40	18.07	26.46	25.05	17.30	15.75
5-AxleTandem	5.5-9.2	6.95	12.64	28.3	-	5.204
6-Axle T. Tridem	-	9.04	-	22.56	27.96	21.721

3.4 Formulation of Life Cycle MR&R Profiles

Pavements are constructed to serve for longer periods of time and include all costs incurred during the life cycle besides the initial construction cost. The costs incurred during pavement life cycle include rehabilitation, periodic maintenance, routine maintenance, and reconstruction. Consider a general pavement maintenance and rehabilitation (M&R) profile, also termed as strategy (Figure 6). An M&R profile is a set of maintenance and rehabilitation activities over one life cycle of a pavement segment [74]. It is assumed that the pavement profile starts with the reconstruction cost at year zero and followed with different rehabilitation treatments whether functional or structural at specific time intervals while maintenance treatments are applied at each year during "N" years of pavement life [79].

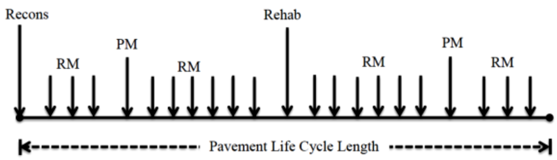

Figure 6: Pavement life cycle maintenance

M&R profiles were formulated based on the treatment types and their service lives. A total of thirty M&R profiles were formulated for six traffic loading levels on national highways using twenty-five years life cycle length. Thus, five M&R profiles were formulated for each level of traffic loading (very high, high, medium, medium to light, light and very light). The time span for each M&R treatment (functional or structural) was selected based on the range of service lives presented in Table 9.

3.5 Cost of MR&R Profiles

The overall cost of each M&R profile over twenty-five years life cycle for six traffic loading levels was determined. For estimation of present worth cost a real interest rate of 5% was used. The present worth of M&R treatment was estimated using the interest equation as presented by equation (3).

$$PW_{M\&R} = \sum_{i=1}^{m1} X \left[\frac{Cost_i^{Rehab}}{(1+r)^{t\_Rehab_i}}\right] + \sum_{i=1}^{m2} X \left[\frac{Cost_i^{PM}}{(1+r)^{t\_PM_i}}\right] + \sum_{i=1}^{m2} X \left[\frac{Cost^{RM}}{(1+r)^{t\_RM}}\right] \quad (3)$$

Where:

PWM&R = present worth of rehabilitation and maintenance treatment,

r = real discount rate,

n = the year of application of rehabilitation or maintenance treatment,

m1 = the number of rehabilitation treatments applied to the pavement,

m2 = the number of periodic maintenance treatments applied to the pavement,

m3 = the number of routine maintenance treatments applied to the pavement,

Rehab = rehabilitation treatment,

PM = periodic maintenance,

RM = routine maintenance (Sahin et al., 2014).

Present worth of MR&R was calculated by adding the reconstruction cost to PWM&R cost.

After calculating the PW for thirty MR&R profiles, Equivalent Uniform Annual Cost (EUAC) was determined using the equation (4) [80].

$$EUAC_{(MR\&R\ Cost)} = \left[MR\&R\ Cost \times \left(\frac{i(1+i)^n}{(1+i)^n-1}\right)\right] \quad (4)$$

3.6 Estimation of ESAL for MR&R Profiles

The average annual numbers of ESALs experienced by the pavement during twenty-five years of life cycle were determined using GVWs and traffic data discussed in earlier section. The ESAL estimation involved the sum of annual ESALs for each truck class in each traffic group as shown in equation (5).

$$\sum_i^k ESAL = Truck\ AADT \times 365 \times D_d \times L_d \times G_f \times \%Class_i \times ESAL\ Class_i \quad (5)$$

Where;

ESAL = Sum of Equivalent Single Axle Load of all truck classes for each traffic group

AADT = Average Annual Daily Truck Traffic

Dd = Directional distribution factor

Ld = Lane distribution factor

Gf = Growth factor

%Class = Percentage of trucks in Classi

ESAL Classi = Individual ESAL of trucks in Classi [81]

ESALs were determined assuming that traffic stream composed of 25% trucks. Directional distribution was taken as 0.5 considering that 50% truck traffic will be in one direction and other 50% will be in opposite direction. Lane distribution factor was considered as 0.8 assuming that 80% trucks will be travelling in the outer lane. Growth factor was calculated as per equation (6).

$$G_f = \left[\frac{(1+i)^n - 1}{i \times Y}\right] \quad (6)$$

Where;

r = Real discount rate,

n = number of years for which growth factor has to be applied,

Y = Number of years [82].

