Journal of the Ghana Institution of Engineering (2022) 22 : 3
https://doi.org/10.56049/jghie.v22i1.7

ORIGINAL RESEARCH

Optimum axle load limit on the trans west African highway – a case study of Ghana's coastal corridor

Ernest Opoku Agyemang Tufuor*

Received: 27 January 2022 / **Accepted:** 20 June 2022
Published online: 8 July 2022

Abstract

The Economic Community of West African States recently reviewed regulations on axle weights. Ghana rolled out its new regulation in January 2014. The allowable axle weights in the new regulation are much stiffer (e.g., the allowable single axle limit is now 11.5 tonnes compared to 13.5 tonnes, previously). Regional freight haulers contend that the new regulations make Ghana's corridor less attractive to trade. However, the road agency sees it as a way of maintaining and extending road pavement life. The goal of this study is to find the optimum axle limit that is economically feasible to create a balance between road preservation and port competitiveness. Data collected on 47,959 individual trucks from July 2010 to December 2013 were analyzed. A calibrated Highway Development and Maintenance model for Ghana was used to estimate the total transport cost. The analysis showed that 19 % of trucks were overloaded, and footwear was the most frequently overloaded commodity. Overloading was common with all trucks, but 3-axle trucks experienced the highest extent of overloading. It was found that if the road agency maintains a high road maintenance standard (e.g., International Roughness Index = 3 m/km), then the optimum axle limits will be from 12-13 tonnes, 20-22 tonnes, and 28-29 tonnes for single axle, tandem axle, and tridem axle, respectively. However, at a low maintenance target (IRI = 7 m/km), the optimum limits need to be 12.5 tonnes and 18-19 tonnes for single axle and tandem axle, respectively, while the optimum tridem limit remains unchanged.

Keywords: Axle Load, Optimum Limit, Road User Cost, Road Agency Cost

Introduction

The Economic Community of West African States (ECOWAS) is aligning its priorities toward the economic integration of member states by reconstructing regional road corridors and harmonizing standards. ECOWAS gives priority to the construction of the highway from Nigeria-Benin-Togo through Ghana to Cote D'Ivoire, where approximately 65 % of the region's economic activities are centred (Dumitrescu, 2013). Ghana harbours approximately 56 % of this priority road section on its coastal boundary from Elubo to Aflao, as shown in Figure 1. It can also be seen on Figure 1 that there are 4 permanent axle load stations along the Ghana corridor (GHA, 2022; MRH, 2013).

To protect the life span of Ghana's roadway system, and especially its transit corridors to facilitate trade and economic growth, the country rolled out a new Axle Load Regulation in January 2014 (B&FT, 2014a) per the enacted Road Traffic Regulations of 2012 - Legal Instrument 2180 (DVLA, 2017). The regulation stipulated stricter or reduced allowable axle limits on loaded trucks. For example, an allowable single axle limit was changed from 13.5 tonnes to 11.5 tonnes.

*Corresponding authors's email:
ernest.tufuor@auburn.edu

[1]Auburn University Transportation Research Institute, 1220 Shelby Center, Auburn University, Auburn – Alabama, USA.

This resulted in numerous agitations by the ports and the haulage associations. The haulers and the port authorities contend that the stricter regulations make Ghana's corridor less attractive to trade. However, the road agency sees it as a way of maintaining good surface conditions and extending the life of the road pavement (B&FT, 2014b). This study, therefore, seeks to determine the optimum axle limit that is economically feasible to implement, which will create a balance between road preservation and port competitiveness. The study, thus, analyses the axle weights of trucks plying this road section within the Ghana corridor to ascertain the optimum axle limit.

Figure 1 Corridor map showing study road corridor with permanent weighbridge stations

ISSN: 0855-0743 /

Literature review

Studies have shown that road transport cost in Africa is about six times more expensive than in Pakistan, and even more than in Europe, where labour rates are relatively higher (Rizet and Hine, 1993). Excessive deterioration of road pavement leading to poor road surface conditions has been identified as a major contributing factor to high transport costs (Limao and Venables, 2001). Rolt (1981) stated that the legal axle limit of developing countries ranges from 8-13 tonnes for single axles and 8-20 tonnes for tandem while others are without any legal limits. It is known that overloading causes problems in developing countries due to the huge costs involved in road maintenance and rehabilitation. Strathman (2001) argued that axle load enforcement in terms of setting overloading penalties and weight limits largely prevents high incidences of axle overloading. This is true and not surprising if a strict enforcement regime is implemented. For example, though Ghana has set overloading penalties and weight limits, Opoku (2009) showed evidence of excessive overloading on Ghana's transit corridor, which may probably be due to enforcement challenges. The Ghana Highway Authority reported that overloading ranges between 15 % - 28 %, which would probably increase both road user and road agency costs (MRH, 2016). More specifically, overloading leads to higher road maintenance costs and shortens pavement service life (Oyekanmi *et al.*, 2020).

