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Impact of Overloaded Vehicles on Flexible Pavement: Case Study of Belhiya-Butwal Road in Nepal

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Abstract:
The traffic volume along major Highways is rapidly increasing due to the increase in economic growth in Nepal. Similarly, the proportion of freight traffic is also in the growing trend. Previous studies on the axle load survey had unveiled that significant proportion of freight vehicles are found beyond the permissible axle loads. It has been understood that major cause of pavement failure is due to the vehicle overload. This study is aimed at the determination of impact of axle load intensity to the pavement structure which is related to its service life and cost of its strengthening.
The quantitative analysis technique for identifying the axle load impacts on the pavement structure at Belhiya-Butwal Road Section has been adopted in this study. The loading pattern for each vehicle type was categorized into the three types as fully loaded, partially loaded and empty. These loading patterns have been considered in terms of equivalent standard axle load (ESAL). ESAL shall be properly taken into consideration during the design of the new pavement as well as strengthening of existing.
The study has unveiled that freight vehicle loading spectrum significantly vary according to the number of axles and wheel configuration. The front axle loads of all observed samples were found within the maximum permissible load limit i.e. six tones. The loading pattern for rear single axle (for two-axle truck) and tandem axle types was found significantly higher than the permissible loads. The study found that the overloaded truck-traffic caused the reduction in the service life of the pavement by 29.6 % less than the expected design life for the case of standard axle loading. The cost of the pavement strengthening becomes 29.73% more with the increase in the axle load intensity. The study has raised the issues of proper considerations of ESAL during the pavement design and the development of effective axle load control mechanism.

Keywords: *Vehicle damage factor, permissible axle load, standard axle load, vehicle overloading*

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I. Introduction

Flexible types of pavements are those which have low flexural strength and wheel load is distributed from grain of mineral components of the pavement layers. Design life (or design period) is the time from original construction to terminal condition for a pavement structure. A terminal condition refers to a state where the pavement needs reconstruction. Road infrastructure is used by various types of vehicles among which heavy vehicles imposes the most critical loading, causing damage in pavement structure, which ultimately leads to an increased maintenance and rehabilitation costs. During the design of road pavements, each type of vehicle is converted into Equivalent Standard Axle Load (ESAL) to consider their impact on road structure [1].

During the life of pavement, various types of vehicles pass on the design lane and numerous factors influence pavement damage. Traffic loading on road pavements is characterized by a number of different types of vehicles with variations in load magnitude, number of axles and axle configuration. The increasing axle load and/or total vehicle weight shortens the pavement service life and increases the departmental cost to maintain pavement condition at an acceptable level. It is expected that the impact of overweight truck on pavement service life is affected by pavement structure, traffic characteristics and overweight percentage. It was found that the greater increasing of Gross Vehicle Weight (GVW) led to significant decreasing of the pavement service life and more overlays [2]. It was also found that the effect of vehicle loads was diminished by increasing the asphalt layer thickness and sub-grade stiffness and little effect on the impact of vehicle loads, if the pavement distress is fatigue cracking [3].

Fatigue criteria determine its failure on pavement with sub-grade modulus otherwise its failure criterion is based on pavement deformation. Thicker pavement has higher Equivalent Axle Load Factor (EALF) when its failure is permanent deformation otherwise EALF is lower. Total number of standard axle load is a parameter used for designing of a new pavement structure or showing its remaining life in service pavement structures [4]. The pavement structure considered in the analysis includes flexible pavement and composite pavement with different distribution patterns were observed between the overweight and non-overweight traffic in terms of truck classes and axle load spectra. In general, it shows that 1% increase of overweight truck may cause 1.8% reduction of pavement life [5].

In consideration of above phenomena, axle load is duly considered during pavement design. It is obvious that the higher the load or pressure from the vehicle is, the need for the thicker pavement structure is there. Though there is legal provision for maximum permissible axle load of 10.2 tonnes in Motor Vehicle and Transport Management Regulation-1994 (MVTMR-1994). The maximum permissible axle load or GVW should be supported with the existing axle load pattern in the country and practices adopted in the neighbouring country, like India, to address the cross-border freight movement.

An axle load survey conducted by the Department of Roads (DoR) in 2010 has revealed that about 30% of commercial heavy vehicles are overloaded beyond the permissible axle load. Freight movements of construction materials and industrial raw materials are main commodity causing overloading problems. Overloading of such freight movement is quite often international from the truck entrepreneurs to get more benefit from the trip. In this way, overloading has greater loss of the public economy due to early pavement damage, high maintenance costs as well as it has high operating cost for service provider.

The traffic volume along the major Highways in Nepal is increasing rapidly. At the same time, proportion of overloaded vehicles in traffic system has been significantly rising. Relatively the movement of industrial as well as construction materials by using multi axle heavy vehicles is very common. Due to these overloaded heavy vehicles, the road pavement is deteriorating rapidly with rutting, fatigue cracking and potholes along the Belhiya-Butwal road section. The commodities loaded on the freight vehicles also affect the loading pattern. Ultimately, this phenomenon made premature failure of the flexible pavement. Such pavement failure is related to the loss of service life and increasing cost of maintenance or overlay. The first and most important issue to be considered is the determination of loading pattern and impact of overloaded heavy vehicles along this road section.

The main objective of the research is to determine the impact of overloaded vehicles on the service life and cost implications of flexible pavement in Belhiya-Butwal Road. The specific objectives of the study are as:

- To analyse the volume, composition and loading pattern of heavy vehicles on Belhiya-Butwal section of road.
- To analyse the impact on service life of the flexible pavement used in that road due to overloaded vehicles,
- To compare the cost variances on flexible pavement due to standard and overloaded vehicles.

II. Literature Review

Vehicles are at present classified into three categories under Vehicles and Transportation Management Act, 1993 as heavy, medium and light vehicles. This classification is based on the gross vehicle weight. The heavy vehicles are those vehicles whose gross vehicle weight is more than 10 tonnes. It can be any vehicle with two axles fitted with pneumatic tires like truck, bus, crane, tanker, tractor-trailer, etc. For the purpose of this policy, it can be any construction equipment whose operating weight is more than 10 tonnes. The medium vehicle is that category in which vehicles has GVW of more than 4 tonnes and less than 10 tonnes. Mini trucks, buses, jeep, pickup are fall under this category. Light vehicle category includes the vehicles with the GVW of less than 4 tonnes. Car, Jeep, Motor-Cycles, Pickups generally fall in this category.

