TRUCK LOADING PATTERN AND ITS IMPACT ON PAVEMENT DESIGN

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Abstract

Pakistan being a developing country, with many budget constraints, poor governance and legislation of commercial vehicle’s loading limits facing the dilemma of overloading of commercial vehicles from the last decade, as overloading is the main factor for pavement deteriorations. Highway authorities would be facing the serious problems of maintenance, rehabilitation and reconstruction of existing roads together with designing the future roads to meet the criteria for much higher traffic loadings. Thus, there is grim need to evaluate the impact of commercial vehicle’s overloading on pavement performance to come-up with the optimum solution.

Data of three weigh in motion stations between the two major cities (Peshawar and Rawalpindi) on the main national highway N-5 of Pakistan were collected and analyzed. A comparative study of actual and design load equivalency factors (NTRC-1995) were carried to determine the impact of current loading pattern on the pavement performance. AASHTO flexible pavement design method was applied to compute the axle load equivalency factors and thicknesses required for pavement structures. Furthermore, the effect of variation in truck factor due to current loadings, on pavement design practice in Pakistan in term of performance period and economy was evaluated. It is found that, on average 90% of the commercial vehicles in Pakistan are going overloaded than the suggested limits with axle type-2 vehicle is more damaging to pavement structures having truck factors 2.65 times more than the design truck factors. Moreover, it was analyzed that the pavement structure designed on the basis of truck factors suggested by NTRC would get deteriorate in 3.5 years rather than 10 years with the economic loss of 4.5 million rupees approx.
I. Introduction

Transportation agencies spend a large amount of money to construct and in the restoration and preservation of road networks in all parts of the world annually. The transport system is the backbone of the development of any country, but on the other hand, the budget requirements for the construction, maintenance and rehabilitation of the system are also very high. The pavements are designed to last, and a huge quantity of investment budget necessary to lengthen the period of life through maintenance and repair but often do not perform as expected.

The main problems that appear in the pavement are, cracks in the surface and failure of the pavement before the life expectancy and it eventually because of the pavement hunched under traffic loads due to variation in traffic loads and overloading of commercial vehicles along the year. There may be some other issues such as environmental changes, physical description of the materials and structural degradation that causes deterioration; however the traffic load frequency, intensity and the configuration of axle is primary factor for the pavement dissertation.

Heavy/Commercial traffic is the most important cause of structural failure in the pavements such as the Rutting and fatigue cracking. High loads, axle configurations, truckproportion increment also led to early road deteriorations, necessitating load limitations and early replacement.

Accurate information on the size of the cargo transport is a prerequisite for the design and analysis of the structures of the pavement. Underestimation of design traffic can lead to premature failures in the pavement structures and excessive rehabilitation costs, whereas, overestimation can result in moderate pavement designs that are less cost effective. (VI)

Like other developing countries pavement deterioration caused by overloading of commercial vehicles has been a major issue in Pakistan from the last few years. Furthermore, it is expected that with the huge upcoming infrastructure and economic activities under China-Pak Economic Corridor the truck traffic will increase. Similarly, Overloaded commercial vehicles due to absence of enforcing legal load limits in Pakistan, results in great damaging factor as compared to other countries.

Pavements structures are designed such that to tolerate the expected number of standard axles (18-kip) during the analysis period. In order to ascertain standard axle loads, the factors effecting includes total vehicle load, axle configuration, tire inflation pressure etc. must be taken into consideration to convert legal axle loads into equivalent standard axles. The procedure adopted to convert loads into standard axles is AASHTO pavement design guide method, as used by most of the countries globally. (I)

II. Importance of Study

Overloading of commercial vehicles contribute huge to the pavement damage thus decreases pavement life and thereby increases the pavement maintenance and
rehabilitation cost. The damage caused to the pavement by passage of a heavy commercial vehicle relies on its gross weight likewise how this load is distributed to the underlying pavement layers.