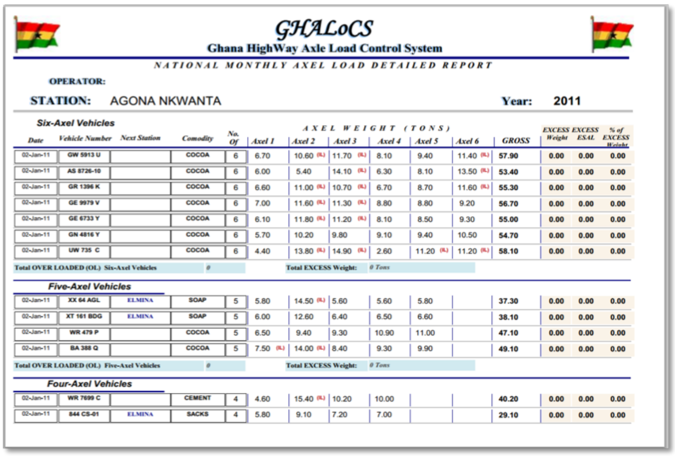
Logically, the cost of transporting freight decreases with the increasing tonnage of freight per vehicle. However, the cost of road construction and maintenance increases with increases in axle weight. Freight carriers are always motivated to maximize profits, which leads to a high probability of exceeding the legal axle limits to the point where additional costs (including penalty costs) cannot offset the excess revenue to be accrued. Therefore, the rate of enforcement and stiffer penalties for overloading affect transport operators (Strathman, 2001). There is also the issue of freight flow imbalance caused by the frequent empty return of trucks that adds to transport costs. It will therefore be beneficial to the transporters and the road agency to allow for trucks to be articulated with more axles to carry heavier gross loads to recover these losses. According to Sparks and Neudorf (1987), the general economic productivity of using an 8-axle truck is more than a 5-axle eighteen-wheeler truck.

A study by Meyburg *et al.* (1994) found that the optimum axle weight limit in the United States was 145 % of the legal limit. Also, the optimum axle load limit in the United Kingdom was estimated by Rolt (1981) to be strongly correlated with freight tonnage, vehicle conditions, and the exponent of pavement damage. The method adopted by Meyburg *et al.* (1994) is based on models accepted in the United States with readily available data. However, the method used by Rolt (1981) suits this study because the applied model (i.e., the Road Transport Investment Model) has been modified and improved as the HDM-IV (Highway Development and Maintenance) model, which is accepted and mostly used in Ghana.

Adarkwa et al. (2012) estimated the cost of overloading or additional costs to be incurred by the government of Ghana. The authors used the HDM-IV model to determine the difference between the total cost to the road agency and road user for a "do-minimum" scenario and an "overloading scenario." The study concluded that the overloading cost to the government was about US$230,000 per km per year (more than the cost of rehabilitation) and about US$30million per year to truckers on the Tema-Paga Road corridor. Rolt (1981) showed that "the total cost of operating the transport system initially decreases as axle load increases but passes through a minimum value at the optimum axle load before increasing again". An optimum axle control limit is therefore the ultimate limit that is known to produce the least total transport cost.

Data Collection and Modelling

Secondary data on truck axle configuration, axle weights, and type of commodities being hauled were collated for 47,959 trucks from July 2010 to December 2013. This was collated from the data logger of the Agona-Junction permanent axle weigh station, which is strategically located on the study corridor (GHA, 2022). The data consists of 60 % 6-axle trucks, 16 % 3-axle trucks, 14 % 5-axle trucks, 6 % 4-axle trucks, and 4 % 2-axle trucks. The collection system was automated with strict monitoring systems and low error margins (WATH, 2010). Figure 2 is a sample of the raw output showing the axle types, weights, and type of commodity.


GHALoCS
Ghana HighWay Axle Load Control System
NATIONAL MONTHLY AXEL LOAD DETAILED REPORT

OPERATOR:

STATION: AGONA NKWANTA Year: 2011

Date	Vehicle Number	Next Station	Comodity	No. Of	Axel 1	Axel 2	Axel 3	Axel 4	Axel 5	Axel 6	GROSS	EXCESS Weight	EXCESS ESAL	% of EXCESS Weight
Six-Axel Vehicles														
02-Jan-11	GW 5913 U		COCOA	6	6.70	10.60 (IL)	11.70 (IL)	8.10	9.40	11.40 (IL)	57.90	0.00	0.00	0.00
02-Jan-11	AS 8726-10		COCOA	6	6.00	5.40	14.10 (IL)	6.30	8.10	13.50 (IL)	53.40	0.00	0.00	0.00
02-Jan-11	GR 1396 K		COCOA	6	6.60	11.00 (IL)	10.70 (IL)	6.70	8.70	11.60 (IL)	55.30	0.00	0.00	0.00
02-Jan-11	GE 9979 V		COCOA	6	7.00	11.60 (IL)	11.30 (IL)	8.80	8.80	9.20	56.70	0.00	0.00	0.00
02-Jan-11	GE 6733 Y		COCOA	6	6.10	11.80 (IL)	11.20 (IL)	8.10	8.50	9.30	55.00	0.00	0.00	0.00
02-Jan-11	GN 4816 Y		COCOA	6	5.70	10.20	9.80	9.10	9.40	10.50	54.70	0.00	0.00	0.00
02-Jan-11	UW 735 C		COCOA	6	4.40	13.80 (IL)	14.90 (IL)	2.60	11.20 (IL)	11.20 (IL)	58.10	0.00	0.00	0.00
Total OVER LOADED (OL) Six-Axel Vehicles	0					Total EXCESS Weight:	0 Tons							
Five-Axel Vehicles														
02-Jan-11	XX 64 AGL	ELMINA	SOAP	5	5.80	14.50 (IL)	5.60	5.60	5.80		37.30	0.00	0.00	0.00
02-Jan-11	XT 161 BDG	ELMINA	SOAP	5	6.00	12.60	6.40	6.50	6.60		38.10	0.00	0.00	0.00
02-Jan-11	WR 479 P		COCOA	5	6.50	9.40	9.30	10.90	11.00		47.10	0.00	0.00	0.00
02-Jan-11	BA 388 Q		COCOA	5	7.50 (IL)	14.00 (IL)	8.40	9.30	9.90		49.10	0.00	0.00	0.00
Total OVER LOADED (OL) Five-Axel Vehicles	0					Total EXCESS Weight:	0 Tons							
Four-Axel Vehicles														
02-Jan-11	WR 7699 C		CEMENT	4	4.60	15.40 (IL)	10.20	10.00			40.20	0.00	0.00	0.00
02-Jan-11	844 CS-01	ELMINA	SACKS	4	5.80	9.10	7.20	7.00			29.10	0.00	0.00	0.00

Figure 2 Sample raw data from Agona permanent weigh station

Analysis of the raw data

Weighbridge operators normally record default values for trucks that are empty. This appears to have rendered the minimum observed gross weights to be far below what is expected as shown in Table 1. These outliers will affect the mean weight; therefore, the median is used as a better sample representation. Table 1 shows that 6-axle trucks were the most common weighed truck. The 6-axle trucks constitute approximately 60 % of the truck population that were weighed and 19 % of them were found to be overloaded. The least overloaded trucks were 5-axles –they constitute 14 % of the vehicles that were weighed but only 3 % were found to be overloaded. Though the 3-axle trucks constitute only 16 % of the observed trucks, approximately 34 % were found to be overloaded. The differences in overloading trends as a function of the different axle types may be due to the type of commodities they haul.

Figure 3 shows the types of commodities and the percentage of trucks that were overloaded. It may be seen that the top-most frequently overloaded commodities in decreasing order of magnitude were footwear, coconut, cosmetics, assorted goods, and manganese.

Table 1 Category description of truck weights

Truck Type	Gross Vehicle Weight (Tonnes*)						Number of Trucks		
	Legal Limit**	Observed Levels							
		Min.	Max.	Median	Stdev.	Observed	Overloaded & %	
6-axle	61	15.0	98.6	58.2	5.7	28775	5577	19%
5-axle	52 - 55	14.4	63.7	46.1	8.5	6714	224	3%
4-axle	37 - 46	12.4	58.1	40.3	7.3	2878	429	15%
3-axle	31	10.8	59.8	29.1	5.1	7673	2599	34%
2-axle	21	7.9	36.9	18.2	3	1918	245	13%
Total						**47959**	**9075**	**19%**

Note: *1 tonne = 1000kg
**ECOWAS/UEMOA Standard (WATH, 2010) – The range of values for the 5 and 4 axle trucks depends on the axle configuration (e.g., tandem or tridem)

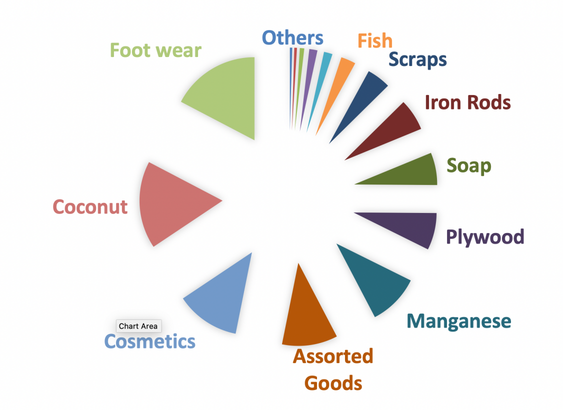


Figure 3 Most frequent overloaded commodities

Figure 4 shows the extent or magnitude of overloading per axle type. It may be seen that overloading was common in all trucks, but the extent (magnitude) of the overloading was highest in 3-axle trucks. A preliminary investigation of the data showed that the 3-axle trucks haul most of the frequently overloaded commodities such as footwear and coconuts. A policy direction in terms of providing weighing pads and enforcing weighing at the loading points of these commodities is envisaged to reduce the level of overloading.