3.7 Model Development for Pavement Damage Cost Estimation

MR&R profiles formulated for each traffic group helped to generate thirty observations for model estimation. For the model estimation EUAC was considered as response variable (Y) and average annual ESALs as explanatory variable (X). Ordinary Least Square (OLS) Regression techniques were used for the estimation of model. Different functional forms for the model were tried and the transformations to the b “Y” done to improve the model fit and correct the model assumptions like constant error variance. The different functional forms that were tried included: natural log, square root, square, reciprocal, power, inverse square, and inverse square root. The estimated results for all these functional forms were analysed critically. The model with square root of EUAC was found to be best with

R-square value of 0.77 and final functional form of the model is as shown in equation (7).

$$\sqrt{EUAC} = \beta_0 \times \beta_1 \times ESALs \qquad (7)$$

Where;
β_0, β_1 = model coefficients, and
EUAC = equivalent uniform annual cost per km [83].
The model details are summarized in table 9.

Table 9: Pavement damage cost model details

Variable	Coefficient	t-Value	P-Value
Intercept	1457.157	145.054	<0.0001
ESALs	0.000147	9.686	<0.0001
R-square	0.77		
No. of observations	30		
Mean absolute % error	0.02		

High value of R-square and very low (close to '0') value of mean absolute percentage error shows that the model is able to accurately model the given maintenance costs. The model results suggest that MR&R cost depends on traffic loading (ESALs). The model estimates are intuitive. The model results suggest that ESALs are positively associated with EUAC. The model suggests that the pavement repair costs will be higher when the pavement will sustain high traffic loading (higher annual average ESALs).

3.8 Marginal Pavement Damage Cost Estimation (MPDC)

MPDC is the increase in agency's Maintenance, Repair and Rehabilitation (MR& R) total expenditure due to one additional vehicle load on given pavement segment. MPDC was estimated by differentiating the estimated pavement damage cost function (equation 3.6) w.r.t. ESALs and the resulting expression is shown in equation 8 [84].

$$\text{MPDC} = 2(\beta_1)\left[\beta_\circ + \beta_1 \times (ESALs)\right] \qquad (8)$$

Estimated cost function presented in equation 8 can be used to obtain the MPDC for different traffic levels. Using the estimated cost function and annual average ESALs marginal pavement damage cost was calculated for national highway system. The estimated MPDC was estimated as Rs. 0.494 per ESAL-km for Pakistan.

The pavement deterioration (the loss of pavement performance) is attributed to two factors: loading and climate [85]. Considering 80 – 20% split for load and non-load share of PDC, MPDC due to loading was estimated as Rs. 0.395/ESAL-km.

3.9 Comparison of MPDC with Existing Toll Rates

A comparison of road use fee based on MPDC with existing road use fee (toll rate) was carried out. For comparison purpose 275 km road segment of N-5 from Lahore to Islamabad was considered. Currently there are six toll plazas on this N-5 segment and two/three axle trucks pay Rs 110 at each toll plaza while trucks exceedingly more than three axles pay Rs 210 at each toll plaza.

The current road use fee of six toll plazas and road use fee based on MPDC for two, three, four and five and more than five axle trucks are calculated as follows.

Case 1: The two-axle truck

Currently, it is loaded two trucks axles Rs. 110 in every yard and there are three yards proceeds between Rawalpindi and Peshawar on N-5. However, the current charges on road users (flat fee) for two-axle truck are Rs. 330. Based on PDC, these charges will be as follows.

Current Toll:
Toll plazas = 3
Toll at each toll plaza = Rs. 110
Total toll = Rs. 330

Charges based on PDC:
Charges (PDC) = Distance ×ESAL× PDC
Charges (PDC) = 165 × 4.81 × 0.475
Charges (PDC) = Rs. 377

165 km have been used, and the average value of 4.81and ESAL PDC value of 0.475 / ESAL-km (2016) fixed rupees in the formula to calculate the

actual Pavement Damage Cost. The estimated fee based on the actual PDC for two axle truck class as Rs. 377.

Case 2: Three-axle truck

Currently three axle trucks are calculated Rs. 110 in every yard and there are three yards proceeds between Rawalpindi to Peshawar on N-5. However, the current charges on road users (flat fee) for two trucks axle is Rs. 330. Charges calculated based on PDC using 165 km have been used, and the average value of 6.85 ESAL and PDC value of 0.475 / ESAL-km (2016) fixed rupees. The estimated fee based on the actual PDC for three-axle truck as Rs. 540.

Current Toll:
Toll plazas = 3
Toll at each toll plaza = Rs. 110
Total toll = Rs. 330

Charges based on PDC:
Charges (PDC) = Distance ×ESAL×PDC
Charges (PDC) = 165 × 6.85 × 0.475
Charges (PDC) = Rs. 540

Case 3: Four-axle truck

Currently it is loaded four-axle trucks Rs. 220 in every yard and there are three yards proceeds between Rawalpindi to Peshawar on N-5. However, the current charges on road users (flat fee) for trucks four-axle is Rs. 660. The charges were calculated on the basis of PDC 165 km which have been used, and the average value of 10.61 and ESAL PDC value of 0.475 / ESAL- km (2016 fixed rupees). The estimated fee based on the actual PDC a three-axle truck class as Rs. 831.

