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Paper Title:

Can Humans Predict the Future? Consequences of Inaccurate Traffic Forecasting

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Abstract:

In designing roads, traffic volume, traffic loading and subgrade strength are major inputs whose values bear a strong influence on the design outcome. For this reason, it is important that their values are as accurate as possible.

Inaccurate estimation of the above inputs leads to inequitable distribution of resources, reduced rate of network upgrading, early failures or overly conservative and expensive designs, and reduced benefits to the population.

This study, demonstrates the difficulty in predicting traffic growth, pavement design loading and the consequences of the estimated predictions.

Data from the Central Vehicle Registry (CVR) of Ethiopia for a ten-year period was analysed and compared to the gross domestic product (GDP) for the same period. The general growth rate of vehicles registered in the country was determined through use of the same data.

In addition, data from eight weighbridge stations around Ethiopia was analysed to compare the vehicle equivalence factors (EF) for a typical 3-axle truck, across the country. Secondly, the growth rate of heavy vehicles from one of the weighbridge stations for a period of ten years was determined. Lastly, the EFfor a typical 3-axle truck over a period of ten years at different percentiles was computed and used to determine the design cumulative equivalent standard axles and the subsequent pavement structure for a typical design period.

The growth rate of vehicles from the CVRwas found tohave a strong correlation to the GDP. The truck growth rate computed from the weighbridge station showed a weak correlation to the GDP and a different trend and growth rate from the general vehicle growth rate determined from the CVR data.The EF varied widely across all eight weighbridge stations but with a few similarities between some stations. There was a significantly different design cumulative equivalent standard axle load (mESA) obtained from the different growth rates. This led to different required

pavement structures.Additionally, the findings also showed a major difference in the computedEF from that contained in ERA’s pavementdesign manual.

The findings demonstratethe implication of the approaches used in estimating traffic loading for pavement design on the final pavement structureand consequently the designcost. Therefore, equal importance should be placed on detailed traffic studies as is done on pavement materials, especially for low-volume sealed roads.

1 Introduction

1.1 Background

Ethiopia is a country located in the part of Eastern Africa usually called "TheHorn of Africa". It is populated byover 94 million inhabitants, the second-most populous nation on the African continent after Nigeria. Ethiopia is a Federal state with 10 Regional statesand occupies a total area of 1.1million square kilometres. Its capital and largest city is Addis Ababa.Ethiopia is one of the ten fastest growing economies in Africa with average annual double digit Gross Domestic Product (GDP) growth rate for the last ten years or so. With highest attention given to the transportation development sector by the government, mega projects have been designed and are being implemented to improve accessibility within the country. The recent light railway system commissioned in the capital city, Addis Ababa, Addis – Adama Expressway, the Addis Ababa – Djibouti railway line and many other road sector development programs show the effort to improve the transportation system in the country.

The Ethiopian Roads Authority is charged with the responsibility to manage the Federal Road Network and provide technical assistance to the regional and city roads authorities implementing the Road Sector Development Program (RSDP). At the end of a long civil war and down fall of the military government in 1990, the road network was highly deteriorated and needed a major rehabilitation. Accordingly, a Road Sector Development Program aimed at rehabilitating the existing road network and creating access was launched. Throughout the last 18 years since the RSDP was launched, the road network has increased by more than five-fold. Under this program many road projects were implemented; new construction projects as well as rehabilitation projects. As a result the road network of the country has been significantly improved.

ERA, through the RSDP has developed the road network size from 26,550 km in 1997 to 110,414 km in 2015 (an increase of 316 per cent). As a result, the road density per 1000 square km has increased from 24 km in 1997 to 100.4 km in 2015.The road network distribution under the Federal Road Network is as shown inTable 1.

Table 1: Federal Road Network Classification of Ethiopia

Road Class	Description	Length (km)
A	TRUNK	5,722
B	LINK	7,791
C	MAIN ACCESS	5,919
D	COLLECTOR	3,516
E	FEEDER	4,658
TOTAL		**27,606**

The total length of low-volume roads under the Federal Road Network is 8,174km. Out of the total road network length, 14,055km are gravel roads. A significant portion of the Class C (main access roads)roads are gravel surfaced and are further classified as low-volume roads.

Thus with a large network requiring upgrade to better standards, it is important that resources are spent wisely and equitably. Since the design of roads significantly affects the construction costs, it is important that design inputs are as accurate as possible. A key input to pavement design is the design traffic. The design traffic in itself is dependent on the vehicle equivalence factors used and the forecast growth rate.

1.2 Objectives of the study

The motivation for this study comes from the lack of adequate data regarding the vehicle growth rates and the vehicle equivalence factors used in computing design traffic for pavement design. This is a problem that affects both low-volume roads and high-volume roads.

Materials characteristics, subgrade strength, climatic factors, traffic volume, traffic loading are major factors that significantly affect the performance of roads. Emphasis has been placed in materials research whilst much less emphasis has been placed in data gathering and estimation of growth rates regarding traffic.

Use of estimates that are not close to the actual rates may lead to inadequate pavement structures that fail prematurely or overly conservative pavement structures that deny other roads the opportunity to be upgraded.

This study, demonstrates the difficulty in predicting traffic growth, pavement design loading and the consequences of the estimates. In so doing it is hoped that it will encourage researchers to gather traffic data and trends in order to improve pavement designs.