Permissible axle loads

Maximum allowable axle load is fixed by the regulations as 10.2 tonne. Furthermore, this axle load has been elaborated in the axle load control guidelines approved by the Ministry of Physical Infrastructure and Transport (MoPIT) as per the number of axles and wheel configurations. The axle load regulation is implemented by the Department of Transport Management (DoTM). Permissible axel load as per the wheel configuration is shown in

Table **1**.

Table 1: Permissible Axle Load and GVW (tonne)

S.N.	Wheel Configuration	Max GVW,t
1	Two-axle	16.2
	Two tyres on front axle	6
	Four tyres on rear axle	10.2
2	Three-axle	25.0
	Two tyres on front axle	6
	Eight tyres on rear tandem axle	19
3	Four-axle (12-wheel with rear tandem)	31.0
	Front axle two tyres	6
	Lift axle two tyres	6
	Eight tyres on rear tandem axle	19

S.N.	Wheel Configuration	Max GVW,t
4	Four-axle (14-wheel with rear tridem axle)	30.0
	Front-axle two-tyres	6
	12-tyres on rear tridem axle	24

Source: Axle load Control Guidelines [6]

Vehicle Loading Pattern

A previous study of Thakuri [7] shows that the axle load survey data along the Mugling-Naubise section of the busy national highway (Prithwi Highway) shows that, 20% of 2-axle trucks are overloaded. Similarly, it was found that there is 6% of overloaded in 4-axle heavy trucks. It has been found that goods-vehicles carry higher overloading ranges from 6% to 20% along this highway.

The global scenario shows that, traffic on the road pavement is characterized by a large number of different vehicle types, and these can be considered in pavement design by using truck factors to transform the damage they apply to the pavement to the damage that would be applied by a standard axle. The truck factors to convert trucks into standard axles are defined by considering the average loads for each axle. This process includes the vehicles that travel with axle loads above the maximum legal limit. There are also a substantial number of overloaded vehicles in terms of total vehicle weight. These vehicles cause significant damage to the pavements, increasing the pavement construction and rehabilitation cost. The study revealed that the presence of overloaded vehicles can increase pavement costs by more than 100% compared to the cost of the same vehicles with legal loads [8].

One of the defects caused by heavy traffic on the road is the deformation of the pavement surface due to overloading that is more than the design load. Deterioration of pavements arises from deformation generally associated with cracking under heavy commercial vehicles. The increased traffic loading will then cause failures such as cracks and depressions on the pavement [9]. The defects that most often cause injuries to people and damage to vehicles include inadequate road shoulders, pavement surface that is uneven, improperly marked signs, malfunctioning stop lights, construction negligence, and municipal negligence. Traffic volume and size (especially for overloading) contributes to road safety and conditions. Recognizing of vehicles' uses and applications (industrial transportations) is the key for decreasing road deterioration [10].

Overloaded vehicle has a significant impact on pavement fatigue life and distress. As the studies show, the phenomena intensify when the control of traffic is poor. Increase of percentage of overloaded vehicles from 0 to 20% can reduce the fatigue life of asphalt pavement up to 50%. The calculation of fatigue life of an asphalt pavement structure used in Poland considering data from traffic management at Weigh in motion (WIM) stations indicated that the decrease of percentage of over loaded vehicles by 10% may cause the increase of service life of the pavement from 4 to 6 years [11].

Pavement Failure

The modes of failure for those material types include the fatigue of asphalt material, deformation of granular material, crushing and effective fatigue of lightly cemented material, and deformation of selected sub-grade material. The critical parameters and transfer functions for those material types and modes of failure are discussed and included in the pavement life prediction process [12].

As a developing country, in Taiwan, a large number of infrastructure projects have been undertaken in recent years. Due to these large-scale constructions, not only has the number of heavy vehicles (especially the aggregate-hauling trailers and dump trucks) grown rapidly, but the size and weight of heavy vehicles has also increased dramatically. These factors included a very serious truck overloading problem which significantly affects pavement performance and bridge safety [13].

Properly specified pavement deterioration models are an important input for the efficient management of pavement, the allocation of cost responsibilities to various vehicle classes for their use of the highway system, and the design of pavement structures. However, most empirical deterioration progression models developed to date have had limited success [14].

A recursive non-linear model was developed for the prediction of pavement performance as a function of traffic characteristics, pavement structural properties, and environmental conditions. The model developed as part of this research enables the deformation of an unbiased exponent of the so-called power law and the equivalent loads for different axle configurations. The estimated exponent confirms the value of 4.2 traditionally used. However, it should be noted that this exponent is only to be used for determining damage in terms of serviceability [15].

A procedure developed to estimate the remaining service life of flexible pavements is based upon predicted ride and distress conditions. These conditions are forecasted using equations that involve measurable values of material properties, climatic conditions and design factors. The most significant distress types affecting pavement service life were identified using a discriminant analysis approach. For each of the prevalent

Texas flexible pavements the probability of needing rehabilitation is assessed for different levels of ride and distress, using discriminant functions [16].

The existing design methods assume that the Equivalent Standard Axle Load (ESAL) are valid for all pavement structures and do not consider the thickness and stiffness of the pavement layers. The model was developed based on the tensile strain at the bottom of the asphalt layer that is responsible for bottom-up cracking in asphalt pavement, which is the most widely considered distress mode for flexible road pavements. The work developed in this study also presents the influence of the type of wheel (single and dual) on pavement performance. The result of this work allowed the conclusion that the ESALs for single wheels are approximately 10 times greater than those for dual wheel [17].

The Remaining Service Life (RSL) is the anticipated number of years that pavement is unacceptable condition to accumulate enough functional or structural distress under normal conditions, given that no further maintenance is performed. RSL is calculated from the condition of the asset during that year and the projected number of years until rehabilitation is required. Once RSL is estimated for each pavement section in the network, the section is grouped into different categories It combines the severity and extent of different distresses and the rate of deterioration. It requires development of a performance model and establishment of a threshold value for each distress type. Based on these threshold values, the current distress level and deterioration model for each distress to reach the threshold value, can be computed. The shortest of these time periods is the RSL of the pavement. The definition of the threshold value depends on the criteria used to control long term network conditions. Existing methods rely on various concepts from purely empirical to truly mechanistic. Lack of adequate preference prediction models has been the major impediment in predicting remaining life [18].

