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Line Load Analysis of Live Load Models for Short to Medium Span Lengths Bridges in Pakistan

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Abstract

In bridge designing the live loads plays an important role. Most of the developed countries have their own code for highway bridges design specification while the other countries adopt certain renowned design codes but with certain additions to meet their demands. In Pakistan, two different codes are followed for designing of bridges i-e American Association of State Highway and Transportation Officials and West Pakistan Code of Practice for Highway Bridge. But both of these codes live load models are not representative of the present truck traffic situation in Pakistan**.** For this research study, the MULLA MANSOOR weighing station was selected which is located on Grand Trunk road of Pakistan. This paper aim is to study the statistical analysis of weigh in motion data and comparative analysis of short to medium span length typical I girder bridges i-e 10m to 50m with 5m increment. This will help in comparing the live load effects with the actual truck traffic data for proposing a new live load model in Pakistan. The method applied for achieving the objectives is based on Line load analysis i-e Load Resistance Factor Design Equations spreadsheet for bridges design in Pakistan for developing the Live load model and modification in codes.

Keywords: AASHTO LRFD, Actual truck traffic data, Calibration Factor, Design truck, Live load model, WIM, WPCPHB

1 Introduction

Bridge is a key element of the Transportation System and they should be designed for all types of necessary loadings. The most dynamics of all types of loads for a bridge structure the live load which plays a vital role in the determination of the strength of the structure. In world the developed countries have their own codes for bridges design which are different from one another and therefore it is the time to developing a unique live load model. But some countries adopted the bridge design codes from other. In Pakistan the AASHTO LRDF and WPCPHB (1967) (1) specification are used. There must be traffic live load models that are developed for representing the current actual traffic flow of the country and are meant to be applicable for designing bridges in the future to achieve a good design life. In Pakistan, current live load models in WPCPHB (1967) were taken from British (BS 153, 1937) introduced in INDIA (in 1935). Since then this code has never been updated and resulting in overstressing the infrastructure. Since that time the traffic flow and traffic loads have increased significantly changes and especially the vehicles Gross Vehicular Weights, axle weights and axle spacing while this code has never been updated.

The live load effects on the bridge structure are generally influenced by the following important parameter i-e axle spacing's, span length, number of lanes, number of axles and number of vehicles. But unfortunately in Pakistan the competitions among the marketing, the illegally manufacturing of trucks with larger dimensions to carry more and more weights than legal limits and resulting in the loss in the structural strength and durability. The structure of this article is given below in Figure 1.

2 Problem statement

Two main problems are associated with the Live Load Models in Pakistan i.e.

1. Two different specifications are being used for the design of highway bridges in our country or a mixture of both the codes are used.
2. The prevailing live load models in Pakistan are not the true representatives of the actual truck traffic, as the WPCPHB LL model is taken from British code (1937) and the LRFD LL model is based on Ontario truck traffic data (1977)(2)

3 Research background

(Chan, Miao, & Ashebo, 2004) in his study, extensive (ten years) weigh in motion (WIM) data of different sites in Hong Kong were analyzed statistically and proposed a method for developing the live load model for bridge design. He proposed the Calibration Factors i.e. 1.26 to 1.5 for 10m to 40m span length bridges (3). Nowak (1993) studied the traffic data for developing a live model for bridge design. In this research for getting live load effects i-e moments and shears, he used probability paper for

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extreme daily trucks loads. This research was in continuity of research done in 1977 by Nowak and Linf for live load models on the Ontario Highway Bridge Design Code (OHBDC) but after some time this study made a Live Load Model for AASHTO LRFD. In 1977 WIM data of Ontario was studied for developing the Live Load Model but only the extreme trucks were selected for the analysis of live load effects for various bridge span lengths and this live load model is still in use of the whole USA. Nowak also studied the girders distributions factors by using of FEM for spans varying from 30ft to 200ft and for different girders spacing. By FEM, he concluded that girders distribution factors of AASHTO LRFD were on a safer side than the calculated ones. From this study the live load model was developed and still are using in whole USA. But most of the region in the USA they calibrate this live load model for their own truck traffic conditions (4).