1.3 Scope of the study

This study was carried out in Ethiopia, for the Ethiopian Roads Authority by the Road Research Centre in 2015. It utilizes economic data, vehicle registry data, and axle load data for the period 2005/06 to 2014/15. The study was desk-based relying on vehicle and axle load data obtained from the relevant offices and Ethiopia's economic data obtained from the World Bank website.

2 Techniques for forecasting traffic

In order to compute the pavement loading, it is necessary to know both the volume of heavy traffic and the magnitude of the loads that they carry. This makes the computation of design traffic very difficult since both the growth trend and the loading trend can change over the given design period.Robinson, Danielson, and Snaith (1998)support this difficulty noting that the problem is further compounded by the notorious variability that exists even in estimates of current flows. They further add that the problem exists both in industrialised and in transitional economies.

In order to estimate traffic growthFalck-Jensen, Kildebogaard, and Robinson (2004)advocate for dividing traffic into three categories: normal traffic, diverted traffic and generated traffic.Normal traffic growth relates to the increase in traffic volume due to the cumulative annual increases in the number and usage of motor vehicles. Diverted traffic represents the vehicles that change from analternative route between the same origin and destination as a result of road improvement. Generated traffic is the additional vehicle travel that results from road improvement. The effects of diverted and generated traffic are usually short term whereas normal traffic growth spans throughout the life of a given road; thus the need to estimate this growth rate as best as possible.

Heggie (1972) discusses two methods of forecasting traffic, forecasting models and tests of association. He further explains that forecasting models are developed from time-series analysis or from cross-sectional data analysis. He notes that the use of the statistical approach poses a difficulty in telling whether an effect has actually caused an observed change. Discussing the use of tests of association, he notes that the use of best fit lines often obscures the appreciable variations in individual cases. He further notes that economic models are better suited for sensitivity analysis than for making actual forecasts.

Falck-Jensen et al. (2004) also propose methods of forecasting traffic for the three traffic categories; extrapolation of historical time-series data, origin-destination studies for estimating diverted traffic, and demand relationships for generated traffic. They further add that recently it has become clear that there is a tendency for vehicle axle loads to grow steadily over time and forecasts are needed to avoid underestimating future pavement damage.

Bonsall (2006) subdivides models into simple formula, time-series models, moving averages, regression analysis, matrix estimating models, elasticity models and off-the-shelf package models. He points out that many models are data hungry and therefore costly to develop. This may not be justifiable in the low-volume roads context. He further adds that models are useful only if they deliver useful results on time without undue data demands, and this generally means simpler models should be preferred to complex ones. He concludes that users of models are apt to forget that models are simplifications of reality whose predictions should be treated as estimates rather than precise forecasts. This is in support of an earlier publication by Tuckwell (1980) titled "Traffic Forecasting: A Complicated Form of Crystal-ball Gazing". In this publication, given that theUK's Department for Transport forecasts were based on economic GDP, and the GDP was rising at rates between 20-50%, he advises a move away from using exploratory models to casual models. He suggests that a range of forecasts based on low and high growth should be applied to a range of possible design options. An option should then be chosen taking account of economic and environmental factors.

A major problem in forecasting traffic is that often regional or project specific data is not available; only national data is sometimes available, and this national data may not be applicable to a localised region within the country. In a situation such as in the design of low-volume roads, where it may be unjustifiable to spend large resources in traffic studies so as to get a close estimate to reality, reasonable estimates may be obtained from national or regional studies.

Causal models whether developed for a specific purpose or general purpose are costly due to the collection costs of large quantities of data. Off-the-shelf modelling packages still require collection of local data to calibrate the models.

In our study, for the reasons presented above by the various authors, we have therefore chosen to go with simple time-series analysis.

3 The East African Axle load Study

Between December 2010 and September 2011, Japan International Cooperation Agency (JICA) carried out a study "Harmonization of Vehicle Overload Control in the East African Community". In this study, axle load data was collected from selected weighbridge stations in East Africa. The results showed that in Burundi 15.6% of the axles in that station were overloaded whilst the majority of axles were between only 3 to 4 tonnes; at a station in Tanzania, 2.4% of the axles were overloaded, whilst the majority of the axles were 7 to 8 tonnes; in Uganda, 11.2% of the axles were overloaded, whilst the majority of the axles were between 7 to 8 tonnes. Unfortunately no data was presented for Kenya in the report. By comparison, in Ethiopia at the same period in one of the major weighbridge stations (Modjo), 6% of the axles were overloaded, whilst the majority of the axles were between 9 to 10 tonnes. It should be noted that in all these countries the legal limit for a single rear axle is 10 tonnes. These results show the variation of loading characteristics in a wider region even if the legal loading limits are the same. One cannot therefore only rely on legal limits for computation of the design traffic load.

4 Methodology of our study

4.1 Economic data

From literature, relationships for forecasting traffic growth rate can be computed from or correlated to Gross Domestic Product (GDP). GDP is the quantitative measure of the total economic activity in a given country. The two major forms of GDP are Nominal GDP (current prices) and Real GDP (constant prices). Real GDP factors out the effect of inflation and compares the GDP for different years from one base year; conversely, Nominal GDP considers the values for each year as they are without factoring out inflation.GDP can further be sub-divided into GDP expenditure, GDP production and GDP total. Since economic activity involves movement of goods and people, it follows then that GDP (which is a measure of economic activity) is linked to some extent with traffic growth. Ethiopia's GDP data for the period 2005/6 to 2014/15 at 2000 constant prices was obtained from the World Bank website.