An overloaded truck has a load or gross weight exceed their maximum legal loads. In Indonesia, main factor behind the overloaded trucks is economic issues, for example the owner of commodities or truck owner attempt to minimize transportation cost by carrying an overload. On the other hand, law enforcement has not been optimal yet. Overload truck restrictions through weigh station failed to prevent it. Without further intervention by the government, the continuous use of overload truck causes a serious problem on pavement preservation and planning policy in Indonesia. To calculate the impact of overloaded vehicles on pavement structure, it can be calculating the remaining service life of the pavement. Remaining Service Life (RSL) has been defined as the estimation of total years that a pavement will be functionally and structurally in a normal condition by only routine preservation. The RSL will be calculated using Equation 1[19].

$$RSL = \frac{CESAL\ standard}{CESAL\ Overload} * DL \qquad \text{Equation 1}$$

Where RSL is remaining service life of pavement (years) and DL is design life and CESAL is Cumulative Equivalent Single Axle Load.

AASHTO (1993) developed a model to estimate the total number of traffic during the service life by using the following cumulative equivalent single axle loads (CESAL) by Equation 2.

$$CESAL = 365 * AADT * D_D * D_L G_R * VDF \qquad \text{Equation 2}$$

Where, Directional distribution factor (D_D) is 0.375 in the case of Belhiya-Butwal Road assuming the 20% of the total vehicles diverted in the access road. Lane distribution factor (D_L) is 100%. Annual growth factor (G_R) was calculated using the formula ($G_R = \frac{(1+g)^n - 1}{g}$). The growth rate is practiced to adopt as 5 percent.

The reduction of service life could be indicated by the deviation of the pavement service life due to the different magnitudes of traffic load that have to withstand by the pavement structure. To calculate the reduction of service life, a relationship between traffic load and service life is possible to be developed by using the American Association of State Highway Transport AASHTO (1993) design guide as shown in Equation 3.

$$W_p = W * \frac{(1+g)^n - 1}{g} \qquad \text{Equation 3}$$

In which, w_p is the predicted traffic load in ESAL, W is the traffic load in basic year in ESAL, g is the traffic growth rate for which type $\boldsymbol{i}$ (%) and n is service life in year.

The impact of the vehicles and mainly the overloads on the pavement performance was analysed by converting all axle loads and vehicles into a representative axle, i.e. ESAL. According to the AASHTO Guide of Pavement Structure (1993), ESAL is the ratio between the damage of the passage of an axle on pavement and the damage of a standard axle, usually the 80 KN single axle loads, passing on the same pavement. It can be presented in Equation 4.

$$ESAL = \left[\frac{P_x}{P_{ref}}\right]^{\propto} \quad \text{Equation 4}$$

Where, P_x is the actual axle load, P_{ref} is the standard axle, mainly with α = 4, even though it is recognized that there is no unique power value and it varies with pavement type, distress considered, failure level and contact stresses [20]. For tandem or tridem axles, the Equation 4 is applied for all individual axles of the axle group, meaning that for tandem axle, it is applied two times whereas for tridem axles it is applied three times.

Taking into account the type of axle, i.e. single, tandem or tridem, Language and Compilers for Parallel Computing, LCPC (1994) proposed Equation 5, for the calculation of ESAL, which it is based on Equation 4 and added the coefficient 'k' which is a function of the axle type (single, tandem or tridem), and 'α' is a coefficient that is a function of the type of pavement, most importantly the pavement stiffness. The 'k' coefficient, extracted from the French Pavement Design Guide, has been presented in Table 2.

$$ESAL = k\left[\frac{P_x}{P_{ref}}\right]^{\propto} \quad \text{Equation 5}$$

Table 2: Values of the k and coefficients for the French method

Pavement Type	α	k		
		Single axle	Tandem axle	Tridem axle
Flexible Pavement	4	1	0.75	1.1
Rigid and Semi-rigid Pavement	12	1	12	113

Source: LCPC (1994)

Because of the effect of one load on pavement can be completely different on another pavement, coefficient 'k' of Equation 6 must quantify this effect. Also, the effect of a single or dual load have different effects on the pavement, coefficient 'k' can also be used to measure this effect. Thus, Pais & Pereira (2018) proposed a model to calculate the coefficient 'k' as function of the pavement composition, axle type and wheel load based on a mechanistic analysis of an extended set of different configurations of pavements, type of axles and wheels.

$$k = a_1 * (H_{asp})^{a_2} * (H_{gra})^{a_3} * (E_{asp})^{a_4} * (E_{subg})^{a_5} * e^{(a_6 ALP)} \quad \text{Equation 6}$$

$$ET = \sqrt[3]{\frac{(H_{asp}{}^3 * E_{asp} + (H_{gra})^3 * E_{gra}}{E_{subg}}} \quad \text{Equation 7}$$

where, H_{asp} is the thickness of the asphalt layer (m), H_{gra} is the thickness of the granular layer (m), E_{asp} is the stiffness of the asphalt layer (MPa), E_{subg} is the stiffness of the sub-grade (MPa), ALP is the Axle Load Parameter as defined in
Table **3**. The values of a_1, a_2, a_3, a_4, a_5, a_6 and ET (Equivalent Thickness) are given in
Table **4**, where the value of α is 4.

Table 3: Axle Load Parameter (ALP)

Single axle Single wheel	Single axle Dual wheel	Tandem axle Single wheel	Tandem axle Dual wheel	Tridem axle Single wheel	Tridem axle Dual wheel
1.0	2.0	2.7	4.1	3.8	5.2

Source: Pais and Pereira (2018)

Table 4 Constants for Equation 6

α	ET(m)	a_1	a_2	a_3	a_4	a_5	a_6	R^2
4	≤1.2	1.08E+01	-9.41E-01	6.69E-02	-2.85E-01	3.04E-01	-1.41E+00	0.992
	>1.2	5.20E+00	3.33E-02	1.82E-03	1.15E-01	-1.17E-01	-1.33E+00	0.975

Source: Pais and Pereira (2018)

The VDF is the multiplier to convert the number of commercial vehicles of different axle loads and axle configuration to the number of standard axle load repetitions. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the vehicle axle configuration, axle loading and terrain type from region to region. The VDF is derived from axle load surveys on typical sections so as to cover various influencing factors, such as traffic mix, mode of transportation, commodities carried, time of the year, terrain, road conditions and degree of enforcement [21].