It may also be seen from Figure 4 that, there is a gradual reduction in the level of overloading from 2010 to 2013. In other words, the overloading levels for the years 2010 and 2011 are slightly higher than for 2012 and 2013. The gradual decline can be attributed to the increase in awareness and institutionalization of axle load implementation regulations by ECOWAS member states.

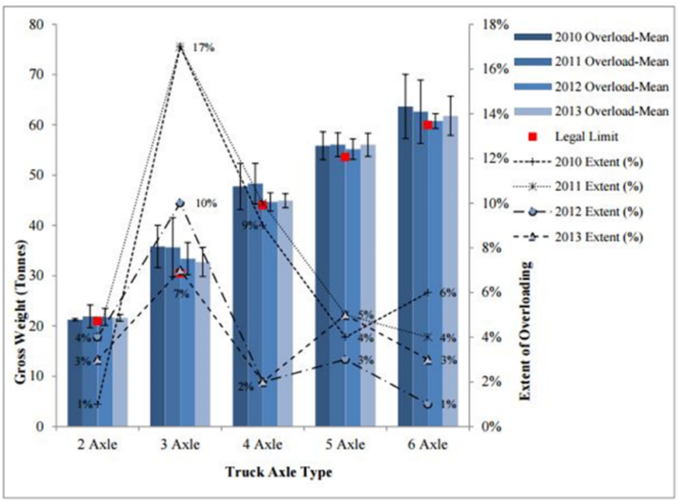


Figure 4 Overloading trends of truck axle type (with standard error bars)

The highway development and maintenance model

The HDM-IV model flow chart used in the study is illustrated in Figure 5. There are four main steps in the modelling process. The first step is to model the road and vehicle characteristics of the study area. The next is to determine the specific road maintenance regime(s) being implemented by the road agency and the associated costs. For example, the costs, periods, and triggers of pothole patching, asphalt overlay, rehabilitation, etc. Step 3 is to select a specific vehicle axle type that is being used on the study road and preload with variable freight tonnages. The total transport cost per each axle type as a function of different freight is then estimated in the fourth step. The process is repeated for each axle type and several loops to estimate the transport costs for both road user and road agency. A plot of transport cost versus axle load is used to obtain the optimum axle load limit, which is the load that gives the minimum transport cost.

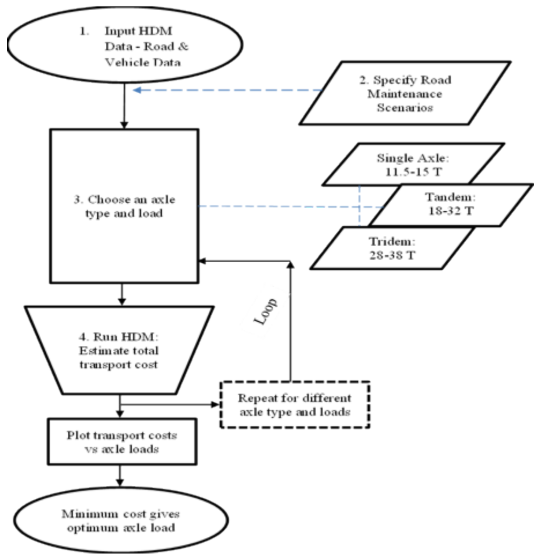


Figure 5 Flow chart of the HDM-IV modelling process.

In this paper, the HDM-IV model parameters calibrated for the Ghana road sector (Koranteng-York *et al*., 2015) were used. Axle weight/load is identified as the independent variable and transport cost is the dependent variable. It was initially assumed that freight is transported by only one type of vehicle fleet with the axle under consideration carrying all the loads. A 20-year analysis period, which is a typical design life for most highways in Ghana, is used. An annual traffic growth rate of 5 % and a discount rate of 15 % (Koranteng-York *et al*., 2015) were assumed. The selected axle loads range from 11.5-15 tonnes (for the single axle), 18-32 tonnes (for the tandem axle), and 28-38 tonnes (for the tridem axle), as reviewed in other jurisdictions (JICA, 2011). The motorized Average Annual Daily Traffic (AADT) for the study section is 1,566 with 6 % trucks. Two scenarios were considered:

- High maintenance regime: responsive road maintenance with a target of International Roughness Index, IRI=3 m/km
- Low maintenance regime: with a target of IRI=7 m/km

As previously stated, the flow procedure was repeated for different axle loads (single, tandem, and tridem) to determine each corresponding total transport cost (road user + road agency costs). The model analysis was based on total freight tonnage (for the port to be competitive), the pavement damage and road maintenance regime (road agency objectives), and finally the user cost (cost for transport operator to be in business). A sensitivity analysis was performed for a 20 % increase in the projected traffic volume to avoid the risk of future changes in the determined optimum values. The percent increase was selected because typically traffic projections are underestimated since only registered vehicles are considered and it is assumed that a 20 % increase will be sufficient to cater for unregistered vehicles or other traffic growth contribution factors in the worst-case scenario. This was done to identify how much variation in the traffic volume will impact the model results.