Presently, all over the Pakistan the Truck ESAL factors used for the design of flexible and rigid pavements are based on, “Axle load survey on National Highways” carried out by NTRC in 1995. This is un-erectable fact that since 1995 the volume and the loading pattern of heavy vehicles all over the country have increased to greater extent due to transfer of shipments by road instead of rails. Furthermore, due to change in production industry, truck operating weights have been changed but no such revision or update has been made to the truck EASL factors since 1995. (IV)

The tendency of the surplus load is progressively getting worse due to the introduction of newer and stronger trucks with wider bodies and transfer of careering goods by rail to the truck traffic. Moreover, because of weak enforcement of rules and regulations, corruption haulers are benefited and roads are getting worse. Therefore, it is vital important to assess the extent and impact of heavy commercial vehicles along the country, so that the balance between the management and the protection of the infrastructure and the economy has been made. This is the main reason for the implementation of this study, such that the problems of deterioration of the existing roads can be minimized and the special consideration would have been taken for the future.

III. Purpose & Scope

The prime scope of this research includes the comparison of current volume of traffic and the EASL factors due to increment of overloading to the truck EASL factors calculated by NTRC in 1995 which will be helpful in identifying the potential causes of pavement deterioration due to overloading of commercial vehicles and suitable remedies will have to be suggested for the design, maintenance and rehabilitation of pavements in Pakistan.

The primary objectives of this research are as follows:

- To evaluate the current trend of loading of commercial vehicles in Pakistan by investigating 3 WIM stations data.
- To calculate the truck ESAL factors considering current loading pattern of commercial vehicles and its impact on pavement design.
- To compare the current truck ESAL factors with ESAL factors established by NTRC in 1995.
- To investigate the design life of previously designed pavement based on NTRC data and its performance period.
- To compare the cost sensitive analysis of currently design pavement with the previous one.

IV. Background

As loading frequency of commercial vehicles is considered as the main factor for pavement distresses and performance of the highway networks can eventually be
determined by variation in the truck traffic, that’s why most of the researches work globally in the field of traffic overloading and its impacts.

Pais, Amorim and Minhoto (2013) investigated the influence of overloaded vehicles on pavement performance and construction/maintenance costs by analyzing the truck factors for different vehicles on set of different asphalt layers having varying stiffness moduli for subgrades. They concluded that by increasing the thicknesses of asphalt layer the effect of vehicle load on the pavement structure can be diminished. It was also suggested by them that overloading impact on the pavement performance can be reduced by taking into account the maximum legal weights of commercial vehicles. (VI)

Rod E. Turochy, S. Michelle Baker, and David H. Timm (2005) performed a study on 13 different sections of Alabama to explore the effect of space and time related variations in axle load and their effect on pavement design. Furthermore, the extent of distinction of axle load at the site on two directions and between sites across a larger area is also quantified using such measures. Finally, they carried out case sensitive analysis to the thickness of pavement to change the input parameters related to the characterization of the movement of heavy vehicles. (X)

H.K Salama, K. Chatti and RW Lyles, in "Effect of Heavy Multiple Trucks on Flexible Pavements Damage Using in-service Pavement Performance data” analyzed the impact of various truck configurations using in-service data in Michigan state on the flexible pavements in the term rutting and roughness using Regression analysis. They pointed out that multi-axle trucks produced more rutting damage to the pavement than isolated and tandem-axle trucks. While single-axle and dual-axle trucks were more sensitive to cracking than tridem and multiple axle trucks. Furthermore, it was concluded that evidence of pavement roughness due to different axle configurations was not significantly drawn. (IX)

Dawid Rys, Jozef Judycki and Piotr Jaskula (2015) in their research concluded that load balancing factors are related to the ratios of loaded vehicles and the axle load distribution characteristics. Analysis shows that a 0% to 20% increase in overloaded vehicles can result in an increase of 75 to 100% of load equivalent factors for each WIM station. Similarly, the fatigue life of pavement structures with overloaded vehicles is greatly affected. In the analysis, it was found that the increase in the percentage of excess loads resulted in the reduction of the fatigue life of the asphalt in the range of 50%. Conversely, a 10% reduction in vehicles with excessive loads may result in an increase in the service period from 4 to 6 years. (VII)