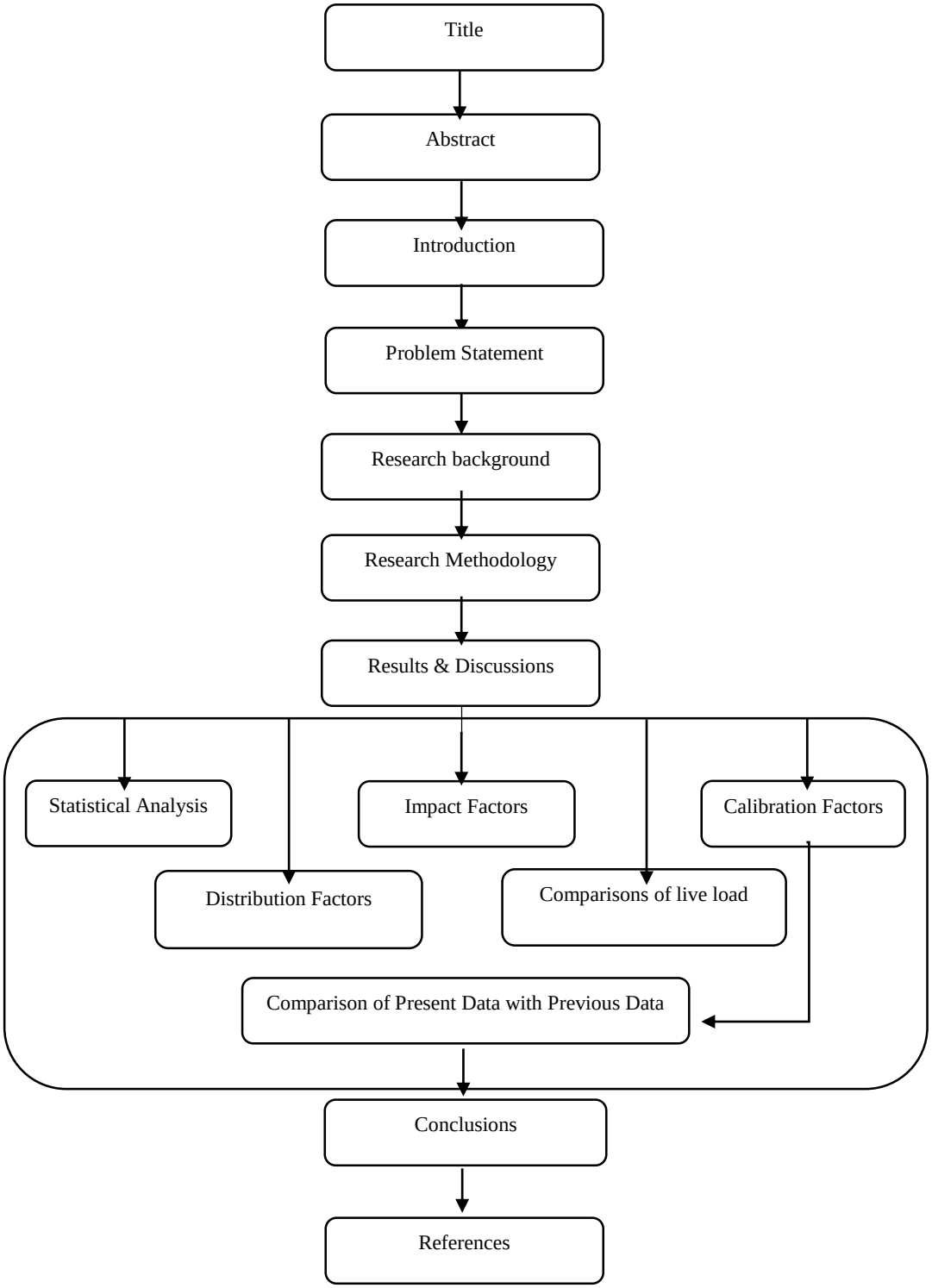

Figure 1: Structure of an article

In another local study, it is carried out by a researcher that the WIM traffic data for N-5 location. He concluded by statistical analysis that all the current traffic is overloaded compared to NHA legal Limits. On behalf of this, he recommended that the calibration factor should be 2.5 for design truck, design tandem and 0.3 for design lane. Hence, the maximum of the 2 combinations is taken for bridge design loads (5). A local study by NTRC collected the traffic data from 5 different WIM stations for studied the statistical analysis. And they concluded that the 3 axle trucks types are more than 50% which damaging the pavement as compared to others due to the small load distribution area. By volume of all trucks, more than 30% the trucks are overloaded to NHA Legal Limits while at some sections it was found the 87% overloaded of 3 axle trucks (6).

In 2015 a local researcher carried out the research for "DEVELOPMENT OF DATABASE OF HEAVY TRUCK LOAD DATA IN PESHAWAR, PAKISTAN". In this research they determine the load data, for which a portable weighing station was designed. Movable weighing station comprises of two rectangular steel plates of sizes 28" x 21" and thickness 1" considering the dimensions of loaded trucks tires and AASHTO specification. The thickness is taken as 1" as the deflection produced by the heaviest truck tire was less than 0.5".He concluded that this portable weighing system was found more flexible as compare to existing weighing stations. He also concluded that the trucks were found more over loaded than permitted NHA legal limits i-e 25% to 40%.This overloading can reduce the design life of the pavement from 15 years to 6.14 and 4.20 years respectively. Thus effective life of the road pavement is reduced from 41% to 28% .And the volume of 6-axle trucks are only 9% of the total trucks and its average weight is 78.3 tons which is 27% overloaded than NHA legal limits(7).

One of the recent researcher he carried out that for 20m to 50m span lengths the live models of WPCPHB requires an enhancement of 65% whereas the AASHTO live load model needs 35% increases to address the current traffic truck situation in Pakistan. They also recommended the 1.35 Calibration Factor for the current traffic truck situation. By these parameters, they also concluded the six-axle trucks with GVW of 40 tons live load model for Pakistan (8). In another local study it was carried out that at MMR weigh station 27.76% and 8.8% of GVW of actual trucks are higher than GVW of HL-93 and Class A respectively (9). A researcher carried out that Class AA loading may be used for a single-lane having span length less than equal to 35m while for multilane it cannot be used as per WPCPHB 1967 code. On the basis of results, he proposed the HLP-16 live model for Pakistan which is the combination of design truck and design lane load (10). According to WPCPHB code, the Impact factor formula is the based on the span length (in feet) in WPCPHB as shown in the equation below. This was taken from AASHTO standards. Although AASHTO standard specification has updated this formula based on research work it was not updated since then.

$$I = 15/L+20 \leq 0.30 \quad \text{Eq. 1}$$

Where the L is span length (Feet). A technique has been done by a Yemen researcher that enables indirect costs to be taken into account in the bridge decision- making process. He applied this technique to study the resilience of bridge during multiple hazards i-e the indirect losses is based on PBEE (Performance Bases Earthquake Engineering) methodology from the PEER (Pacific Earthquake Engineering Research) center. He concluded that the proposed methodology allows to evaluating possible solutions to strengthen the original configuration (11).