HDM-IV model results

The output of the model is presented in Table 2. The base case uses the current traffic data characteristics and the other model parameters as input variables. The sensitivity scenario considers a 20 % increase in the AADT with all other parameters as in the base case. Not surprisingly, the results show that high road maintenance standard (IRI=3m/km) gives lower Road Agency and Road User Costs in the long run and the reverse for low road maintenance regime. The savings in cost is approximately US$0.276/tonnes-km-year to the road agency and US$0.036/tonnes-km-year to the road user. The savings increases to US$0.284/tonnes-km-year and US$0.04/ tonnes-km-year, respectively, with a 20 % increase in traffic volume. In all cases, the cost to the road user is higher than the road agency cost. The road agency cost is approximately 74% of the road user cost.

The total transport cost (road user + road agency costs) per axle configuration is plotted to determine the optimum axle limit (Figures 6, 7, and 8). The total transport cost strongly correlates with the axle loads by mostly second to third-order polynomials with high R^2 values ranging from 75 % to 98 %. The minimum total transport cost occurred at the minimum turning point of the curves. High road maintenance targets yield low total transport costs. It may be seen that the optimum axle limit ranges do not change with a 20 % increase in AADT.

Table 2: HDM-IV output of transport cost for high and low road maintenance regimes

Base Case: AADT 1566 (HGV-6 %)														
Single Axle					**Tandem Axle**					**Tridem Axle**				
Axle Limit (tonnes)	HM		LM		**Axle Limit (tonnes)**	HM		LM		**Axle Limit (tonnes)**	HM		LM	
	RAC	RUC	RAC	RUC		RAC	RUC	RAC	RUC		RAC	RUC	RAC	RUC
10.0	2.1561	3.0202	2.4731	3.0562	**18.0**	2.1561	3.0202	2.4731	3.0562	**28.0**	2.1561	3.0202	2.4731	3.0562
11.5	2.2183	3.0200	2.4731	3.0565	**20.0**	2.1561	3.0204	2.4731	3.0564	**30.0**	2.1561	3.0204	2.4731	3.0564
13.0	2.2183	3.0204	2.4731	3.0571	**23.0**	2.2183	3.0204	2.4731	3.0569	**32.0**	2.2183	3.0200	2.4731	3.0565
14.0	2.2183	3.0207	2.4731	3.0577	**26.0**	2.2183	3.0207	2.4731	3.0577	**34.0**	2.2183	3.0202	2.4731	3.0567
14.5	2.2897	3.0205	2.6082	3.0567	**28.0**	2.2897	3.0209	2.6551	3.0564	**36.0**	2.2183	3.0204	2.4731	3.0571
15.0	2.2897	3.0209	2.6551	3.0564	**32.0**	2.6084	3.0218	2.6551	3.0580	**38.0**	2.2183	3.0205	2.4731	3.0575
Mean	2.2317	3.0205	2.5259	3.0568		2.2745	3.0207	2.5338	3.0569		2.1975	3.0203	2.4731	3.0567
St. Dev	0.0510	0.0003	0.0832	0.0005		0.1709	0.0006	0.0940	0.0008		0.0321	0.0002	0.0000	0.0005

Sensitivity Case: 20 % Increase in Base AADT														
Single Axle					**Tandem Axle**					**Tridem Axle**				
Axle Limit (tonnes)	HM		LM		**Axle Limit (tonnes)**	HM		LM		**Axle Limit (tonnes)**	HM		LM	
	RAC	RUC	RAC	RUC		RAC	RUC	RAC	RUC		RAC	RUC	RAC	RUC
10.0	2.1561	3.5908	2.4729	3.6324	**18.0**	2.1561	3.5907	2.4729	3.6322	**28.0**	2.1561	3.5908	2.4729	3.6324
11.5	2.2183	3.5907	2.4729	3.6328	**20.0**	2.2183	3.5907	2.4729	3.6326	**30.0**	2.1561	3.5910	2.4729	3.6326
13.0	2.2183	3.5912	2.4729	3.6335	**23.0**	2.2183	3.5910	2.4729	3.6333	**32.0**	2.2183	3.5907	2.4729	3.6328
14.0	2.2897	3.5912	2.6551	3.6320	**26.0**	2.2897	3.5912	2.6551	3.6320	**34.0**	2.2183	3.5908	2.4729	3.6332
14.5	2.2897	3.5916	2.6551	3.6324	**28.0**	2.2897	3.5918	2.6551	3.6330	**36.0**	2.2183	3.5916	2.4729	3.6335
15.0	2.2897	3.5918	2.6551	3.6328	**32.0**	2.6084	3.5933	2.6551	3.6354	**38.0**	2.2897	3.5910	2.4729	3.6339
Mean	2.2436	3.5912	2.5640	3.6327		2.2967	3.5914	2.5640	3.6331		2.2095	3.5910	2.4729	3.6331
St. Dev	0.0554	0.0004	0.0998	0.0005		0.1608	0.0010	0.0998	0.0012		0.0497	0.0003	0.0000	0.0006