4.2 Vehicle registry data

National vehicle registry data tracks the actual number of vehicles in the country on a yearly basis. This gives an indication of the vehicle growth rate nationally, and thus we expect to see a similar effect on the roads. This however differs from region to region within the same country and would not be accurate for project specific purposes. If it is the only data available then it may be used. Vehicle registry data for the period 2005/6 to 2014/15 was collected from the Central Vehicle Registry of Ethiopia. The data however was given as yearly totals and not broken down into various vehicle categories. This made it difficult to compute the heavy vehicles growth rate. The heavy vehicles growth rate usually differs from that of other vehicle categories, and it is heavy vehicles that matter in pavement design.

4.3 Axle load data

Axle load data was obtained from some of the weighbridge stations located in various parts of Ethiopia as shown in Figure 1. The spread of the stations provided an indication of the variation of the axle loads across the country.

To analyse the trend and impact of axle loads, data was obtained from eight weighbridge stations in different regions of Ethiopia. For seven stations the data used is the sum for each station for a period of 10 years during the period 2005/6 to 2014/15. For one major station (Modjo) the data obtained was the yearly total for fourteen years for the financial years 2001/2002 and 2014/2015. The Modjo station is located on a principal import-export route in Ethiopia. It was chosen for detailed analysis and trend generation because its location on the major economic route means the growth trend in the axles from this station is closely linked to the GDP.

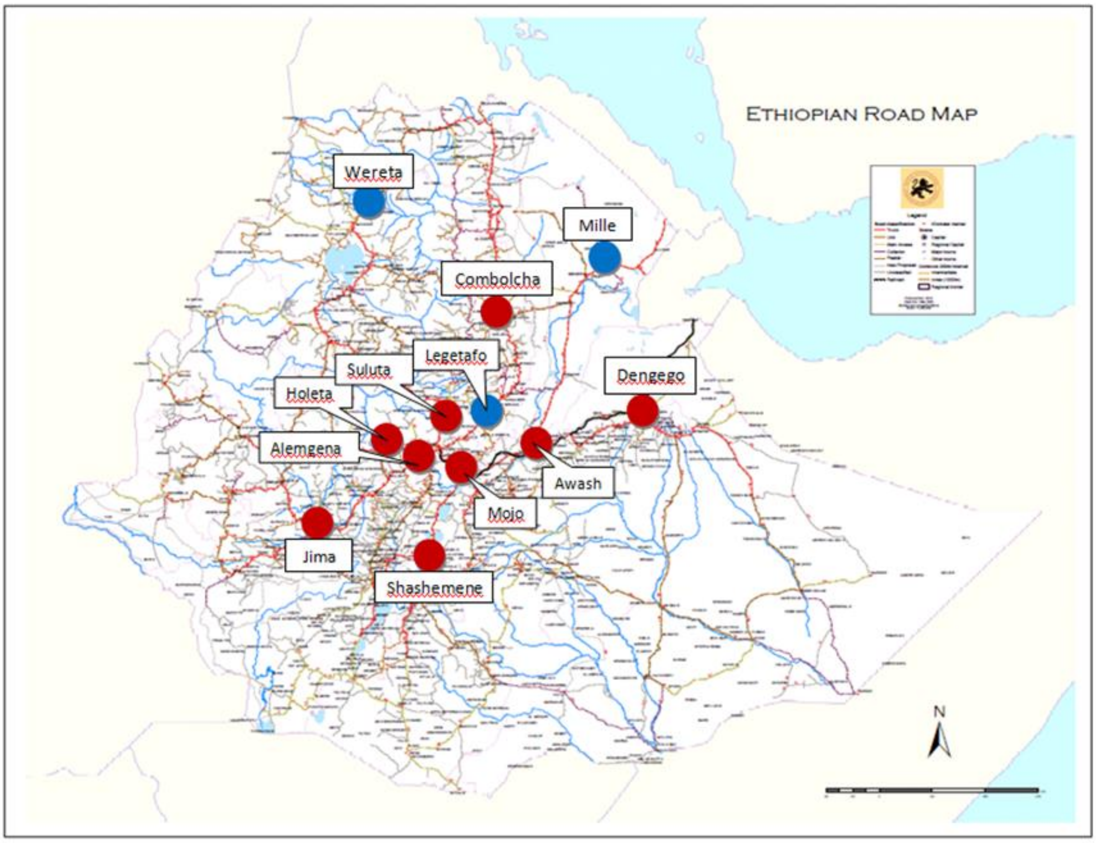

Figure 1: Axle load control Weighbridge locations (Red circles show existing weighbridges and the Blue circles show new weigh bridge locations)

The weighbridge stations for Ethiopia are mostly located in the central part of the country as seen in Figure 1. This shows the difficulty in obtaining axle load data that can be used in locations far from the centre; moreover the nether regions have more low-volume roads than the central parts of the country.

4.4 Analysis procedures

As discussed in chapter 2 above, the method of analysis adopted to estimate traffic growth rate is the time-series analysis. The growth rate was computed using the formula $r = \left(\left(\sqrt[n]{\frac{A}{P}}\right) - 1\right) \times 100$ where

$r$is the growth rate in %,

n is the period under consideration in years,

P is the number of vehicles, axles, GDP, in year 0,

A is the number of vehicles, axles, GDP, in year n.

Relationships between GDP growth and vehicle growth were investigated. The growth in the number of axles was used as proxy for heavy vehicle growth rate. A trend relationship was obtained from this. In addition a simple formula relating the estimated heavy vehicle growth rate from the GDP was also developed.