By another Yemen researcher, he studied the cost control on concrete bridges during the designing phase. He concluded the reasonable modelling for cost control of concrete bridge during designing. He proposed an alternative method of calculating costs by integrating the model of parametric approximation with the method of the unit price (12). By an Iraq researcher, he analyzed the existing composite girders bridges by finite element analysis with the help of ANSYS. He considered all composite bridges are relay on shear connectors. He concluded that the stresses in steel beam, shear connectors and concrete slab under the worst condition of loads of single truck condition do not reach to high values as compared to ultimate capacities of these materials i-e 31.47%, 35.78% and 29.91% of steel yield for load cases MS1, MS2 and MS2 respectively. He also concluded from the research work that maximum deflection is 59mm for span length of 35.75m and 55mm for load case MS1 and 53mm for load case MS3 (13).

4 Research methodology

This research includes the two main parts i-e Descriptive statistical analysis and parameters (impact factors, distribution factors, calibration factors). Secondly the comparison of live load models of LRDF, WPCPHB and Actual trucks and developing a live load model. The explanation and the flow chart are given below in Figure *2*.

- For this research, the WIM is used for collecting the truck traffic data. The parameter including is the GVW, axle spacing, axle weights, and the number of axles. In this study, only one specific location was selected i.e. N-5 MULLA MANSOOR.
- For developing or analysis of live load models the quality of WIM data is been more important. In this the data are filtered in excel for removing errors.
- The following limitations are applied during filtration of data i.e. Ignore single axle loads, Ignore the GVW less than or equal to 9 tons, No multiple presence of trucks in lanes considered, for comparison National Highway Authority (NHA) typical girders and bridge section for two lane bridges were considered, and only for short to medium span lengths (10m to 50m) were considered with 5m increment. After that filtered data are used for the analysis of short to medium bridge by using LRFD equation excel sheet i-e Line load analysis.

5 Results & discussions

5.1 Weigh data statistics

For this research the N-5 MULLA MANSOOR (North and South) data was taken from weigh station and was statistically analyzed. By volume of legal vs. overloaded, from Figure *3* it is clearly shown that the traffic is 84% overloaded while the remaining 16% is in legal limits. While traffic count by volume, the trucks are classified based on axle wise as shown in Figure *3* which is clearly shown that the three axle type of trucks is dominating in numbers i-e 60% of total traffic data. Second, most is the two axle trucks with 26%. Five axle trucks are the least

among the composition. From Figure *3* it can also be observed that over half of the vehicles are overloaded and among the 3 axle vehicles is more overloaded as compared to others.

Figure *4* shows that the Mean values of each type of truck MMR were calculated and compared with the NHA legal limits. In all cases, the mean was above the legal limit. Maximum value observed for two and three axles and six axle trucks are more than double of the legal limits which are the most killing vehicle types are shown in the graph below.