Table 5: Table Values of Standard VDF

Vehicle Type	VDF	Remarks
Heavy Trucks (three axle or more)	6.50	
Heavy two axles	4.75	Hilly terrain 3.50
Mini trucks/tractors	1.00	
Large buses	0.50	
Buses	0.35	

Source: DoR (2013)

Cost implication due to Overloaded Vehicles

Pais and Pereira (2018) investigated the impact of overloaded vehicles using a vehicle weight database by examining the truck factors for different vehicle categories. The study concluded that overloaded vehicles increase pavement damage and life-cycle costs by about 30% compared to the cost of the same vehicles with permissible axle loads. Using the fatigue equations defined by Shell method and considering a pavement with a granular layer with 20 cm, the researchers defined the thickness of the asphalt layer (h) as expressed in Equation 8.

$$Log(h) = a + b(\log(N))^2 + \frac{c}{Log(N)}$$ Equation 8

Where, N is the cumulative number of standard axels. The constants a, b, and c are factors depending on the stiffness of the sub-grade and asphalt layer as given in Table 6. The value of stiffness of the asphalt layer E_{asp} is the stiffness of the asphalt layer andE_{subg} is the stiffness of the subgrade. This equation represents the best fit of the thickness of the asphalt layer.

Table 6: Constants used in Equation 8

Easp (MPa)	Esubg (MPa)	a	b	c
5000	20	-4.94E-01	6.63E-03	-2.79E+00
	40	-2.66E-01	5.32E-03	-4.49E+00
	60	-8.48E-02	4.53E-03	-5.91E+00
	80	1.22E-01	3.67E-03	-7.44E+00
	100	2.80E-01	3.12E-03	-8.71E+00
	120	3.10E-01	3.18E-03	-9.23E+00
	140	3.99E-01	2.95E-03	-1.01E+00

Source: Pais and Pereira (2018)

Thus, the study of impact caused by overloaded vehicles has been made by calculating the pavement thickness required to support the traffic which includes the vehicles with legal (permissible) loads and overloaded vehicles. For determining the cost increment due to the overload vehicles, the cost of the construction is calculated both conditions of fatigue laws [8].

III. Methodology

The study adopted the method of quantitative analysis of the axle load survey data then identifying the impact of the axle load on the flexible pavement for the Butwal-Belhiya road section.

The study has conducted the axle load survey data of 2630 vehicle was taken into the considerations. The study area is presented in Figure 1. The most recent axle load survey data was referenced from the Department of Transport Management (DoTM).

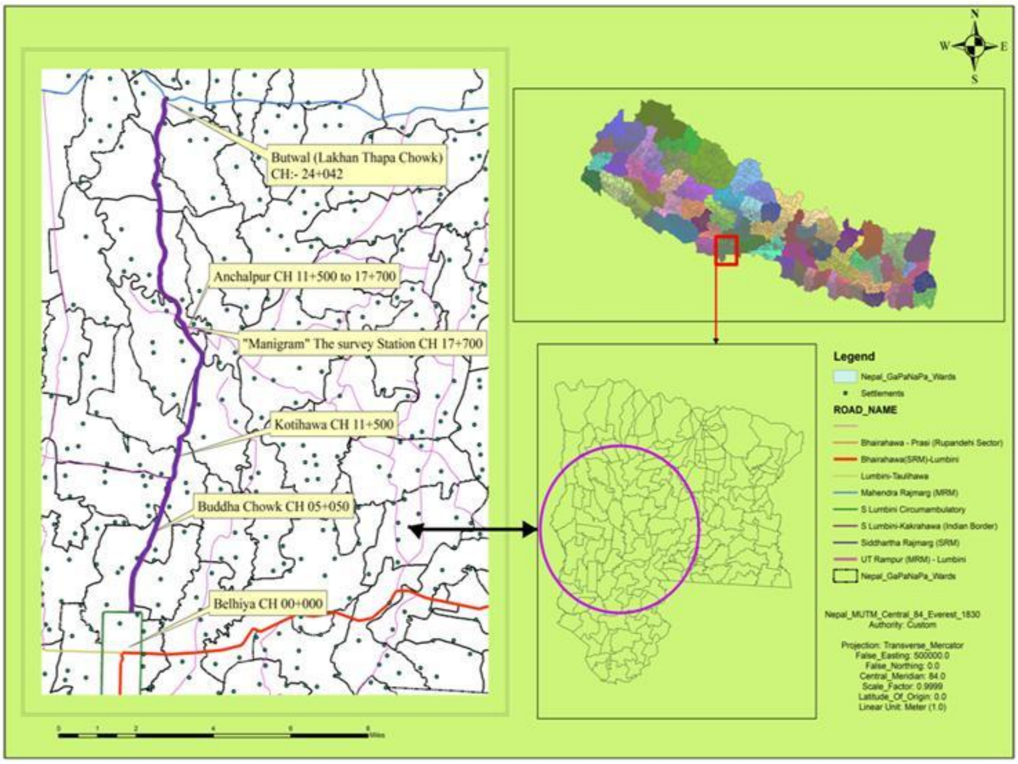

Figure 1: The Study road section

Axle load pattern:

The axle load pattern was determined from the analysis of axle load survey data which was comprised of weights of front and rear axles (tandem/single) and the gross vehicle weight. Each vehicle has been differentiated as the empty, partially loaded and fully loaded trucks. The axle load was compared with the permissible axle load limits and equivalent factors were determined by the statistical analysis. On the basis of median value of axle-weights of all trucks, ESAL values of all axles and gross vehicle weight were determined using the combined model of AASHTO (2013) and Pais and Pereira (2018) as presented in Equation 5.

Coefficient 'k' has been calculated by using the existing thickness of asphalt (H_{asp}) and granular layer thickness (H_{gra}). Similarly, modulus of elasticity of asphalt (E_{asp}), sub-grade layer (E_{subg}) and granular layer (E_{gra}) were taken from the model of Pais and Pereira (2018). Equivalent Thickness (ET) was calculated by using the Equation 7. Then it was compared with the value of 1.2 and constants a_1, a_2, a_3, a_4, a_5 and a_6 were taken form the

Table **4**. Then the coefficient 'k' was calculated using the Equation 6. After the determination of the coefficient 'k', all the ESAL values were determined using Equation 5.

