Deterioration Analysis of Flexible Pavements under Overweight Vehicles

J. M. Sadeghi[1] and M. Fathali[2]

Abstract: In this paper, the influence of overloading on the operational life of flexible pavements is discussed, leading to the development of a deterioration model for pavement and a ticketing formulation for overweight vehicles. To conduct this research, a theoretical model is developed for flexible pavements. Using this model, sensitivity analyses are made and the significant parameters that influence the deterioration of pavement under truck loading are investigated. The relationships between the passing loads and the number of allowable load cycles are obtained. These relationships form the basis for further models by which the damage ratios of flexible pavements are assessed and vehicle fines determined. A numerical example is presented to indicate the applicability and practicality of the proposed models.

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CE Database subject headings: Flexible pavements; Damage; Deterioration; Vehicle; Weight.

Introduction

Overloading is among the most important causes of the deterioration of flexible pavements. This is especially critical in developing countries where the transportation of heavy freight on city roads and highways is increasing. Inspections indicate that this problem causes a great deal of damage to road networks and results in noticeable maintenance and repair costs (Maheri and Akbari 1993). In order to overcome this problem, one has to develop other branches of transportation such as railroads, increase the bearing capacity of pavement for the heavier traffic loads, and improve the axle load distribution of overweight vehicles. Ticketing regulations for overweight vehicles can also be introduced so that the users either reduce their loads to the allowable limits or pay compensation fees or fines for the damage.

Such regulation requires a method for calculating the fine. Little research had been done to develop a reasonable algorithm for the determination of these kinds of fines. This research was therefore conducted to investigate the deterioration patterns of flexible pavements under excess loads with a view to developing a practical method for calculating the fines for overweight vehicles.

To begin, a theoretical model was made for the typical flexible pavements used in most countries (CPMO 2004). Using this model, sensitivity analyses were made in order to investigate the main parameters influencing the deterioration of pavements under the vehicle loads. The parameters included asphalt layer thickness, pavements temperature, subgrade conditions, and vehicle speed. The effect of these parameters on the behavior of pavement under various loading conditions was formulated. Mathematical correlations between the loading condition and the operational life of pavement were then developed. Pavement fatigue and rutting failure were the main criteria used in the development of these correlations. These were then used to develop pavements deterioration models and overweight vehicle ticketing models. In order to show the applicability of these models, a numerical example is presented.

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Modeling Procedure

Model Geometry and Mechanical Features

There are two major models for the analysis and design of flexible pavements (Haung 1993). The first, most practical, and widely used one is based on Burmister's elastic layered theory (Burmister 1958) and the second one is based on the finite-element numerical method. The major limitation of the layered theory is the assumption of homogeneity. In this theory it is assumed that the mechanical properties are the same throughout the layer. With some modifications, the method can be applied to layered systems consisting of viscoelastic and nonlinear elastic materials. On the other hand, it is difficult and inaccurate to model the pavements configuration, especially at the layered boundaries, when using the finite-element method. This method has been rarely used for routine design purposes due to the large amount of computer time and storage space required. The first model was used in this research. The configuration of the typical layered model as suggested by the Country Planning and Management Organization (CPMO 2004) is presented in Fig. 1. As indicated in the figure, it is composed of four layers.

The basic assumptions are as follows: (1) each layer is homogeneous, isotropic, and linearly elastic with an elastic modulus E

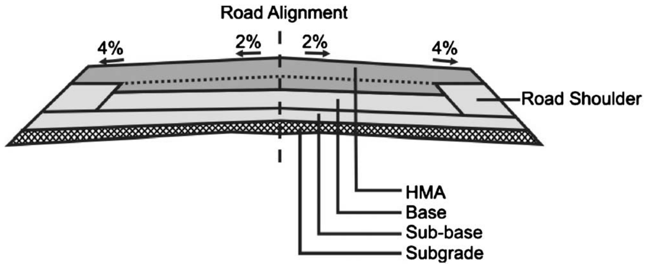

Fig. 1. Cross section of typical flexible pavements

and a Poisson ratio ν; (2) the material is weightless and infinite in area extent; and (3) each layer has a finite thickness H, but the lowest layer is infinite in thickness. The geometry and mechanical features of the model as suggested by CPMO (2004) are presented in Table 1.