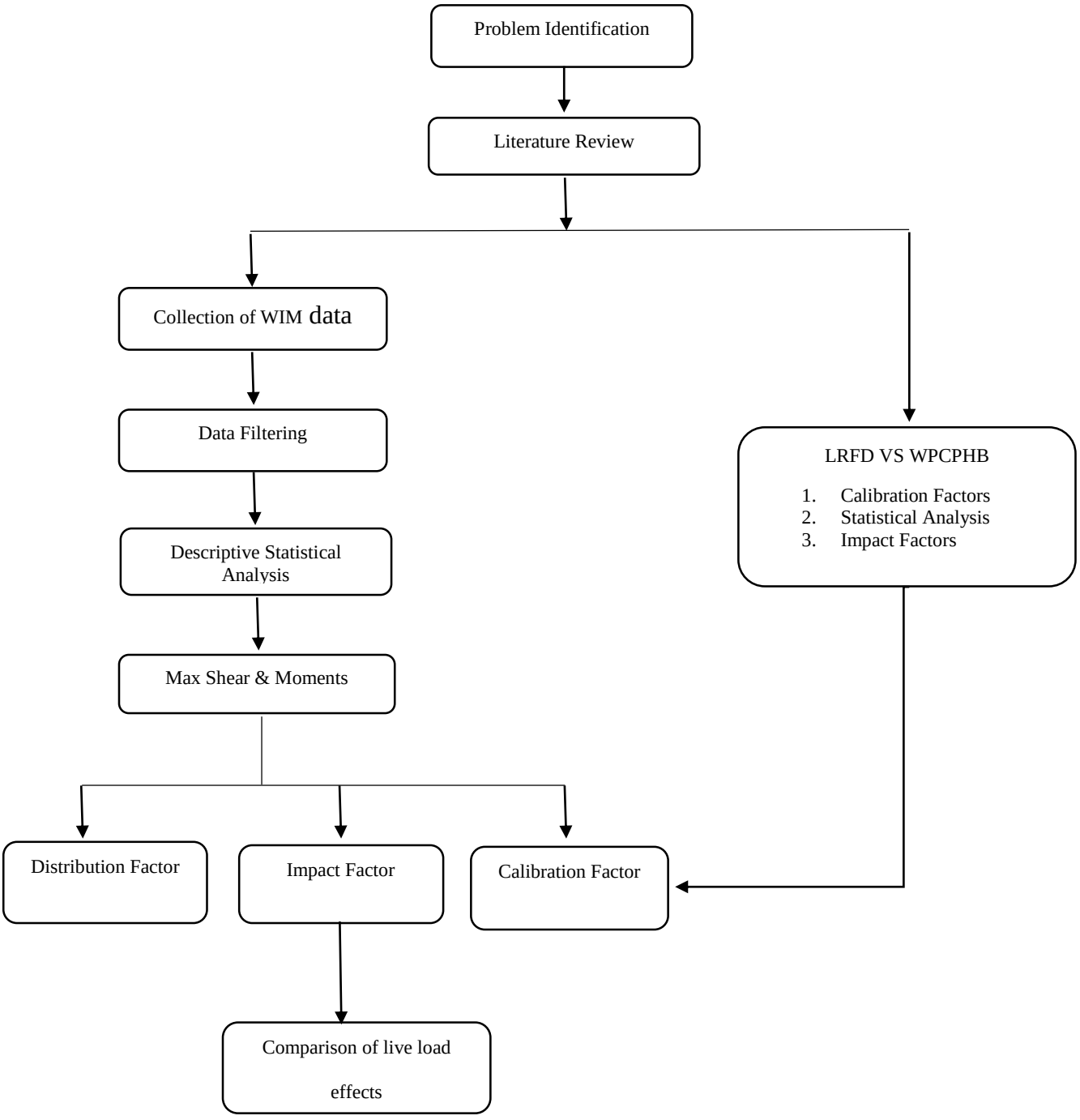

Figure 2: Research Methodology

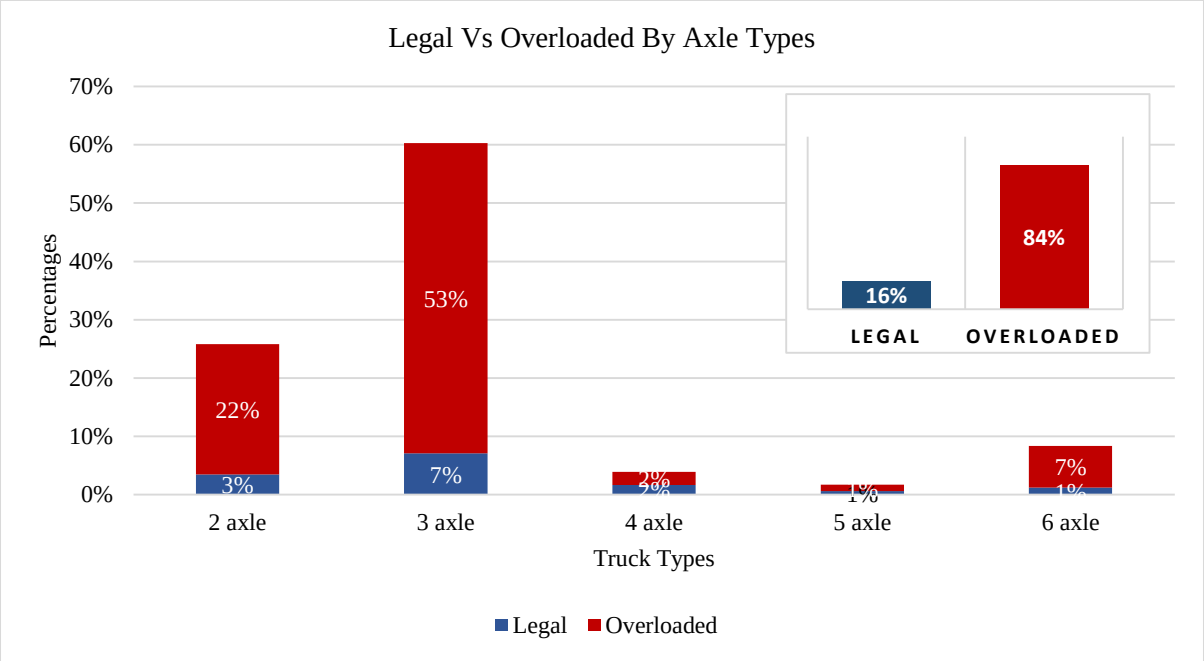

Figure 3: Legal Vs Overloaded By Axle Types

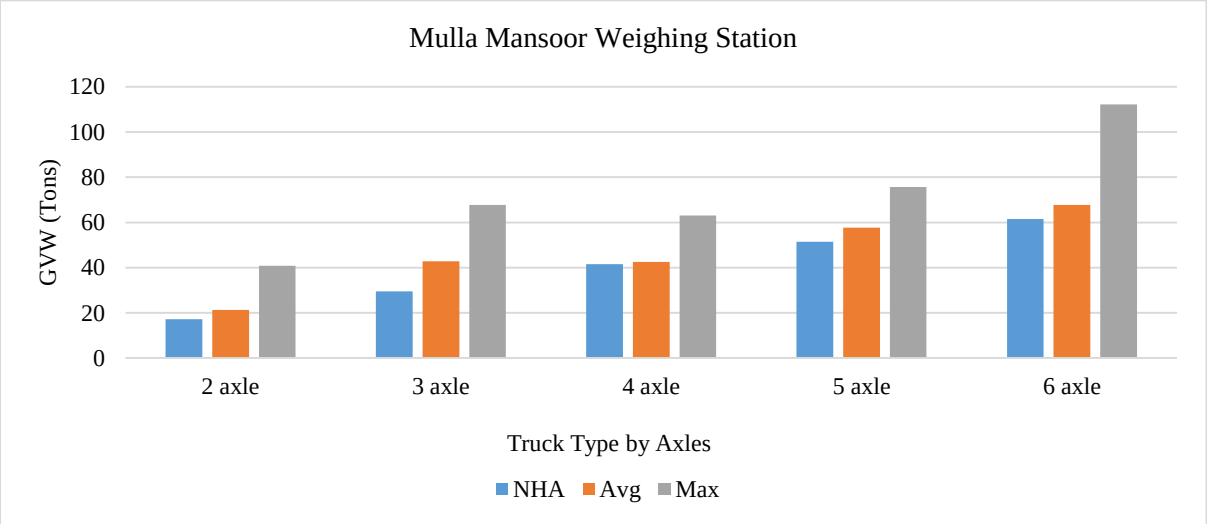

Figure 4: MMR GVW

5.2 Distribution factors

Distribution factor is an important parameter for designing of bridges which depends on girders spacing, skew angles, span lengths, etc. DF is usually found by different methods like in WPCHB it is fond by "S over D method" and in LRFD by a simplified equation. But in the "S over D" method it is used only for truck type loading but not for military tank loading i-e CLASS AA Loading. The DF from LRFD is more realistic than "S over D method" for designing purposes. For comparison of live DF of prevailing codes, a typical I-girder bridge was selected with girder spacing of 1.08m, the bridge section remains constant while only the span length varied from 10m to 50m.

5.2.1 AASHTO LRFD Distribution Factors

It can be observed from Table 1 the values of DF from S over D method are changes for Moments but in case of Shear these values are constant i.e. the Moment DF is decreasing from 0.98 to 0.639 with increasing in span lengths where in case of Shear DF is constant i.e. 0.966 while the span lengths are increasing with 5m increment. In this only 10m to 50m span length bridge are analyzed.

5.2.2 WPCPHB Distribution Factors

For the selected typical I girder bridge WPCPHB, S over D (S=3.54ft & D=5.5ft) method gives the constant value of distribution factor i.e. 0.6436 for Moments and Shears for short to medium span lengths bridges. As a result, it is not safe to be used for realistic design in current truck traffic situations in Pakistan

5.2.3 LRFD VS WPCHBP Distribution Factors

In the given below Figure 5, it is clearly shown that the DF from WPCHBP is not applicable for realistic design as compared to LRFD. While the DF from LRFD is too conservative as compared to WPCHBP for short to medium span bridge design. S over D method doesn't give realistic values as each girder in a bridge cannot have the same proportion of load effects and it is only used for truck loading not for CLASS AA Loading.