The pavement design life (DL) period was taken as 10 years. Using the values of VDF as in the Table 5, predicted traffic volume the cumulative equivalent standard axle load (CESAL) for both standard and overloaded condition were determined using Equation 2.

The Model developed by Jihanny, Subajiyo and Hariyadi (2018) was used for the calculation of remaining service (RSL).

For analysing the cost variances on flexible pavement due to the overloaded vehicles, thickness (h) of overlay was calculated. The ESAL values for standard and overloaded condition were calculated using the Equation 5. On the basis of modulus of elasticity of sub-grade (E_{subg}) the constants a, b and c were determined. Using the Model developed by Pais and Pereira (2018), the thickness of overlay was calculated using Equation 8. The analysis of axle load pattern and overloading has been considered for two and three axle trucks.

IV. Results And Discussion

The results of the study are comprised of mainly breakdown of traffic flow as per the loading intensity and loading pattern (fully, partially and empty) as well as the method of calculation of remaining service life. Similarly, the study has unveiled the method of determining the VDF for particular type of vehicles and the cost implications of overloaded vehicles.

Vehicle Composition and loading pattern

The axle load survey data of 2630 heavy vehicles was analysed for the various loading pattern and axle configuration. The composition of the study traffic is shown in Figure 2.

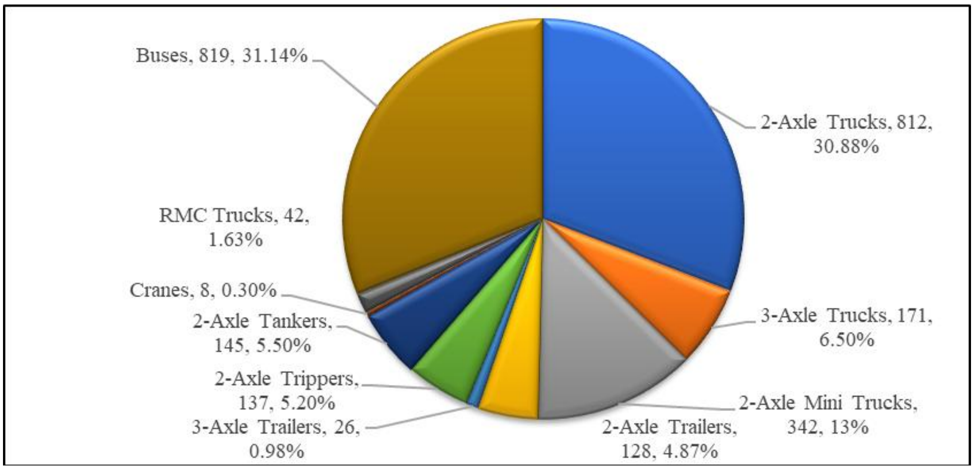

Figure 2: Vehicle Composition in the study road section

In the study road-section, it has been noted that the freight vehicles are more than the passenger vehicle due the road is connecting the cross-border trade route. Major commodity for the trucks is the industrial goods and raw-materials imported from India. The vehicle loading condition has been separated as empty, partially and fully loaded and overloaded for the analysis of loading pattern. The percent of empty, partially loaded and fully loaded were found as 16.27, 18.56 and 65.17 percent respectively.

Vehicle overloading was analysed as per the axle configurations. It has been found that 11.5 % two-axle trucks were overload on front axle. Similarly, 48.3 % of rear axles of the similar type of trucks were found overloaded. Similarly, it has been found the 32.6 percentage of trucks were found overloaded considering with the gross vehicle weight (GVW) limits as shown in

Table **1**. In the case of three-axle trucks, the front axle and tandem axle were overloaded by 13% and 38.30% respectively. The GVW of three-axle trucks was found as 27.97% more than the permissible load limit. Loading intensity of fully loaded, partially loaded and empty trucks on front and rear axle is shown in Figure 3.

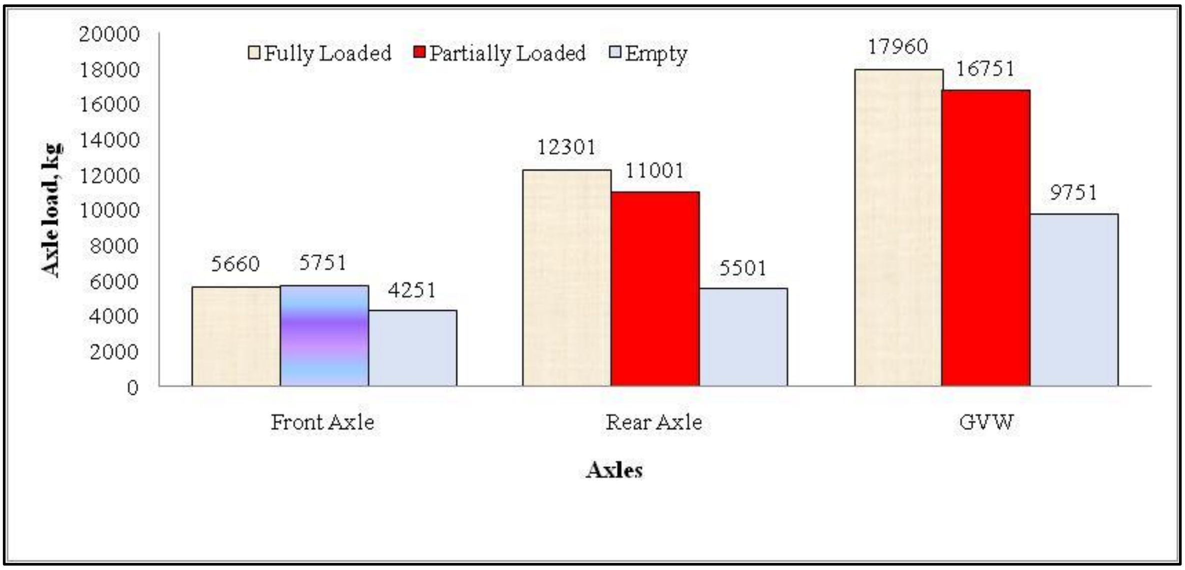

Figure 3: Axle load intensity of two-axle trucks

Load distribution of two axle trucks was plotted in the cumulative percentile graphs as in Figure 4. It was found that 72 percent of rear axles of the two-axle trucks were exceeded the permissible axle load of 10.2 tonne.