Note: HM: High Maintenance Regime @ target IRI =3 m/km
LM: Low Maintenance Regime @ target IRI = 7 m/km
RAC: Road Agency Cost (US$/tonnes-km-year) and RUC: Road User Cost (US$/tonnes-km-year)
Total Transport Cost = RAC + RUC

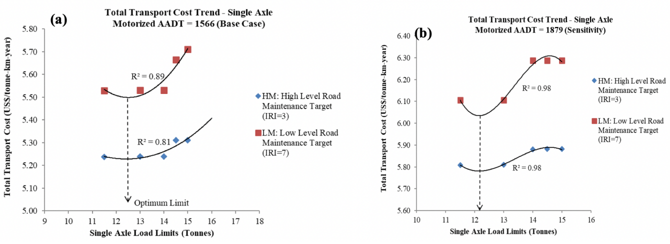


Figure 6 Optimum limit at minimum transport cost for single axle (a) base case, and (b) sensitivity case scenarios

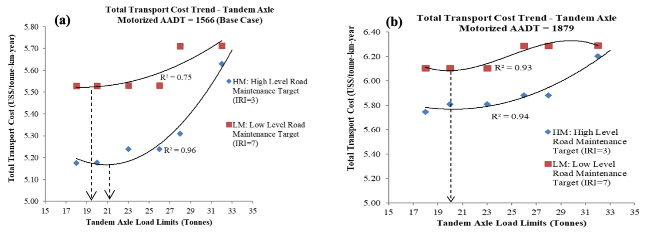


Figure 7 Optimum limit at minimum transport cost for tandem axle (a) base case, and (b) sensitivity case scenarios

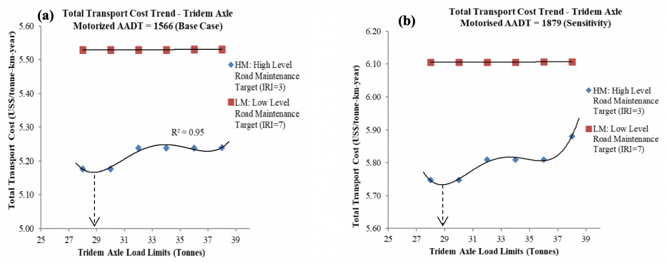


Figure 8 Optimum limit at minimum transport cost for tridem axle (a) base case, and (b) sensitivity case scenarios

It may be seen from Figures 6, 7, and 8, that the optimum axle load ranges from 12-13 tonnes for a single axle, the tandem axle ranged from 20-22 tonnes, and the tridem axle was 28-29 tonnes. Table 3 gives a summary of the model equations, deduced from the curves, which can be used to predict the optimum axle limit for a predetermined total transport cost or vice versa.

Table 3 Model predicted equations

Scenario Description	Model Prediction Equations
Single Axle	
High Road Maintenance Target (IRI=3)	$y = 0.035x^2 - 0.868x + 10.930$
Low Road Maintenance Target (IRI=7)	$y = 0.000x^3 - 0.003x^2 - 0.113x + 6.344$
Tandem Axle	
High Road Maintenance Target (IRI=3)	$y = 0.001x^2 - 0.043x + 5.922$
Low Road Maintenance Target (IRI=7)	$y = 0.004x^2 - 0.149x + 6.720$
Tridem Axle	
High Road Maintenance Target (IRI=3)	$y = 0.000x^4 - 0.021x^3 + 1.057x^2 - 23.161x + 194.381$
Low Road Maintenance Target (IRI=7)	$y = 5.5256$

Note:'y' is the total transport cost (road user cost+road agency cost) in US$/tonne-km-year
'x' is the axle load limit in tonnes

The optimum axle limit for each case is at the point where the total transport cost is the least. That is the minimum turning point of each of the predicted curves. The following hypotheses were tested at a 5% significance level to determine the effect the changes in axle load have on transport costs with respect to different maintenance regimes and different axle types.

- Null hypothesis 1: There is no significant difference between the mean values of the total transport cost at a high maintenance (HM) regime and low maintenance (LM) regime.
- Null hypothesis 2: There is no significant difference between the mean values of the total transport cost for a single axle and tridem axle for a low maintenance regime.
- Alternative hypothesis: There is a significant difference for each null hypothesis.