6 Impact factors

As the (WPCPHB, 1967) is not revised therefore, no research study conducted on impact factors like other codes like (AASHTO, 2007). Load effects grow with dynamic loading and this increase depends on different parameters. The WPCPHB codes have an impact factor as a function of span length for truck train loading which decays non-linearly with an increase in length. While in LRFD it gives, a fixed value of 33% for truck loading, making it uniform for all types of spans. Before LRFD i.e. in AASHTO Standard Specification, IM factor was also a function of length but it gives 7% to 9% higher value than WPCPHB for bridges over 20m spans. As compared to WPCPHB, LRFD also has the different provision of impact factor for fatigue limit state i.e. 15% allowance instead of 33%. There is no provision of impact factor for lane loading in LRFD while in WPCPHB for Class AA loading it gives 10% dynamic increment. The maximum value of IM factor is 30% for Class A loading which is 3% lower than LRFD in short spans up to 9m. A conclusive comparison is done of impact factor for both the codes and is shown below in Table 2 as well graphically in Figure 6.

7 Comparisons of live load effects

Live loads effects were calculated using the beam line analysis method, and respective impact factors and distribution factors were multiplied with them. For actual truck traffic live load distribution factors & impact factors of AASHTO LRFD were used.

It is clear from Figure 7 & Figure 8 that the AASHTO LRFD is not representing the actual truck loading in Pakistan as it is increasing with span lengths increasing.So it should need to be calibrated.It is also clear that the average trucks are above of both codes which are too much critical condition for highway bridges in Pakistan.As well as from graphs of moments and shears it is also clear that WPCPHB 1967 is much lower than all the loads which is also not representing trucks loading in Pakistan,so it is not a safe method for the realistic design of short to medium span lengths highway bridges in Pakistan.