R. Chaudary and A.B Memon (2011) investigated the effect of variance in the truck factor on pavement design. According to her, the Axle type 3 truck is the most damaging to the roads compared to other species. Also, actual trucking factors are much more than truck design factors. Moreover, the trucking factors used to design the pavement were taken from the old study of 1993 and should be revised according to current loading processes and implemented for the design of new roads. (II)

Bruce, Morton and A. Visser (2004) extensively studied the effect of tire inflation pressure and axle load spectra on pavement design methods. Prior to their studies, the pressure of truck tire inflation related with axle load plays an important role in the
deterioration of flexible platforms. They have been assessed in their study that pressure of tire inflation and vertical stress are directly related and the increased tire contact stress esaccelerate the deterioration of surface layers and the base layers of most flexible paving structures. It has also been formulated that high quality broken stones and stable bitumen bases can withstand high tire pressures, while thin surfaces are greatly affected by increased tire pressure. (III)

Dawid Rys, Jozef Judycki and Piotr Jaskula (April 2016) in Poland analyzed up to 5 million vehicles using WIM station data on four highways and one express way to ascertain the load equivalent factors for particular flexible and semi-rigid paved structures. They use four computational methods and then compared results to determine load equivalent factors. They concluded that the adverse impact of traffic loads was higher for the thinner pavement structures and that the load equivalent factors evaluated by GUT method for the semi-solid pavement designate that the treated cement base pavement structure could have a higher fatigue life compared to the asphalt base pavement, provided that no overloaded vehicles occurred.

Moreover, increasing the maximum load of the legal axis increases the average load-balancing factors. According to calculations, load balancing factors were well correlated with overloaded vehicles. Dynamic loads of vehicles have a detrimental effect on pavement structure and depend on pavement roughness, vehicle speed and suspension parameters. Dynamic loads significantly affect the values of load equivalency factors. (VIII). The research presented in this paper is actually the comparative analysis of axle load factors to truck factors established by NTRC in 1995 and their impact on the pavement design practice in Pakistan.

V. Analysis Procedure

Structural designing of the pavement infrastructures mainly done by converting the passage of axles, for large variety of commercial vehicles, into an equivalent standard axle of 18-kip (80KN) used as reference for the pavement design. The procedure for determining of equivalent factors for load and the influence of current loading pattern on design of pavement in account of performance period and economy is presented in figure-1.
The analysis of impact of current commercial vehicle’s loading pattern on the pavement design was carried out using AASHTO guide for design of flexible pavements method by studying the following.

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Load Equivalency Factors for legal vehicles.
Load Equivalency Factors for overloaded vehicles.
Load Equivalency Factors for average vehicles (legal + overloaded vehicles)
Impact of current loading pattern (Truck factors) on the design Truck factors.
Impact of current loading pattern on the performance life of the design pavement.
Impact of current loading pattern on economy.

The proportions of empty vehicles across three WIM stations was accounted less than 1% approximately for all axle types, and hence were eliminated for the analysis purposes.

VI. Procurement of Data

Data was collected from three weighing in motion stations, located at Sangjani, Mullah Mansoor and Eminabad on Peshawar-Rawalpindi corridor of main national highway of Pakistan N-5. Seven days data was collected for all three stations from the two directions, north and south bound during the month of March, April and May 2017.

Vehicle loading is considered as main factor for the design and performance evaluation of road structures. Extra loadings results in poor performance of roads in term of comfort and ride quality. Damage caused to road pavements due to light vehicles, i.e. vans, Suzuki’s and passenger cars is negligible as compared to commercial vehicles. Therefore, only commercial vehicles with 2-axle, 3-axle and multi-axle were measured for the case study. The weigh in motion data of the effective and loyal weigh stations on main highway N-5 of Pakistan is taken into consideration for the current research. The data was procured from toll link Islamabad office through NHA. The data used for analysis is almost 7 days duration including gross vehicle weight and the weight on each axle, and consisting of all type of commercial vehicles that is single, tandem and tridem axles. The following table-1 will show the snapshot of data used for the study.