Table 4 Test statistics for comparing total transport cost

	Comparing Total Transport Cost (US$/tonne-km-year)							
	Base Case		Sensitivity Case		Base Case		Sensitivity Case	
	HM	LM	HM	LM	Single Axle	Tridem Axle	Single Axle	Tridem Axle
Mean	5.26	5.46	5.84	6.17	5.58	5.52	6.20	6.12
Stdev	0.10	0.16	0.10	0.09	0.01	0.00	0.10	0.00
p-value	<0.01		<0.01		0.18		0.08	
Remarks	Significant		Significant		Not Significant		Not Significant	

Note: HM is High road maintenancce regime, LM is Low road maintenancce regime, and Stdev is standard deviation

Table 4 shows the results of the student t-test assuming unequal variances. The results from Table 4 show that, because all the p-values are lower than 0.05, there is a significant difference between the mean values of the total transport cost for high road maintenance regime(s) and low road maintenance regime(s) at a 5 % significance level. As usually predicted, the total transport cost at a high maintenance level is lower than the total cost of low maintenance. In contrast, at a low maintenance regime, there is no significant difference between the mean values of the total transport cost for a single axle and that of a tridem axle at a 5 % significance level. Though it costs more to use a single axle per tonne-km-year compared to a tridem axle, the differences in the total transport cost were statistically not significant. In other words, the benefit of using a tridem axle over a single axle is insignificant at a low maintenance regime.

Discussion of Results

Extent and level of overloading

In this paper, the average overloading level was found to be 19 %, which falls within the national overloading range of 15-28 % (MRH, 2016). Overloading was found to be common in all trucks, but the magnitude or extent of the overweight is higher with 3-axle trucks. The 3-axle trucks usually carry local commodities, in this case-mostly footwear and coconut, and operate within the boundaries of the country (e.g., from farm gates to market centres). The patterns at these local loading points are usually informal and based on how expertly a driver can maximize the loading space in the truck to maximize in-pocket profit. Consequently, these truck drivers or loaders gain experience and, as such, has a higher tendency to overload over time. It is therefore important to identify these loading points as a focus for education on axle loading. Six-axle trucks are also frequently found to be overloaded because they ply long distances and often have contingency plans to carry extra loads for monetary gains.

Optimum axle load limit

The total transport cost corresponding to each optimum axle load limit (i.e., single, tandem, and tridem) remains flattened around the optimum load as may be seen in Figures 6a, 7a, and 8a. In other words, the total transport cost is insensitive to changes in axle load near the optimum value. The flat curve for the tridem situation in Figure 7 indicates a constant agency and user cost because the pavement may have reached its terminal serviceability level and the same cost will be incurred even with more loads.

The optimum axle limits estimated in this paper are similar to the ranges from other studies and that of the ECOWAS/UEMOA agreed limits as shown in Table 5.

Table 5 Comparing results in tonnes

Type of Axle	(GHA, 2022) Highway Authority	(JICA, 2011) ADT=10000 (9 % HGV)	This Research AADT 1566 (6 % HGV)		(WATH, 2010) ECOWAS/UEMOA Agreed Limit
		@IRI=4	@IRI=3	@IRI=7	
Single	13.5	12-14	12-13	12.5	12.0
Tandem	23.0	-	20-22	18-19	20.0
Tridem	30.0	-	28-29	Flat	25.0

In comparison, it can be deduced that the current Ghana axle limits and the ECOWAS/UEMOA recently agreed limits should be given a level of tolerance depending on the operational roughness of the road surface. Also, the optimum axle limit is dependent on the maintenance regime that is being practiced by the road agency. Considering the budgetary constraints of most road agencies within the West African region, a road roughness index that is close to the low maintenance regime (e.g., IRI=7) is often what is pertained. Consequently, a one-point allowance to the ECOWAS/UEMOA agreed limits would be reasonable for optimum operations at least for the Ghana coaster corridor.

Conclusion and Recommendations

This paper presented the results of an analysis of the axle weight of trucks on Ghana's coastal transit corridor. The goal of this study was to find the optimum axle limit that is economically feasible to create a balance between road preservation and port competitiveness. The objectives were two fold: (1) to determine the level of overloading, and (2) to estimate and compare the optimum axle limit with current legal limits. The following were found:

• Approximately 19 % of trucks were overloaded and the most frequent overloaded commodities were footwear and coconut.

• Overloading was common with all trucks, but 3-axle trucks overloaded the most frequently e.g., 34 % of all 3-axle trucks were overloaded.

• The optimum axle limit is dependent on the maintenance regime that is being practiced by the road agency. For example, if the road agency maintains a high road maintenance standard (e.g., International Roughness Index = 3 m/km), then the optimum single axle limit will range from 12-13 tonnes, 18-22 tonnes, and 28-29 tonnes for single axle, tandem axle, and tridem axle, respectively. However, at a low maintenance target (IRI = 7 m/km), the optimum limits need to be 12.5 tonnes for a single axle, from 18-19 tonnes for a tandem axle, and the tridem axle should remain unchanged.

• The optimum axle load limits did not change with a 20 % increase in the annual average daily traffic.

• The estimated optimum axle load limits were found to be similar to the range of values from other studies and that of the ECOWAS/UEMOA agreed on limits. However, considering the budgetary constraints of most road agencies and the fact that a low road maintenance regime is often the practice in the sub-region, it was concluded that, a one-point allowance to the ECOWAS/UEMOA agreed limits would be reasonable for optimum operations for the Ghana coaster corridor.