Table 1: LRFD Live Load Distribution Factors

Span length	10m	15m	20m	25m	30m	35m	40m	45m	50m
M	0.98	0.814	0.817	0.769	0.732	0.703	0.678	0.657	0.639
V	0.96	0.966	0.966	0.966	0.966	0.966	0.966	0.966	0.966

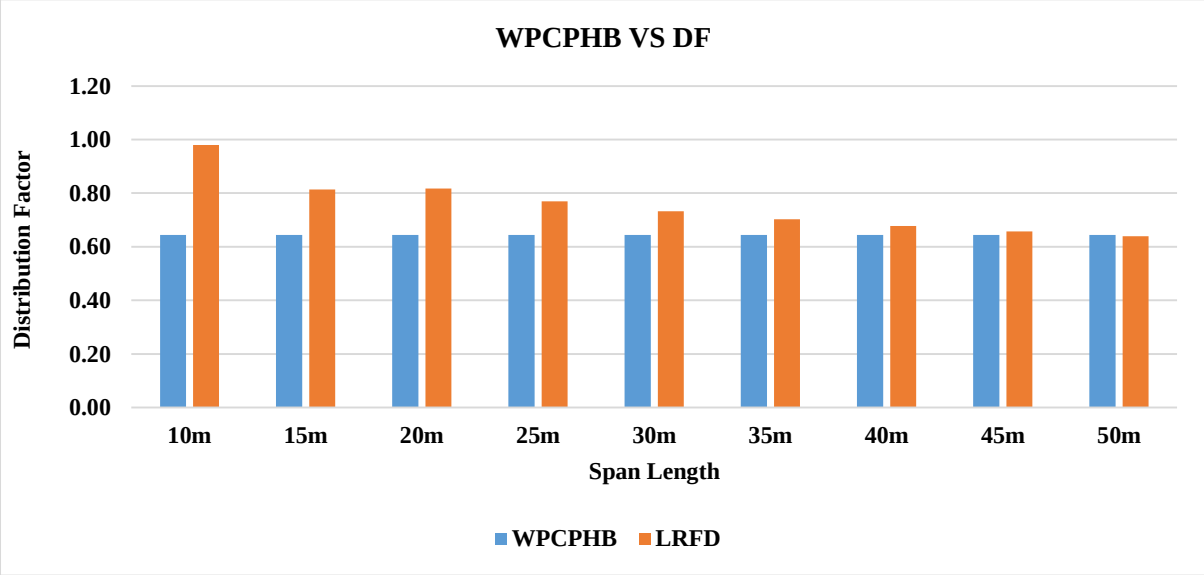

Figure 5: WPCPHB vs LRFD DF

Table 2: Impact Factors

Span Lengths	10m	15m	20m	25m	30m	35m	40m	45m	50m
LRFD	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Class A	1.28	1.22	1.18	1.15	1.13	1.11	1.1	1.09	1.08
Class AA	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