The axle load data from the various stations was used to compute the equivalent standard axles (ESA) for the weighed axles.The formula used was ESA = (axle mass/8160)^n. The damage exponent, *n*, used was 4.0.In the absence of other reliable data, the sum of the ESAs for the first 3 axles wastaken as the vehicle equivalence factor (EF) for 3-axle trucks. The EFs were computed at 50th, 75th and 90th percentiles of the individual axle masses. The EFs were then used to compute design traffic and also for comparison of loading effects at different weighbridge stations. Vehicle growth rates forecasted from GDP and axle number time-series data were used in the design traffic computation.A subgrade class of S3 was chosen arbitrarily. The resulting pavements were then compared. The comparison of the pavement structures resulting from different EFs was used to demonstrate the difficulty and consequences of inaccurate traffic forecasting.

5 Results and discussions

5.1 Forecasting based on vehicle registry data

The time-series trend of vehicle growth was plotted as shown in Figure 2so as to determine the growth rate represented by the line of best fit.

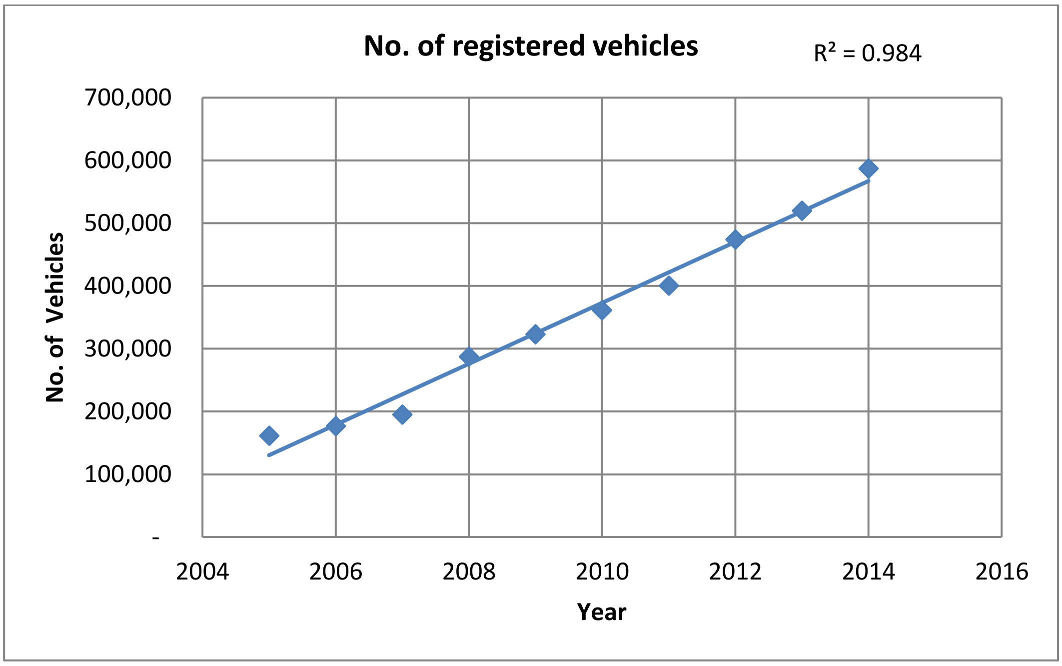

Figure 2: Vehicle growth trend

The vehicle growth rate computed by the formula described in section 4.4 was found to be 16.4%. As previously mentioned, the data available was not categorised by vehicle type, hence it could be erroneous to assume that heavy vehicles are also growing at the same rate. The challenge of obtaining data compatible for pavement engineering purposes is apparent in this case.

5.2 Forecasting from the GDP

Ethiopia's GDP Production (2000 constant prices) trend is presented in **Error! Reference source not found.**. The trend is highly stable, and for this reason if a stable trend exists in the heavy vehicles growth rate, then a relationship can be developed for predicting heavy vehicle growth rate from the GDP forecast. GDP forecasts however are usually limited to short periods whereas for pavement design purposes, traffic forecast is required for 15 to 20 years. The GDP Production growth rate computed by the formula in section 4.4 is 10.5%.