It is recommended that the Ghana Highway Authority and the Ghana Port Authority should collaborate strongly in enforcing axle load limits. Specifically, portable axle weighing pads will be essential at loading points especially at strategic market centres or farm gates to avoid initial pavement damage before enforcement at permanent weigh stations. In addition, it is recommended that the government of Ghana should relocate funding for more routine and periodic maintenance activities to achieve desirable IRI levels that contribute to lower total transport costs and, hence, make the port of Ghana competitive. Future studies will apply this research methodology to other transit corridors within the ECOWAS region. Also, other economic indicators such as accident costs and environmental costs can be included in the model.

Acknowledgement

The author wishes to acknowledge the assistance from officials of the Ghana Highway Authority and the Axle Load Working Group at the Ministry of Roads and Highways. Also, the guidance from Dr. Sam Owusu-Ababio at the University of Wisconsin-Platteville is appreciated.

Conflict of Interest Declarations

There are no commercials or associations that may pose a conflict of interest in connection with the submitted material.

References

Adarkwa,K. A., Poku-Boansi, M., and Obeng-Atuah, D. (2012). Overloading of freight vehicles on Ghana's transit corridors. Policy and Planning Directorate – Ministry of Roads and Highways.

Business and Financial Times. B&FT. (2014a). Challenges in transit trade disturbing – operators. [online]. Available at: https://www.ghanaweb.com/GhanaHomePage/business/Challenges-in-transit-trade-disturbing-Operators-317512 [Accessed 05 May 2021].

Business and Financial Times. B&FT. (2014b). Tussle over truck axle-load policy.[online]. Available at: https://www.ghanaweb.com/GhanaHomePage/business/Tussle-over-truck-axle-load-policy-310309 [Accessed 05 May 2021].

Driver Vehicle and Licensing Authority. DVLA. (2017). Road traffic regulations 2012, LI. 2180. [online]. Available at: http://www.dvla.gov.gh/singlenews [Accessed 06 July 2021].

Dumitrescu, A. C. (2013). Africa-Abidjan-Lagos trade and transport facilitation project (ALTTFP): P096407-Implementation Status Results Report: Sequence 08.

Ghana Highway Authority. GHA. (2022). Permissible axle load limits. [online]. Available at: https://www.highways.gov.gh/d_limit [Accessed 15 May 2022].

JICA. (2011). Study for the harmonization of vehicle overload control in the East African community. Final Report. PADECO. Co. Ltd

Koranteng-Yorke, J.B., Ghataora, G. and Odoki, J. (2015). Rational approach for tropical pavement design using life-cycle principles: case study of Ghana. International Journal of Pavement Engineering, 16(8), pp. 667-683.

Limao, N. and Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. The World Bank Economic Review, 15(3), pp. 451-479.

Meyburg, A. H., Schuler, R. E. and Saphores, J. D. (1994). Impact assessment of the regulation of heavy truck operations. In Project number 17-7-88-B.

Ministry of Roads and Highways. MRH. (2013). Ghana truck

truck drivers guide. [online]. Available at: http://www.mrh.gov.gh/files/publications/Drivers_Guide.pdf. [Accessed 26 Feb 2020].

Ministry of Roads and Highways. MRH. (2016). Status of implementation of UEMOA road map on axle load control. Published by UEMOA.

Opoku, G. M. K. (2009). Overloading problem and related axle load control regime in Ghana. A Study Commissioned by The Royal Danish Embassy, Final Report.

Oyekanmi O. J., Ibe C. C., Ebiringa O. T., and Ejem, E. A. (2020). Analysis of the extent of overloading on the Nigerian highways. International Journal of Transportation Engineering and Technology, 6(1), pp. 22-29.

Rizet, C. and Hine, J. (1993). A comparison of the costs and productivity of road freight transport in Africa and Pakistan. Transport Reviews. 13(2), pp. 151-165.

Rolt, J. (1981). Optimum axle loads of commercial vehicles - developing countries. TRRL Lab. Report 1002, Crowthorne, UK.

Sparks, G. A. and Neudorf, R. D. (1987). Productivity implications of vehicle weight and dimension regulations. Journal of the Transportation Research Forum, Transportation Research Forum, 28(1), pp. 392-401.

Strathman, J.G. (2001). Economics of overloading and the effect of weight enforcement. Center for Urban Studies College of Urban and Public Affairs Portland State University: Portland, OR, USA.

West Africa Trade Hub. WATH. (2010). Implementation of axle weight rules in UEMOA member stations. Lessons learned from transit traffic in Ghana. [online]. Available at: http://www.borderlesswa.com/sites/default/files/resources/mar11/implementation-axleweight-rules-ghana.pdf. [Accessed 05 July 2020].

Whiteside, R. E., Chu, T. Y., Cosby, J. C., Winfrey, R. and Whitaker, R. C. (1973). Changes in legal vehicle weights and dimensions: some economic effects on highways. NCHRP Report, (141).

.