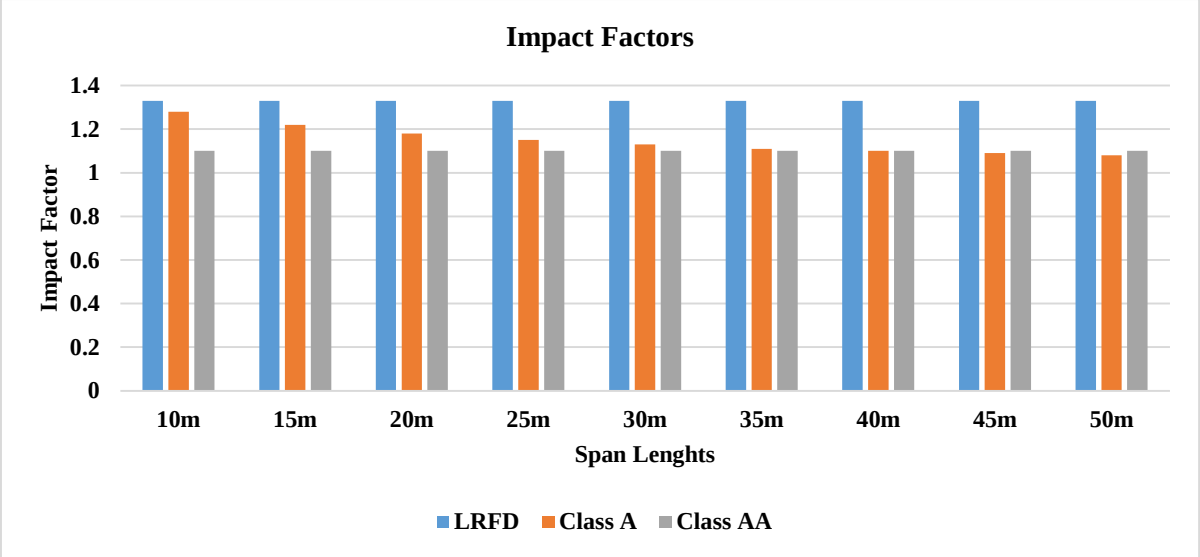

Figure 6: Impact Factors

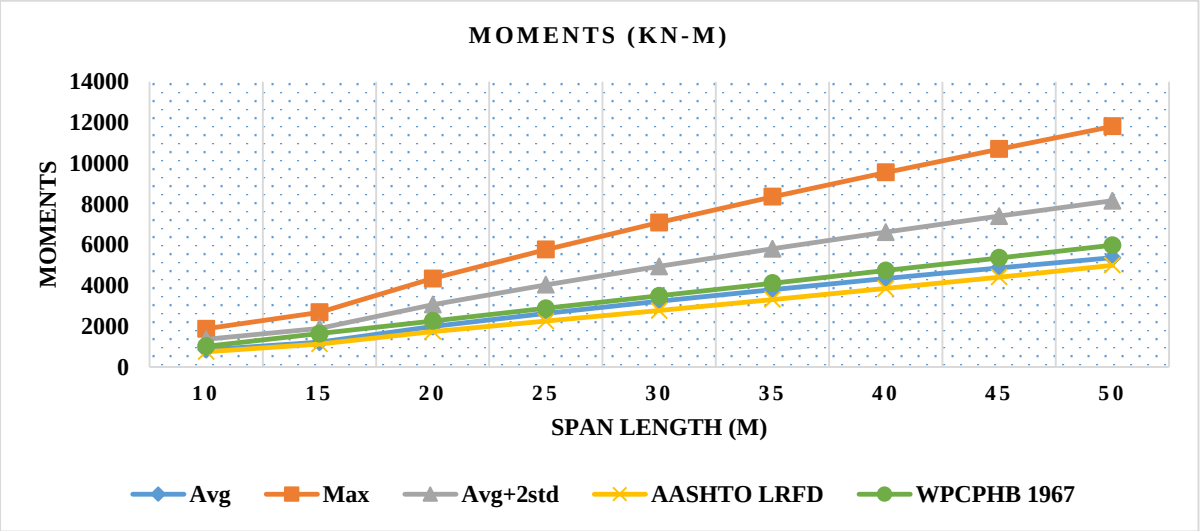

Figure 7 Comparison of Moments

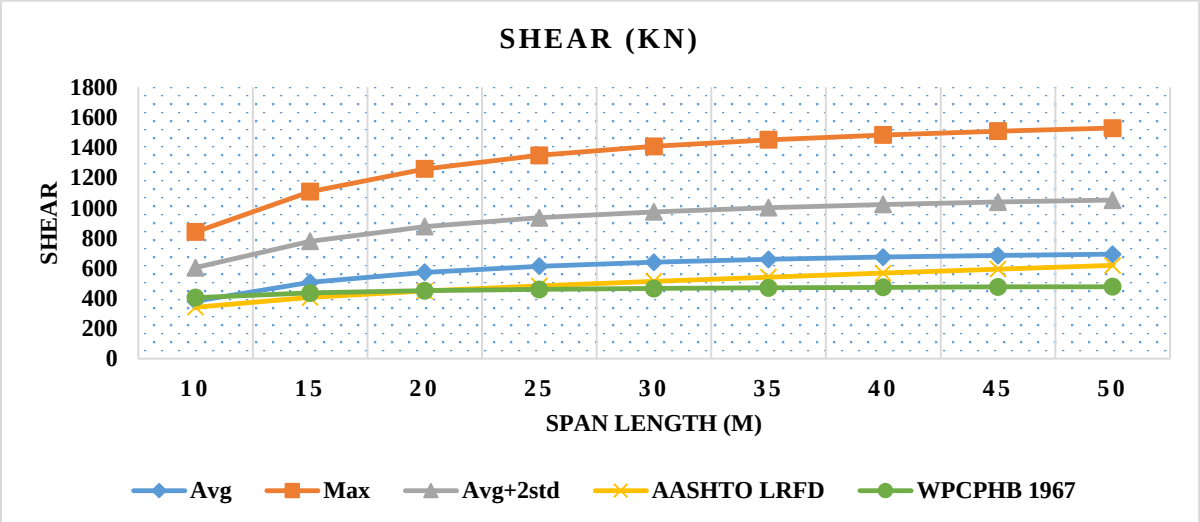

Figure 8 Comparison of Shears

8 Calibration factor

Calibration Factor "r" is the ratio of maximum load effects of actual trucks traffic load (avg+2std) with renowned code i-e Shear and Moment of WIM of traffic to the maximum live load effects of renowned codes. Many developed/advanced countries have their own updated bridge design codes based on prevailing traffic loadings so generally they don't need any Calibration factor. But in developing countries like Pakistan which are still using WPCPHB (1967) which do not fulfill the Traffic demand now-days. So they need to calibrate these live load models. The following are the "r" based on Line load analysis for 10m to 50m span length with 5m increment. For this study the WPCPHB, AASHTO, and Actual traffic data i-e Avg+2Std is done for comparison. Distribution factors and impact factors for actual trucks were used with respective prevailing codes i-e WPCPHB and AASHTO LRFD. The calibration factors proposed for short to medium span length bridges for WPCPHB & LRFD are 1.35 and 1.7 respectively. In case of analysis for moments and shears for short to medium span length bridges (10m – 50m) the following power equations (Eq. 2 and Eq. 3) can be used i.e.

$$\text{Moment (KN-m)} = 1555.2L^{0.7848} \quad \text{Eq. 2}$$

$$\text{Shear (KN)} = 821.47L^{0.1669} \quad \text{Eq. 3}$$

In the above equation "L" is span length in meters.

9 Comparison of present data with previous data

Some previous parameters are compared with some present research work i-e; From 2017 (14) research studies it is compared the statistical analysis data with present data's analysis and NHA from which it is clearly seen that all axles types are overloaded in 2017 as well as in the present situation as compared to NHA legal limits as shown in *Figure 9*.