Current Toll:
Toll plazas = 3
Toll at each toll plaza = Rs. 220
Total toll = Rs. 660

Charges based on PDC:
Charges (PDC) = Distance × ESAL× PDC
Charges (PDC) = 165 × 10.61 × 0.475
Charges (PDC) = Rs. 831

Case 4: Five and more than five-axle truck

The accused are currently five and more than five-axle trucks (see figure 3.8) Rs. 220 in every yard and there are three yards proceeds between Rawalpindi and Peshawar on N-5. However, the current charges on road users (flat fee) for two trucks axle is Rs. 660. The charges calculated on the basis of PDC using distance 165 km have been used, resulting in the average value of 10.94 ESAL and PDC value of 0.475 / ESAL- km (2016 fixed rupees). The estimated fee based on the actual PDC a three-axle truck class as Rs. 857.

Current Toll:
Toll plazas = 3
Toll at each toll plaza = Rs. 220
Total toll = Rs. 660

Charges based on PDC:
Charges (PDC) = Distance ×ESAL× PDC
Charges (PDC) = 165 × 10.94 × 0.475
Charges (PDC) = Rs. 857

The comparison between current toll rate and road use fee based on MPDC for two, three, four and five and more than five axle trucks is presented in Table 10.

Table 10: Comparison of current and proposed toll rates

Truck Class	Current Toll Rate	Road Use Charges based on MPDC	Over/Under Payment of Road Use Fee
Two Axle	330	377	-14.21%
Three Axle	330	540	-63.63%
Four Axle	660	831	-25.91%
Five & More Axle	660	857	-29.85%

Comparison table, which shows the current road use fees (toll rate) to charge commercial vehicles is unfair because it fails to charge road use fees based on the damage that each category of vehicles happens. Damage (ESALs) caused by two trucks axle which is the minimum between the layers of the other truck, may be reduced using existing toll roads. Classes truck with four-axle and five and more than five axles have less damage (ESALs) of three-axle trucks, these groups have reduced the current truck toll rate. So, it can be summarized that the three-class truck axle and increase pay to use the current road tolls, while classes truck with two or four or five, and more than five axles are low wages current usage fees. The use of toll roads based on the distribution of the damage that occurs due to each class of compounds promote the use of trucks with a greater number of axles and thus minimize damage to public sidewalk.

4 Conclusions and Recommendations

Present research estimated PDC for Pakistan. Pavement damage cost was estimated using MR&R cost and traffic data for national highway system of Pakistan. The actual damage cost incurred by different truck classes was also compared with current toll rate.

It was revealed in this study that previous national and international studies have focused on the damage to the pier costs but there were few serious research efforts to estimate the cost of damage to the pavement. This has ultimately led to increase in maintenance budgets, which has been an issue of concern for transport planners in Pakistan. Moreover, the comparison between truck axle loads regulations in Pakistan with other countries have uncovered that higher limits of truck axle loads are implemented in Pakistan in spite of the operation of outdated trucks.

A regression model was also developed as part of this study using the maintenance cost data from NHA and traffic data collected for this study. It was noted that an increase in the average annual ESALs lead to higher cost of highway maintenance. Marginal PDC was estimated to be Rs. 0.59/ ESAL-km (2016) fixed rupees per share of the load in 2016. PDC as Rs. 0.475/ ESAL- km (2016) fixed rupees (80% share of the load in the cost of damage to the pier) for the national highway system. It was revealed from the comparison of the current toll and the cost of actual damages, that it is appropriate to charge vehicles based on PDC. Moreover, rate of fines and tolls on the national highway system must be based on the damage (ESALs) resulting from each vehicle class.

Finally, PDC sensitivity analysis was also done on the basis of differences in the different variables in this study. The results of the analysis showed that the life-cycle costs of the highways are significantly affected by inflation rate, and reconstruction and rehabilitation costs. Thus, it is necessary that the interest rate and cost estimates for rehabilitation and reconstruction are used to estimate the PDC.

Comprehensive and thorough research is essential to identify the factors responsible for high pavement damage cost and to find the counter measures for controlling the overloading and reducing the high pavement repair cost in Pakistan. The present study is based on limited data set therefore; it is also recommended to carry out a comprehensive study at national level for pavement damage cost estimation. The present study has calculated pavement damage cost for different truck classes within permissible weight limits therefore, it is also recommended to carry out pavement damage cost for overloaded heavy vehicles. It is also important because prediction from present results shows that pavement damage cost for overloaded vehicles will be much more than the load under permissible limits. Also, future research effort should be directed to explore the effects of other variables like pavement age, pavement type and climate on pavement damage cost.

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