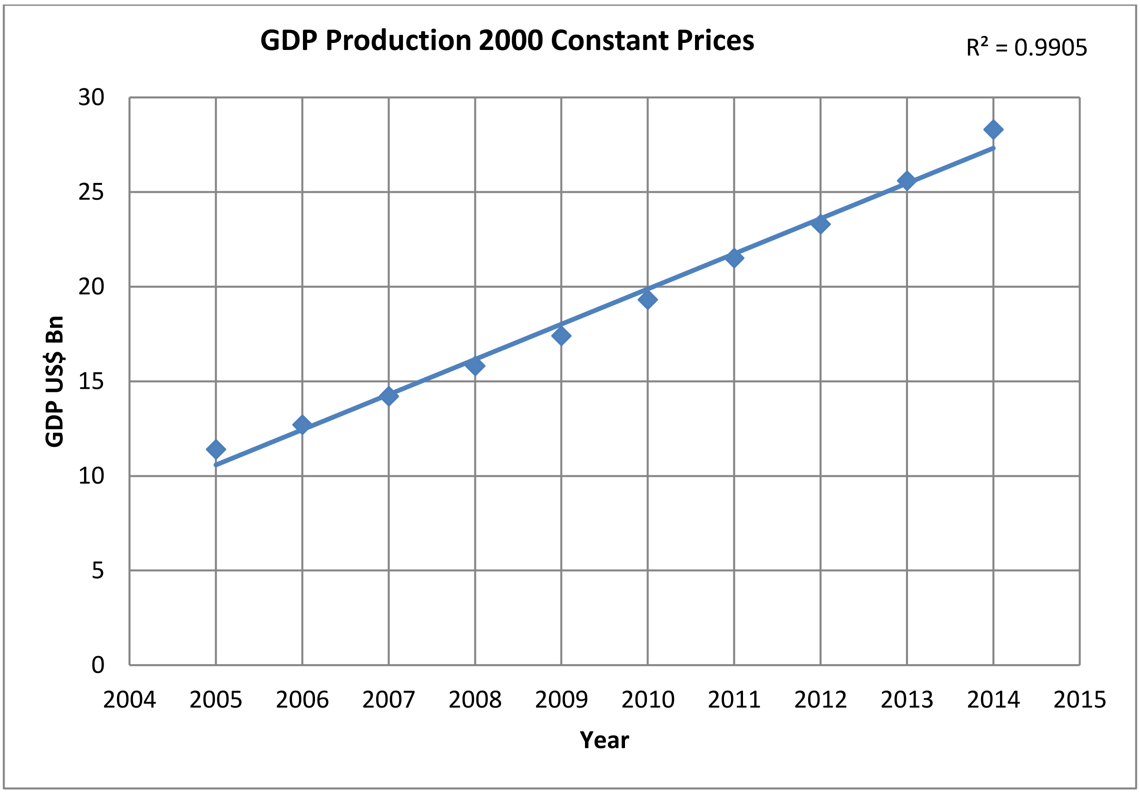

Figure 3: Ethiopia's GDP Production trend (*GDP data from World Bank Website*)

According to The World Bank (2016), the forecast for the GDP growth rates for Ethiopia in 2015, 2016 and 2017 are 9.5%, 10.2% and 9.0% respectively. This averages to 9.6%.

5.3 Forecasting based on weighbridge data

The correlations between growth in number of heavy vehicle axles and GDP total, and growth in number of heavy vehicle axles and GDP Production were investigated. A better fit was found between growth in number of heavy vehicle axles and GDP Production. This is shown inFigure 4. The number of heavy vehicle axles is a very good proxy for the number of heavy vehicles.

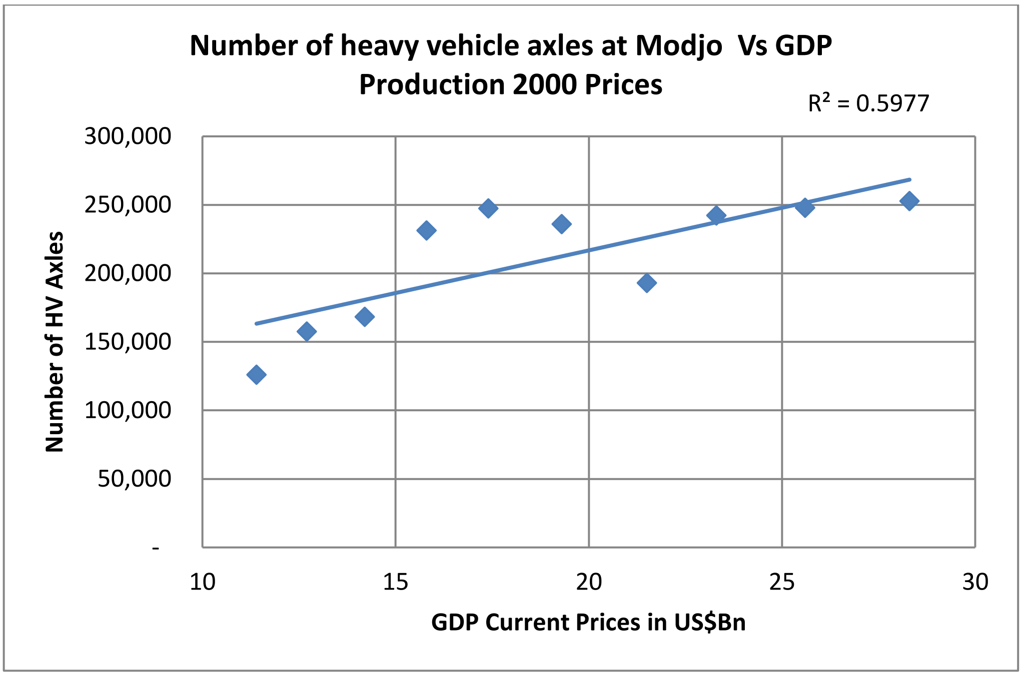

Figure 4: Correlation between number of heavy vehicle axles at Modjo and GDP production

The correlation is however not strong for a linear relationship between the number of heavy vehicle axles at Modjo and GDP. A plot (Figure 5) of the number of heavy vehicle axles at Modjoover the same GDP period (2005 to 2014) was made to determine the growth rate. The growth rate was found to be 6.1%. This rate was then used to establish the relationship between heavy vehicle growth and GDP; that is heavy vehicle growth rate is equals 0.58 times the GDP growth rate.