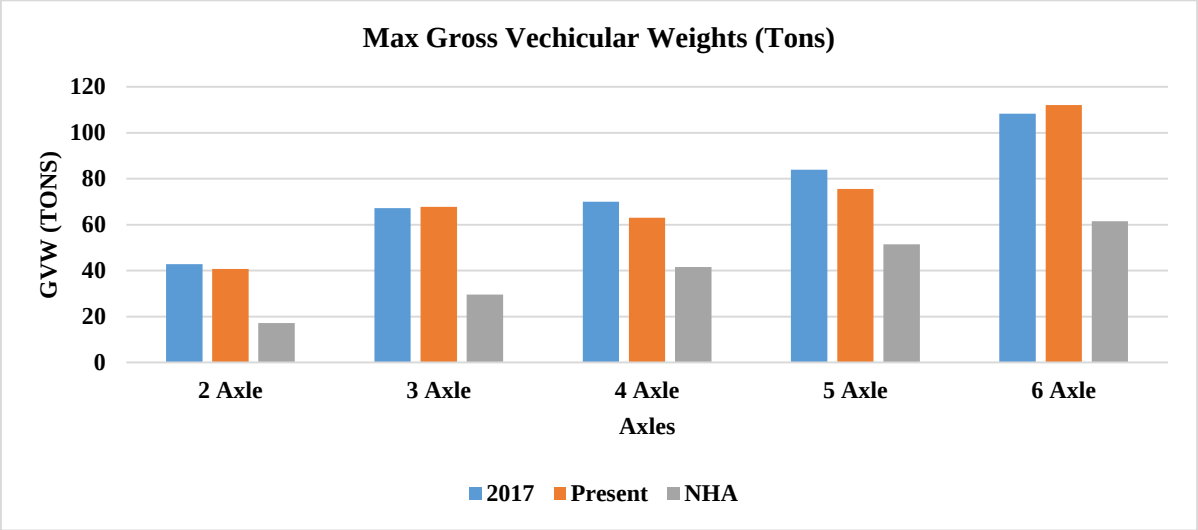

Figure 9 Comparison of Gross Vehicular Weights

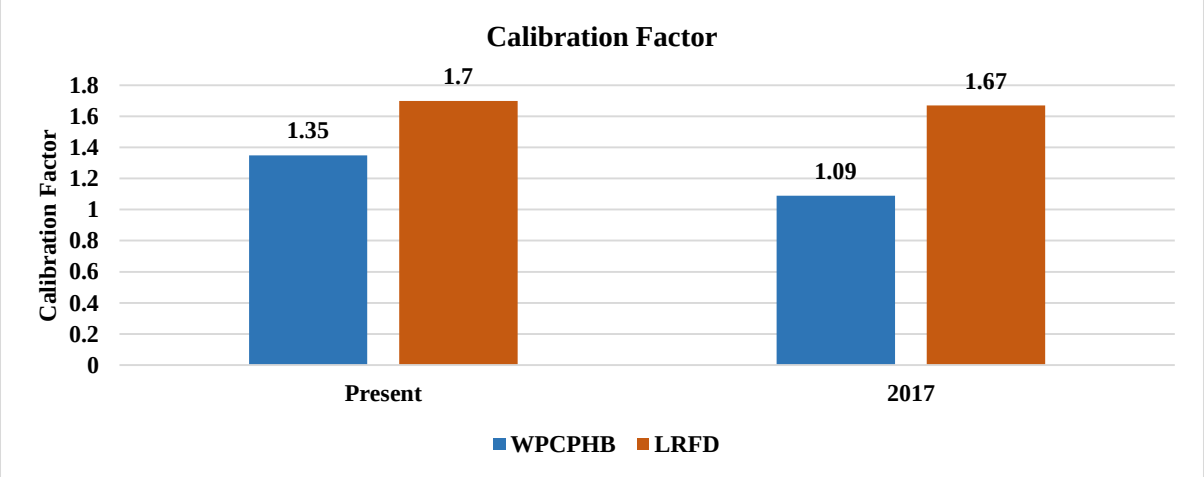

Figure 10 Calibration Factors comparison

From the *Figure 10* it is clearly seen that in 2017 (14) the calibration factor proposed for WPCPHB and LRFD was 1.09 and 1.67 respectively and in this research work the C.F is 1.35 and 1.7 respectively, which means that the WPCPHB and LRFD live loads should be enhanced by 35% and 70% respectively for the analysis and design of short to medium span lengths bridges in Pakistan.

10 Conclusions

On the basis of this research work it is concluded that AASHTO LRFD and WPCPHB live load models are not representing the prevailing traffic in Pakistan and shall be proposed a new live load model for Pakistan current condition. From the above statistical analysis it is clearly seen that actual vehicle weights are over than NHA legal limits. From WIM data analysis it is clear that 84% trucks are overloaded in which the three axle type of trucks are dominating in numbers i.e. 60%.Thus heavy vehicles are making problematic for bridge design in Pakistan. On the basis of all results of DF from LRFD equations can be used instead of DF from WPCPHB. From observation of current truck traffic data the DF from both codes need to be evaluated through field testing and this will be much better for realistic designing. From the results of Impact factors it is clearly seen that the impact factor is neither revised nor calibrated like AASHTO code. While in WPCPHB has an impact factors which depends on span lengths and it decays non-linearly for CLASS AA loading with increasing in span lengths, thus both codes amendment to overcome the deficiency. From moments and shears diagram it is clearly shown that truck traffic loads are overloaded than codes i-e 7% to 16% and 11% to 27% respectively. It is concluded that from "line load analysis" the LRFD distribution factors values are higher than WPCPHB. Both of these codes cannot be used for realistic design of highway bridges in Pakistan so it needs to be calibrated for designing purpose.

From the results it is concluded that the Calibration Factor for WPCPHB & LRFD IS 1.35 AND 1.7 respectively. From all above results it is concluded that a live load model should be proposed for prevailing live load models in Pakistan for current traffic situation.

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