Table 1: Sample of axle wise truck load raw data from Sangjani weigh in motion station.

| Truck type | Axle Configuration | Gross weight | Load (Front wheel) | Load (Rear axle-1) | Load (Rear axle-2) | Load (Rear axle-3) | Load (Rear axle-4) | Load (Rear axle-5) |
|------------|-------------------|--------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 6-axle     | 6-XL-SDT          | 80,378       | 3,094              | 13,291             | 14,571             | 15,019             | 15,686             | 18,717             |
| 2-axle     | 2-XL-SS           | 23,479       | 4,708              | 18,771             |                    |                    |                    |                    |
| 3-axle     | 3-XL-SD           | 78,634       | 7,072              | 50,574             |                    |                    |                    | 20,988             |
| 5-axle     | 5-XL-SDSS         | 81,536       | 4,664              | 17,024             | 17,819             | 21,777             | 20,252             |
| 5-axle     | 5-XL-SST          | 71,187       | 4,694              | 6,269              | 18,564             | 19,882             | 21,778             |
| 3-axle     | 3-XL-SD           | 31,993       | 7,518              | 11,044             |                    |                    |                    |                    |
| 3-axle     | 3-XL-SD           | 41,262       | 6,124              | 18,500             |                    |                    |                    |                    |
| 4-axle     | 4-XL-SSD          | 35,311       | 3,345              | 12,408             |                    |                    |                    | 9,644              |
Overloading not only results in early pavement deterioration but also increases the pavement rehabilitation and maintenance costs. In order to protect the structural and functional life of the road infrastructures national transportation agencies establishes and imposes load limits for various axle groups which are mostly dependent on the tire size, amount of axles, axle grouping and tire inflation pressure. The main National organization “NHA” that is looking after whole infrastructure of roads along the country, conducted many studies to compute the loading limits for each axle such that prepared benchmark for loads and to specify design criteria based on AASHTO prescriptions. (V)

Gross weight limits of each vehicle and for each axle loads specified for enforcement on the highways and motorways in Pakistan are presented as in table-2.

**Table 2: Permissible gross weight for commercial vehicles according to axle configuration.**

| Truck Type                     | Permissible Gross Weight (Tons) |
|-------------------------------|---------------------------------|
| 2-axle (Single)               | 17.5                            |
| 3-axle (Single Single)        | 29.5                            |
| 3-axle (Tandem)               | 27.5                            |
| 4-axle (Single Single Single) | 41.5                            |
| 4-axle (Tandem Single)        | 39.5                            |
| 4-axle (Single Tandem)        | 39.5                            |
| 5-axle (Single Single Tandem) | 51.5                            |
| 5-axle (Tandem Tandem)        | 49.5                            |
| 5-axle (Single Tridem)        | 48.5                            |
| 5-axle (Tandem Single Single) | 51.5                            |
| 6-axle (Tandem Tridem)        | 58.5                            |
| 6-axle (Tandem Single Tandem) | 61.5                            |

**VII. Data Description & Processing**

For the design of pavement, it is essential for the designer to estimate the total number of commercial vehicles traversing the highway in the course of its design life. For this motive it is obligatory to know the exact count of commercial vehicles that will use the highway when it first opened to traffic and to forecast the annual rate of growth.

Traffic studies for highways provide information about various types of vehicles traversing the highway. Traffic volume data indicates the appropriate level of service for the new highway that should be designed and it affects the geometric features of...
the highway. Following figure-2 will represent the overall percent composition of trucks by axle configuration along all the three weigh in motion stations.