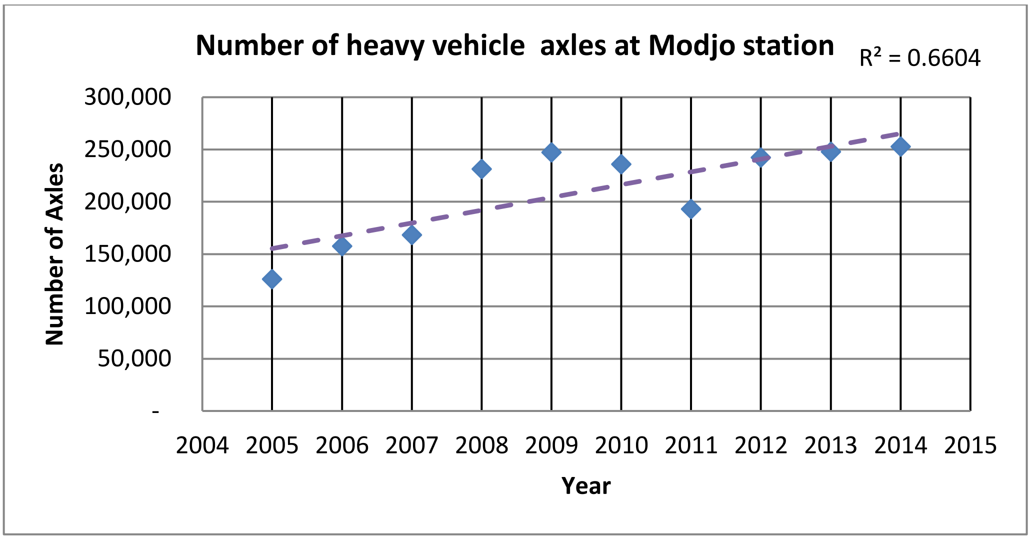

Figure 5: Trend of heavy vehicle axles at Modjo weighbridge station (single period)

Therefore using the GDP growth forecast (average of 9.6% over the next 3 years) cited in section5.2 we can estimate the heavy vehicle growth forecast to be 0.58 x 9.6%, this equals 5.6%.

However from Figure 6, it is apparent that two distinct growth periods exist in this plot.The first period is between 2005 and 2009, and the second period is between 2008 and 2014. If linear growth rates are assumed for the two periods, then the growth rate for the first period is 19.4%, and 1.1% for second period. Strictly speaking the growth period 2005 to 2009 fits slightly better (compare R^2 values) as an exponential trendthan as a linear trend. The exponential trend is represented in Figure 6, by the red curve. The 19.4% growth rate is very high and is unsustainable in the long term and therefore we have not used this for further analysis.

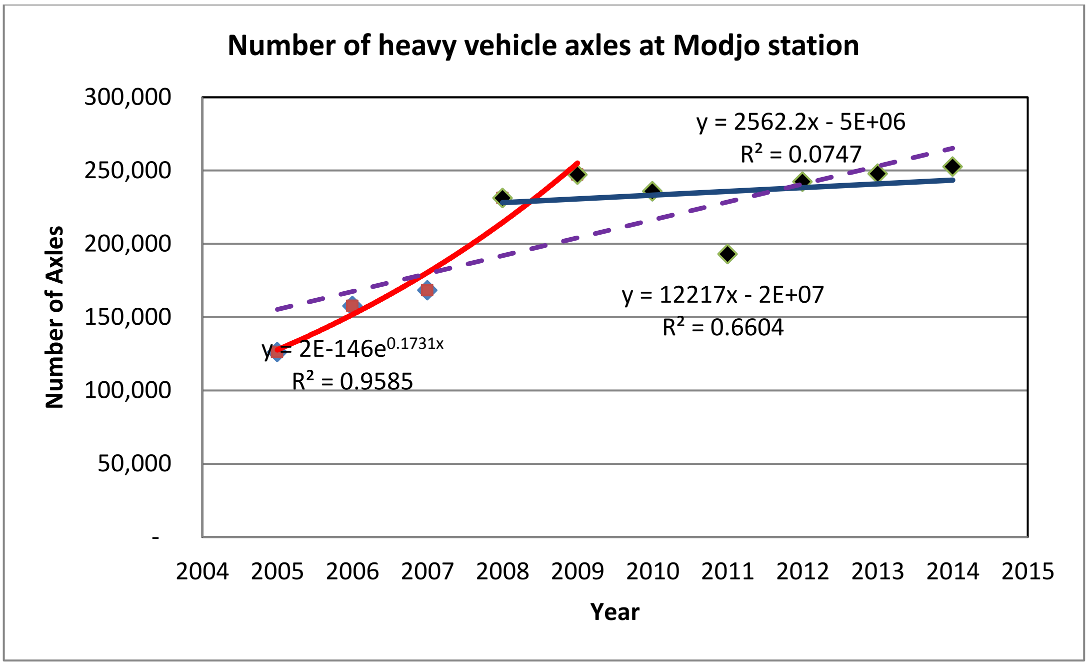

Figure 6: Trend in the number of axles at Modjo weighbridge station (Two periods)

5.4 Equivalence factors

This was computed for the first 3 truck axlesfor all the eight stations using data collected from 2005 to 2014. The 90th percentile of each axle mass and a damage exponent of 4.0 were used to compute the vehicle equivalence factors. The results are shown in Figure 7. This variation of the equivalence factors from region to region shows the importance of conducting regional and project specific studies if better growth estimates are to be obtained for use in pavement design.