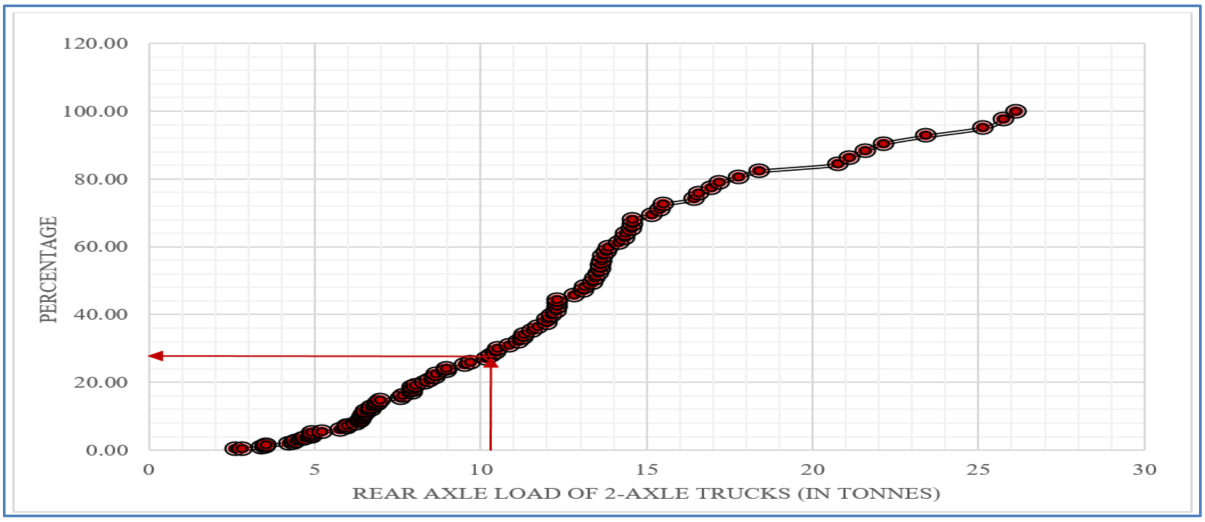

Figure 4: Rear axle load in percentile distribution of two-axle trucks

It has been noticed that the most overloaded commodity causing vehicle overload are cargo of cement, potatoes, steel rods, urea (fertilizer), fodder, sand, bricks, wheat flour, gravel, rice, and etc.
After the statistical analysis of individual axle loads by using the coefficient 'k' of Pais and Pereira the ESAL factor for each group was calculated and presented in Figure 5. It has been concluded that the ESAL for two-axle truck differs as per the loading conditions (partially or fully loaded).

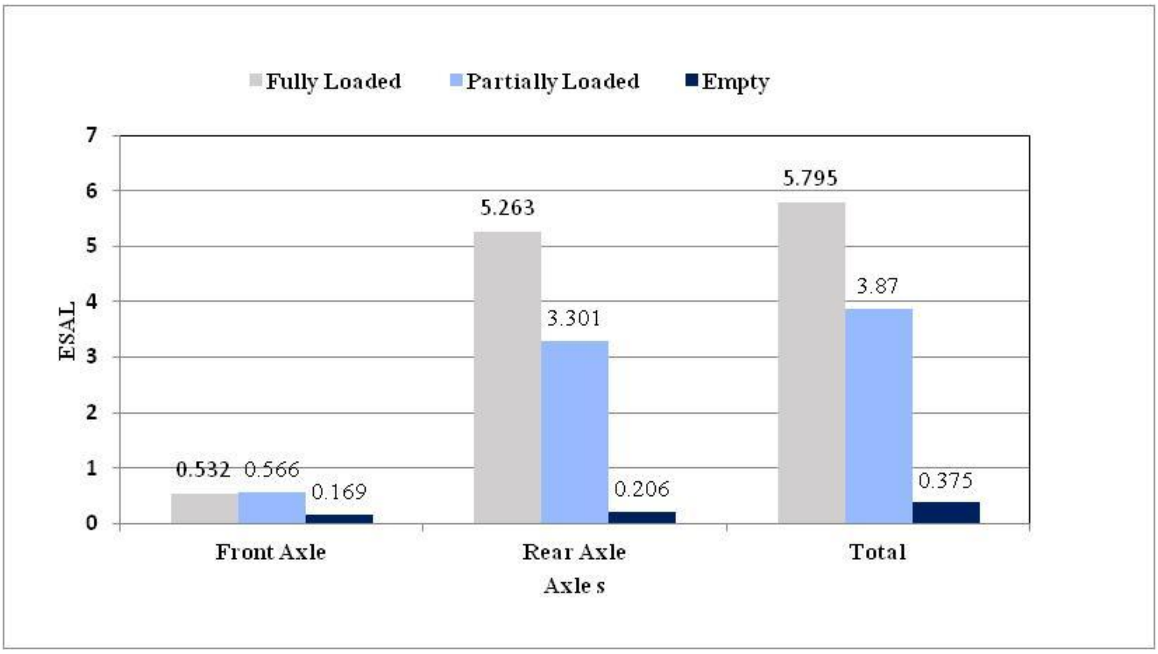

Figure 5: ESAL factor distribution for two-axle trucks

The composition of the three-axle trucks is relatively low (only 7.5%). However, axle load as per the tandem axle configurations shall be taken into considerations for the accuracy of the loading analysis. The average of GVW data along the study road-section was found 28.61 tonne whereas the permissible limit for this group is only 25.00 tonne. The averaged axle load distribution of three-axle trucks is presented in Figure 6.