![Composition of trucks by axle configuration.](image)

**Fig.2:** Composition of trucks by axle configuration.

It was quite interesting to note that the proportion of 2 and 3-axle vehicles is about 90% as compared to other vehicles. During 1995 studies, only 23% of the vehicles were three axles, but now the three axle trucks are being preferred and are gradually replacing the two axle trucks. However, the summary of total truck counts at all the three stations, Sangjani, Mullah Mansoor and Eminabad shown in table-3.

**Table 3: Percent count of different Truck classes along three WIM stations.**

| Vehicle Type | WIM Station | Average Percentage |
|--------------|-------------|--------------------|
|              | Sangjani    | Mullah Mansoor     | Eminabad           |
|              | No of Trucks | %                   | No of Trucks | %     | No of Trucks | %     |
| 2-XL-SS      | 1504        | 29.8               | 1305          | 35.5  | 806          | 24.7  | 30.0               |
| 3-XL-SD      | 2890        | 57.2               | 2242          | 61.1  | 2003         | 61.3  | 59.9               |
| 4-XL-SSD     | 162         | 3.2                | 50            | 1.4   | 130          | 4.0   | 2.9                |
| 5-XL-SDSS    | 41          | 0.8                | 9             | 0.2   | 48           | 1.5   | 0.8                |
| 5-XL-SST     | 70          | 1.4                | 4             | 0.1   | 20           | 0.6   | 0.7                |
| 6-XL-SDT     | 382         | 7.6                | 61            | 1.7   | 259          | 7.9   | 5.7                |
| Total        | 5049        | 100                | 3671          | 100   | 3266         | 100   | 100                |

It is clear from the table-3 that 42% of all the truck traffic was counted on the Sangjani WIM station. Whereas, the proportion of traffic on the other two stations,
Mullah Mansoor and Eminabad is 31% and 27% respectively. It was clearly observed that the volume of 3-axle truck is more along all the stations as compared to other vehicle classes.

For analysis and processing of data following steps were taken:

1- The percentage of empty trucks across all the three stations is less than 1%, except 4-axle trucks, and also the empty truck causes negligible damage to pavement structures, therefore, empty trucks were eliminated from the data.

2- The values in data making no practical sense or having extreme values had been omitted from the data to avoid outliers.

3- Almost 11986 vehicles were counted (Table-3) during seven days survey but after eliminating empty vehicles and outliers, 11217 vehicles were used for analysis.

4- To calculate load equivalency factors by AASHO method, average of each axle load was calculated and then for single axle, average of single axle load was used to calculate LEF.

5- For tandem and tridem axles, the respective average load values were added to use as tandem and tridem load for calculating load equivalency factors.

**Truck Loading Pattern**

The gross weight and corresponding load on each axle during the passage of vehicle on the road is considered as a basic factor for the design of road and rehabilitation of pavements. The exact observation of the loads, mainly overloads applied to the pavement is paramount to speculate the pavement performance life and to interpret the Equivalent Single Axle Loads to be used for pavement design. Thus, in the current research the effects of normal loads and surcharge loads on the pavement will be analyzed in term of pavements life using data base of seven days from three different stations.

Average axle loads were calculated at 3 stations in accordance with the described axle configurations. Table-4 provides the information about average axle loads for each axle configuration including maximum and minimum load values among 3 WIM stations.

**Table 4: Average axle loads of all trucks for all stations.**

| Vehicle Class | Sangjani WIM Station (Load in Tons) | M-Mansoor WIM Station (Load in Tons) | Eminabad WIM Station (Load in Tons) |
|---------------|------------------------------------|--------------------------------------|-------------------------------------|
|               | Lea t Age | Utm ost | Lea t Age | Utm ost | Lea t Age | Utm ost |
| 2-Axle SS     | 8.48      | 21.4    | 36.38     | 8.37    | 21.7      | 34.3    |
| 3-Axle        | 10.0      | 40.4    | 60.97     | 15.3    | 42.3      | 54.5    |

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It is evaluated from the table-4 that the average load plying on all the three stations exceeds the permissible gross weight limits recommended by NHA, Pakistan. At all stations for all vehicle class configuration, the average load exceeds at an average of 10 tons from the permissible limits by NHA. Only 4-axle vehicles at Eminabad WIM station were going at/or near the recommended limit of 39.5 tons. The minimum load 8.37 tons, is of 2-axle vehicle at Mullah-mansoor station while the maximum one is 110.24 tons of 6-axle vehicle class at Sangjani WIM station was measured.