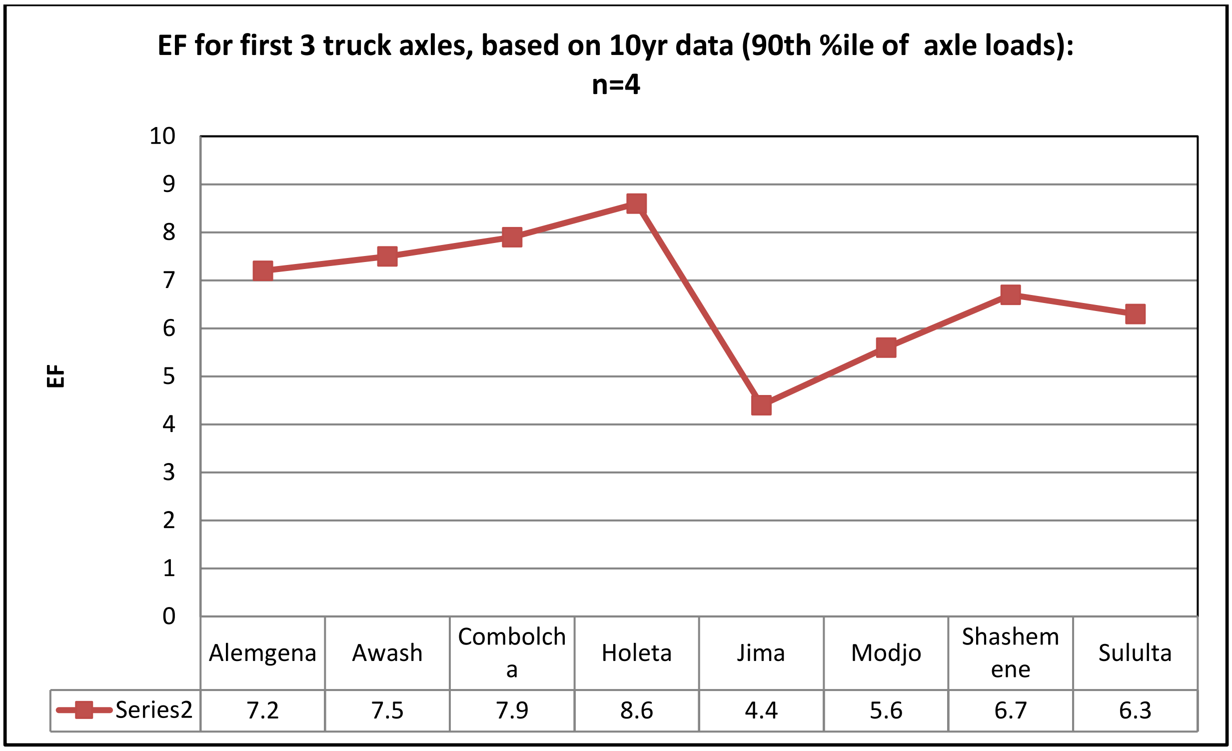

Figure 7: Equivalence factors for first 3 truck axles at weighbridge stations in Ethiopia

Pavement structures designed for roads in the same subgrade class in for example Holeta and Modjo, will be very different because of the large variation in EF between the two areas.

Forecasts of vehicle axle loads are needed to avoid underestimating of future pavement damage. Introduction of a fleet of new and different vehicles can radically alter the axle load distribution on a particular route in a short time (Falck-Jensen et al., 2004).

New government policies may also alter the axle load distribution country-wide. For example, a policy banning the importation and use of 2-axle trucks of rated gross weight above 12 tonne. This forces load redistribution among other truck fleet resulting in significant changes in EF of some vehicles. Since the ESA of each axle varies by the 4^{th} power of the axle's mass, the rise or drop in ESA or EFcan be dramatic, as seen in the period 2003 to 2005 in Figure 8.

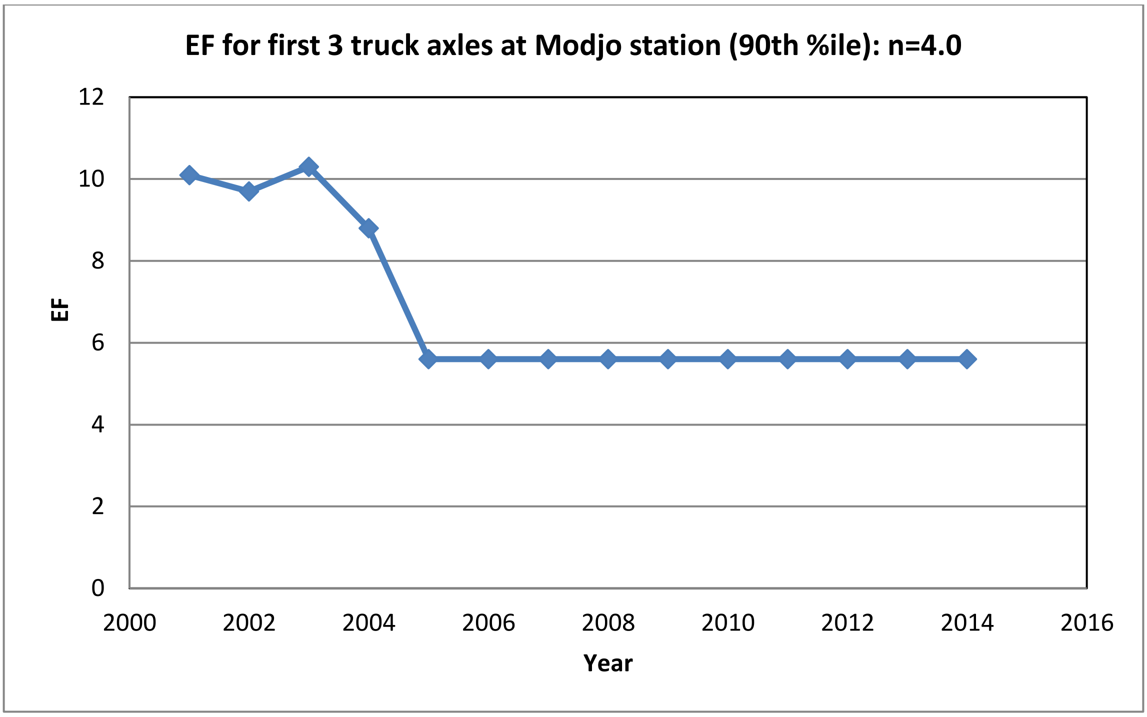

Figure 8: Trend of equivalence factors first 3 truck axles at Modjo weighbridge station