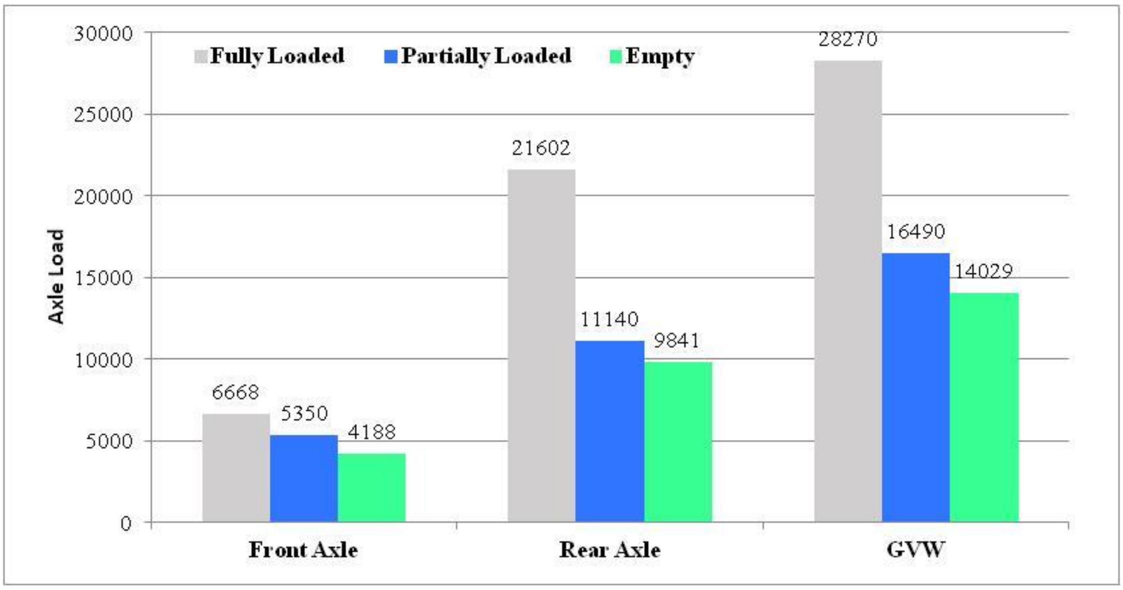

Figure 6: Axle load distribution of three-axle trucks (with tandem)

The ESAL factor was calculated for all loading conditions of three-axle trucks and is presented in Figure 7. The maximum ESAL factor for fully loaded trucks was found to be 8.028. The average ESAL factor was found to be 8.028 which exceeded the standard limit by 6.5 [6]. The minimum ESAL 0.245 was found in empty trucks. The ESAL of front and tandem axle was found within the standard limit but the ESAL of full loaded trucks was found exceeding the standard limit. The ESAL factor distribution is presented in Figure 4.8.

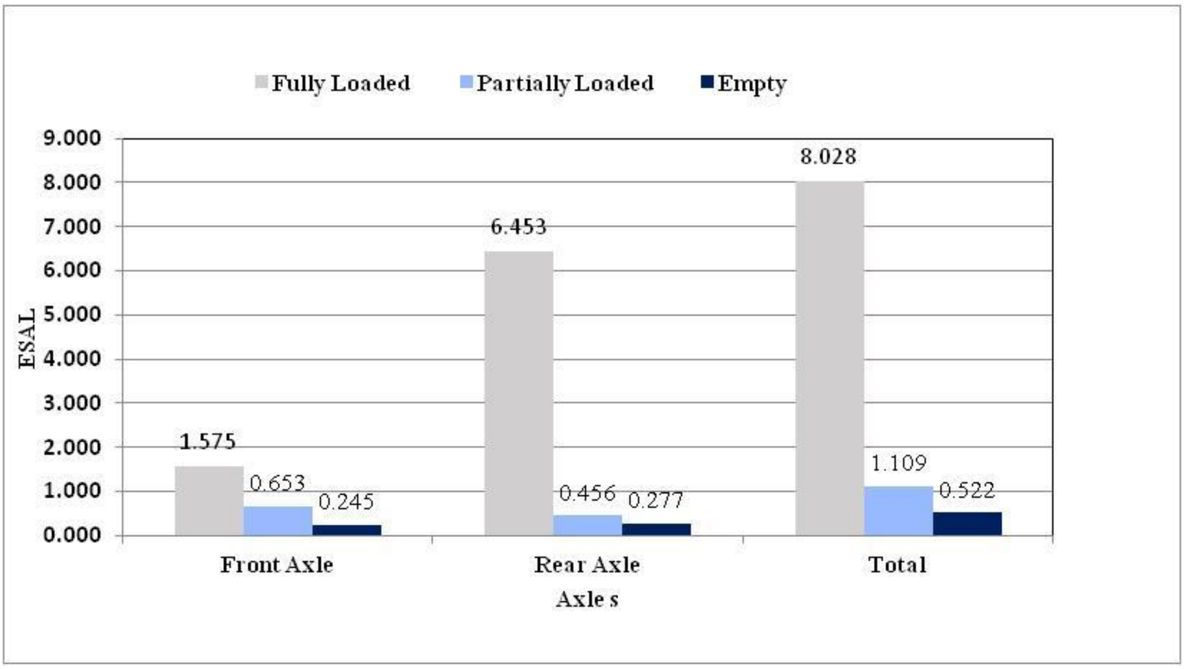

Figure 7: ESAL distribution for three-axle trucks (with tandem)

Graphical representation in above figure shows that the front axle ESAL for 3-axle trucks was found slightly more than the standard axle load limit, whereas the ESAL for tandem and gross axle was found exceeding the standard limit in fully and partially loaded conditions.

Percentile distribution of tandem Axle Load:

The percentile graph of the tandem axle distribution was plotted for the analysis of percentile of exceeding the permissible axle load limits along the study road section. The result in the graph shows that only 34% of trucks were found within legal load in terms of tandem axle and remaining 66% trucks were found exceeding the axle load limit. The percentile graph of the tandem axle of three-axle truck is shown in Figure 8.