Here, figure-3 demonstrates the graphical representation of number of trucks going with the load in limits with respect to overloaded trucks at the three stations.

**Fig.3:** Loaded verses overloaded summary of data at all WIM stations.

It was clear that, percent of overloading along Mullah Mansoor station is more as compared to other two stations. Almost 90% average vehicles going overloaded, this is the major factor for premature deterioration of pavement before reaching its design life.

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Figure-4 represents the vehicle vise comparison of percent of loading within limits and overloading pattern across the three stations.

![Vehicle vise summary of loading pattern](image)

**Fig.4:** Vehicle vise summary of loading pattern, at three WIM stations.

From 11217 vehicles, 10090 vehicles were going overloaded, from which almost 60% of traffic composed of 3-axle truck and the percent of overloading of this type vehicle is 95%. Only 5% of three axle vehicle are going with the load in limits.

The main reason of increased in overloading of commercial vehicles in Pakistan is actually the poor implementation or lack of enforcement of axle load limits, which results in early deterioration of pavement structures and hence the need of huge amount of budget for maintenance and rehabilitation.

**VIII. Impact of Current Loading Pattern**

**Impact on Equivalent Axle Load Factors**

The damage caused to the pavement by the passage of an axle loaded to 80 KN (8.165 tones) is known to be standard axle. The damage caused by different axles is converted into equivalent standard loads and summed up for the life of the pavement. Load equivalency factors depend on the local traffic conditions on a specific road section.

For each vehicle type the Load Equivalency Factor for each axle configuration was computed AASHTO 1993 guide as given in equation.

\[
\log_{10}(W_{t1} / W_{t10}) = 4.79 \log_{10} (18 + 1) - 4.79 \log_{10} (L_{x1} + L_{2}) + 4.33 \log_{10}L_{2} + G_{t} / \beta_{t} - G_{t10} / \beta_{t10}(1)
\]

Then,

\[
\text{EALF} = \left( \frac{W_{t18}}{W_{t8}} \right)
\]

Where, EALF is Equivalent Single Axle Load Factor (Truck Factor).

The LEF values calculated by taking average load from each of WIM station are presented in fig-5 and it can be concluded that, these values differs for particular station.

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The results show that 5-axle single tridem and 6-axle dual tridem are the most damaging to pavement as the LEF for these two trucks are above thirty for Mullah-Mansoor and Eminabad WIM station, which accounts that one flow of this truck class is equivalent to 30 passes of single truck having standard load of 18 kips.

Average LEF were calculated by using the average loads of each WIM station for all the truck classes having single, tandem and tridem axles. Table-5 demonstrates the actual average LEF evaluated from the current study.

**Table 5: Load Equivalency Factors for three different loading criteria’s.**

| Vehicle Type | LEF (Average Load) | LEF (Over Load) | LEF (Load in Limits) |
|--------------|--------------------|----------------|----------------------|
| 2-Axle       | 12.37              | 16.35          | 2.50                 |
| 3-Axle       | 21.29              | 23.38          | 1.80                 |
| 4-Axle       | 14.48              | 22.70          | 6.53                 |
| 5-Axle       | 22.28              | 28.39          | 7.85                 |
| 6-Axle       | 24.59              | 28.61          | 3.04                 |

It can be noticed that the value of average LEF/truck for different axle configurations of truck ranges from 12.37 for 2-axle to 24.59 for 6-axle, however, the highest value of LEF is 30.50 for 6-Axle truck at Eminabad WIM station.