From our analysis, the 50th, 75th, and 90th highest percentiles of equivalence factors for the first three truck axles in Modjo in 2014 are 3.3, 4.2, and 5.6 respectively. The Ethiopian Roads Authority (2011, p.7) in Table B. 3.2 captioned "Average equivalence factors for different vehicle types" provides the value of the average equivalence factor for a fully loaded 3-axle truck in Ethiopia as 12; but the table contradicts itself with the column that contains the value 12 headed as "average equivalent standard axle per vehicle all loaded". If 12 is the EF, then this value is more than twice the 90th percentile EF at Modjo for 2014. If 12 is the equivalent standard axle then for a fully loaded 3-axle truck the EF would be 36. Moreover the heaviest overloaded axles at Modjo usually lie between 18 and 22 tonnes. This would result in very different values from what is contained in the manual. There is therefore a big disparity between what this study has found and what the design manual states.

Despite being from the Roads Research Centre, the team faced difficulty in obtaining data from the weighbridge stations. As a result time-series data was obtained from only one out of the eight stations. It would be very difficult for a private design consultant to therefore obtain similar data. The consultant would therefore be forced to carry out a short term count and axle load survey. We have seen from the data above that axle loads (hence the vehicle equivalence factors) may vary significantly over the years. A short-term survey used to predict long term trends can therefore lead to large errors in prediction.

5.5 Implications for design

In this section, we illustrate the effect of using the traffic growth rate forecasted from the GDP (5.6%), the 9-year (2005 to 2014) time-series trend (6.1%) and the 6-year (2008 to 2014) time-series trends discussed in section 5.3. The EFs used in this analysis will be that for Holeta (8.6) and Modjo (5.6) as seen in Figure 7. For the analysis, we assume the base year of 2014, a 15 years' design life and 2 years construction period before opening to traffic. We further assume that the road in the current year has an average daily traffic of 250 vehicles per day, of which 30 are 3-axle trucks and the design lane carries 15 of these trucks per day. For an S3 subgrade design class, the pavement structures from the Ethiopian Roads Authority design manuals are shown in Table 2.

Table 2: Pavement structures for various growth rates in two different regions

Type of Data	**Growth Rate (%)**	**mESA Computed from EF for:**		**Pavement Structure**	
		Holeta	**Modjo**	**Holeta**	**Modjo**
GDP	5.6	1.2	0.8	200G80, 150G30, 175G15	200G80, 150G30, 150 G15
Axle Load Trend (9yr)	6.1	1.2	0.8	200G80, 150G30, 175G15	200G80, 150G30, 150 G15
Axle Load Trend (6yr)	1.1	0.8	0.5	200G80, 150G30, 150 G15	175G65, 150G30, 150G15

From the table, if the growth rate is taken as 6.1% then the road is a high-volume road in Holeta (1.2 mESA) as compared to a low-volume road in Modjo (0.8 mESA); albeit with minor differences in the pavement structure. At all growth rates, the road is a low-volume road in Modjo. If the growth rate is taken as 1.1% then the road is a low-volume road in both cases;Holeta (0.8mESA) and Modjo (0.5 mESA) although there is a significant difference in the pavement structures.

In the extreme case, the difference in the pavement structures using the different forecast growth rates and the equivalence factors is, a 200 mm base course of crushed rock or modified gravel of CBR 80% as compared to a 175 mm natural gravel base of CBR 65%.

There is little difference between the growth rate predicted by the GDP forecast and the 9-year time-series trend.

5.6 Implications for performance

If the wrong forecast rate or the wrong vehicle equivalence factors are used in a given region, this results in the wrong pavement structure. This could lead to an under-design and hence premature failure of the pavement, or an over-design and unnecessary tie-up of resources that could have been used to improve other roads at the same time.

6 Conclusion

It is not possible to predict traffic growth precisely. However if sufficient data is available, estimates closer to the reality can be made. The challenge is in collecting sufficient data.

The paper advocates for roads agencies to set up long-term round the clock traffic count stations on all road categories in different regions to provide sufficient data to promote more accurate forecasting. Routine axle load surveys should also be conducted at these stations. Given the difficulty in obtaining data, the role of providing the growth rates to be used for design should be moved from design consultants to the research department of the roads agencies.

The growth rate of heavy vehicles flow for Ethiopia was found to be equal to 0.58 times the GDP growth rate. This can be used as estimate where regional or project specific rates cannot be obtained. The difficulty lies in the fact that GDP estimates are only available for short periodswhereas traffic growth rate forecastfor pavement design purposes is required for a period of 15 to 20 years.

The fact that only short term forecasts are reliable raises the question whether developing countries should adopt a strategy of stage design and construction of roads to ensure a more dispersed and equitable distribution of resources.

The paper has shown the situation in Ethiopia and encourages other countries to adopt similar studies.

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