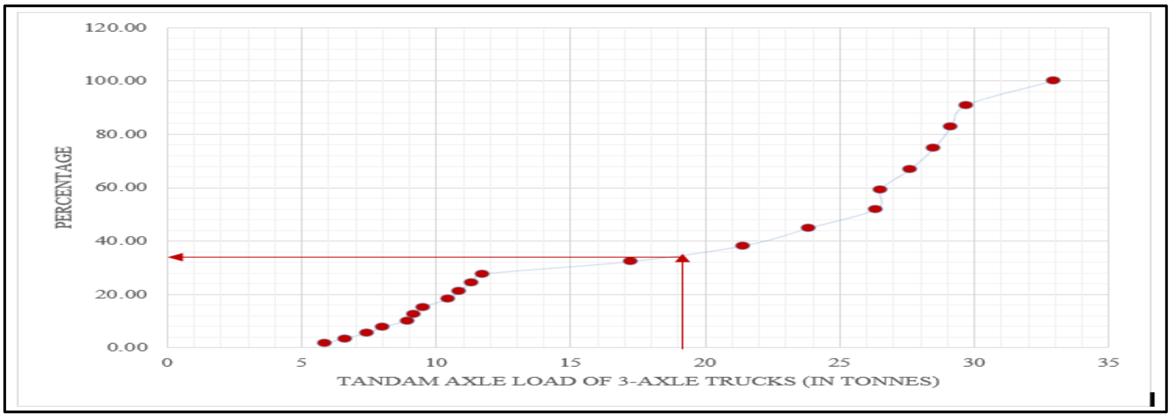

Figure 8: Tandem axle load of three-axle truck in percentile distribution

These types of truck generally carry industrial raw materials or the products such as iron-ore for cement factory, iron beams for steel industry and the steel rods.

Impact of vehicle overload on design service life:

The base year axle load per day was calculated and projected for the 10 years of design life as cumulative equivalent standard axle load (CESAL) by taking the growth rate of 5%. The CESAL for both standard and overloaded condition were calculated for design period. The model developed by Jihanny, Subajio and Hariyadi [19] was used for the calculation of remaining service life (RSL). The remaining service life (RSL) was found as 2.04 years. This study was carried out in 2018 after three years from the completion the construction. Hence, the reduction of the service life due to the overloaded vehicles was found as 2.96 years from the total design life of 10 years. The projection of the standard and overloaded freight vehicles for entire design period of 10 years is given in Figure 9.

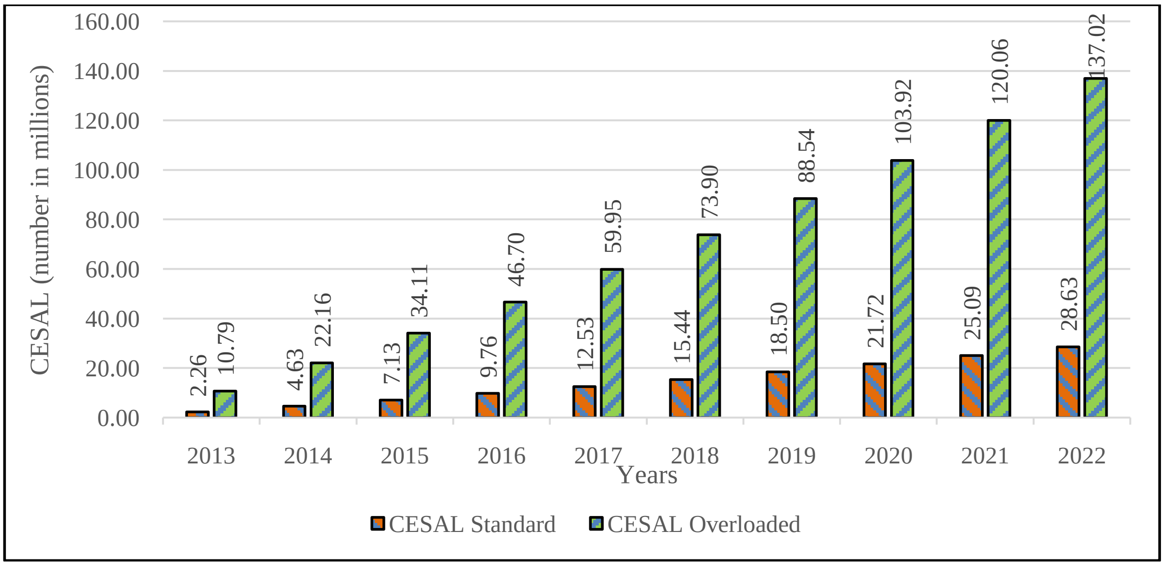

Figure 9: Calculated CESAL for both standard and overloaded trucks

Impact on vehicle overloading on the cost of the flexible pavement:

The impact of the overloaded vehicles on the flexible pavement in terms of the overlaying cost was determined by using the axle load survey data for calculation of the ESALs. Cumulative ESALs of all types of vehicles was found 10.99 million for standard loading conditions and 52.62 million for overloaded conditions. Similarly, the designed thickness was found to be 20 cm and 26 cm for standard and overloading conditions respectively. Thereafter, the cost of vehicle overlaying was found as increased by 29.73%.

V. Conclusions And Recommendations

The study was carried out to interpret the impact of vehicle loading on the flexible pavement. The axle load survey data of 2018 were analysed for this study was taken from the Butwal-Bhairahawa section of Siddharth highway in Nepal. The spectrum of impact of overloading encompassed the deduction of pavement service life and increase in the cost of construction as well as strengthening the pavement.

The loading pattern of the trucks shows that the axle load intensity is varied for each axle configurations. Most of the front axle loads are found within the permissible limits. However, the rear axles bear more loads and most of them are overloaded. The common reason of the vehicle overloading was found as the type of type of freight such as construction materials and industrial products especially the cement and steel and iron products from industrial areas.

The CESAL which is the threshold for the expected pavement life increases rapidly with increase in the axle load intensity. Hence, it causes the reduction in service life. The study unveiled that the impact of the axle load intensity caused the premature failure of the pavement. The pavement damaging effect is exponentially increased with the rate of increment in the axle load. The overloaded vehicles comprising 38.44 % in the traffic volume is reducing the service life by 49.60% of the pavement life.

The impact of the axle loads, i.e. the overloaded vehicle during the entire pavement service life, results in the poor serviceability of the pavement. This requires the frequent repair and maintenance which is related to the cost of the pavement. Furthermore, the thickness of the overlay for the pavement strengthening becomes more with the increase in axle load intensity.

The reduction of service life and the increase in the cost of pavement has tremendous impact in overall transport sector economy, which constitutes the significant portion of Gross National Product. This research recommends that the strategy for the vehicle overloading shall be developed and implemented on the basis of as been vehicle loading patter and axle load configurations.

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