**Design Versus Actual Truck Factors**

NTRC in “Axle load survey on national highway” calculated Equivalent Axle Load Factors based on 24 and 48 hours traffic volume in 1995 and the results of that study were widely used all over the country by consultants and authorities concerned with provincial and National highways for the design and rehabilitation of existing road infrastructure and till now these results are being in use.
During NTRC study only 4,768 trucks were surveyed in 24 hour traffic volume over 30 stations, whereas, in the current study 11986 were counted during 7 days over only 3 WIM stations. Therefore, the current volume and loading pattern will results in accurate and much better as compared to 1995 study. The comparison between calculated and design (NTRC) equivalent axle load factors are shown in table-6.

**Table 6: Comparison of design (NTRC 1995) and actual EALFs.**

| Vehicle Type | Design EALF (NTRC 1995) | Actual EALF (Calculated) | Time Increased |
|--------------|-------------------------|--------------------------|----------------|
| 2-XL-SS      | 4.67                    | 12.37                    | 2.65           |
| 3-XL-SD      | 8.84                    | 21.29                    | 2.41           |
| 4-XL-SSD     | 10.35                   | 14.48                    | 1.40           |
| 5-XL-        | N-A                     | 22.28                    | ----           |
| 6-XL-SDT     | 10.84                   | 24.59                    | 2.27           |

It is evaluated from the comparison that calculated equivalent load factors for all type of trucks is very high than the design LEF taken from 1995 National Transport Research Center study. Furthermore, it is also revealed from the table that the calculated EALF for 2-axle trucks exceeds the design EALFs 2.65 times, which encapsulates that the trend of overburden loads in 2-axle trucks is highest and most damaging to pavements while the 3-axle truck lies the second in overloading.

**Impact on Flexible Pavement Design**

For the analysis of practical effects of current loading pattern on the flexible pavement design, a general AASHTO method was used, by assuming 95% level of assurance and the standard deviation-So- was taken 0.45 for the given level of reliability. The pavement performance level was based on fundamental value of serviceability 4.2 and a terminating value of 2.5. To demonstrate the properties of subgrade, modulus of resilience, Mr.=9600 psi is considered for the analysis purpose. However, the coefficients representing the properties of materials for the three pavement layers were assumed 0.4, 0.13 and 0.12 respectively with the drainage coefficient of 1 for base and sub-base layer having good quality to drain the moisture.

Concerning traffic counts, an annual advancement of 5% was used to calculate the growth factors and the lane and directional split factors were taken 0.8 and 0.5 of a two lane highway for the design life of 10 years. However, for the pavement design practice in Pakistan the truck factors as established by NTRC in 1993 was taken only for 3 type of axle configurations (2-axle, 3-axle & 4-axle) taken into account of traffic volume during 1993 as the proportion of 5 & 6-axle trucks were less than 1% considering 80 % and 20% of loaded and empty vehicles. For average annual truck traffic, three values 889_176_107 were used for 2_3 & 4-axle trucks.

To ascertain the influence of current truck factors on the pavement design, all the statistics discussed above were assumed as same for the comparative analysis of pavements except the proportion of empty vehicles were eliminated in the current...
study. The following table-7 will demonstrate the impact of current loading pattern on the pavement performance.

**Table 7: Impact of current truck factors on pavement performance life.**

| ESALs (million) (10 years) | SN Required | SN Provided | ESALs @Provided SN (AASHTO) | Performance Life due to Impact of Current Truck Factors (approx) |
|---------------------------|-------------|-------------|-----------------------------|---------------------------------------------------------------|
| Designed Str.             | 10.87       | 4.877       | 5.32                        | 20027513                                                      | 3.5 years                                         |
| Current study             | 29.92       | 5.62        | 6.20                        | 62436248                                                      | 10 years                                          |

It is assessed from the above table that the pavement designed on the basis of truck factors determined by NTRC will get deteriorate/failed in 3.5 years by effect of commercial vehicle’s overloading currently plying on the roads.

**Impact of Current Truck Factors on Economy**

Cost analysis was carried to numerate the loss of structural failure of the pavement structure in term of performance period due to impact of current extra loadings. For this purpose National Highway Authority composite schedule rates (CSR Lahore) was used. As it was emphasized in the previous paragraphs, the pavement design on the basis of load factors evaluated in 1993 would get failed in 3.5 years due to impact of current loading pattern. So, there will be two possibilities (assumed) for the designed pavements taking into account the two extreme sides of deterioration.

1st. the pavement deteriorates minimum having only little alligator or transverse cracking and required an overlay treatment for remaining period.

2nd. the pavement got failed entirely due to current loading pattern and required complete reconstruction.

Table-8 will demonstrates the practical effect of currently plying loads on the economic constraints required to construct or rehabilitate the structure. The reconstruction process is actually the replacement of entire asphaltic (surface and base) course, keeping the base and sub-base thicknesses 30cm and 20cm as constant.

**Table 8: Impact of current truck factors on economy.**

| Material | Cost per Cubic Meter (PKR) | Reconstruction Cost (Rupees) (Analysis period= 6 years) | Rehabilitation (Overlay) cost (Rupees) |
|----------|----------------------------|--------------------------------------------------------|---------------------------------------|
|          |                            | @ 1993 truck factors (SN provided = 5.002)             | @ current truck factors (SN provided = 5.79) |
|          |                            | Depth Cost                                            | Depth Cost                             |

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It was evaluated that almost 4.2 million rupees will be required for the treatment overlay cost of the designed pavement such that it can tolerate the huge loadings for the analysis period of 10 years. However, 11 to 14.5 million rupees would be needed to reconstruct the pavement if it got failed entirely by the effect of present loadings.

IX. Synthesis of Interpretations

This research presents an eye view on “Truck loading pattern and its Impact on Pavement (flexible) design in Pakistan” as a comparative study of design and actual truck factors and also contrast of pavement design on current truck factors with the pavement design practice in Pakistan based on 1995 study’s truck factors. The following judgments were made based on the current research work so far:

- The overloading of commercial vehicles in the country is a common phenomenon; on average more than 90% of vehicles are carrying loads above the permissible load limits suggested by National Highway Authority.
- 3-axle trucks dominate the commercial traffic composition making 2/3rd of the total truck population, almost 60%.
- Actual truck factors (based on current study) are much higher than the design truck factors (NTRC 1995), with axle type-2 vehicles are more damaging to pavement structures as their truck factors are 2.65 times more than the NTRC factors as compare with other truck types.
- The impact of current loadings on pavement is such that, the pavement designed for 10 years on the bases of EALFs established by NTRC, will starts deterioration after 3.5 years, and would require a budget of 11 million /4.5 million rupees (approx) for reconstruction/rehabilitation to withstand against such loadings for the remaining analysis period.
X. Future Directions

Prior to this research, following special mentions are directed for future studies.

- In this study it is revealed that, the legal axle load limits could not be implemented in true sense. In order to overcome the problem of overloading of commercial vehicles and to protect the pavements from early deterioration, an attempt could be made for enforcement of the appropriate axle load limits and to strictly impose the official load limits.

- Application of average EALF factors established by National Transport Research Centre for design of individual roads is not appropriate without a considerable traffic study at that corridor and it is necessary to determine equivalent standard axle for each road.

- Prior to this study, it is strongly counsel that the Truck factors evaluated by NTRC during axle load survey in 1995 are out-dated, which must be revised and updated considering the current loadings plying on the roads and to obtain more accurate truck factors for the design of better and strong pavement structures for future and to overcome the problem of earlier damage of pavements.

- Furthermore, as in this study the impact of loading on pavement was determined regarding reduction in performance period and economic loss. It is suggested that a correlation between axle load and pavement damage is essential to determine for each set of load counts in order to retrieve the impact of load on any specific road.

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