Since the environmental temperature has considerable influence on the elasticity modulus of the asphalt layer, the resilient modulus of this layer in different environment temperatures is taken into account based on Table 2.

Loading Pattern

Table 3 indicates the different types of loading patterns applied in this research. These patterns include a single axle with single tires, a single axle with dual tires, a tandem axle with dual tires, a tridem axle with single tires, and a standard axle (Tabatabayi 1996; AASHTO 1993).

To come up with an applicable ticketing and damage model, it is necessary to relate the different types of loading patterns to passing overloaded vehicles. Overweight vehicles in most countries [particularly in the Middle East countries (ME)] fall into the following three groups that encompass 95% of trucks passing roads (Sadeghi and Fathali 2005; CTTO 2005):

1. Two-axle trucks (P_{all}=19 t);
2. Three-axle trucks (P_{all}=26 t); and
3. Five-axle trailers (P_{all}=40 t).

Where P_{all}=truck allowable load based on ME standards. The geometrical arrangement of axles and the distribution of the loads to the axles for the above trucks as suggested by Country Terminals and Transportation Organization (CTTO 2005) are presented in Fig. 2.

Based on the distribution of loads to axles presented in Fig. 2, single axles with dual tires are the critical axles for two-axle trucks. Also tandem axles with dual tires are the critical axles for both three-axle trucks and five-axle trailers.

Failure Criteria

Fatigue cracking, rutting, and thermal cracking are the three principle types of distress considered in the design of flexible pavements (Haung 1972). The fatigue cracking of flexible pavements is based on the horizontal tensile strain at the bottom of hot mixed asphalt (HMA). In this failure criterion, the allowable number of load repetitions (N_f) that causes fatigue cracking is related to the tensile strain (ε_t) at the bottom of HMA and the HMA modulus (E_1) as

$$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3} \tag{1}$$

Rutting occurs only on flexible pavements, as indicated by the permanent deformation or rut depth along the wheel paths. In this failure criterion, the allowable number of load repetitions (N_d) to limit rutting is related to the vertical compressive strain (ε_c) on top of the subgrade as

$$N_d = f_4(\varepsilon_c)^{-f_5} \tag{2}$$

where f_1–f_5=constant coefficients to calibrate the functions so that the predicted distress can match the field observations. For the standard mix used in design, the Asphalt Institute suggests the values of f_1–f_5 as follows (Asphalt Institute 1991)

$$f_1 = 0.0796 \quad f_2 = 3.291 \quad f_3 = 0.854 \quad f_4 = 1.365 \times 10^{-9}$$
$$f_5 = 4.477$$

Also Chrous et al. (1984) indicated that for asphalt layers with the thickness less than 10 cm (4 in.), the f_1 value must decrease to 0.0636. Thermal cracking includes both low-temperature cracking and thermal fatigue cracking. This type of distress is applied as a checking procedure to assess the thermal cracking potential after the thickness design is completed. Taking into account different asphalt temperatures, the effects of this type of distress as well as fatigue cracking and rutting were considered in this research.

Table 1. Geometry and Mechanical Features of Model

Layer number	Layer name	Compaction (%)	CBR	Elasticity (kg/cm^2)	Thickness (cm)	Poisson ratio
1	Asphalt surface (hot mix asphalt)	100	—	—	15	0.36
2	Base	100	50	5,273	15	0.45
3	Subbase	100	30	3,164	30	0.45
4	Subgrade	100	10	2,109	—	0.45

Table 2. Resilient Modulus of Asphalt Layer in Different Environment Temperatures (Karimizadeh and Ameri 1999, with Permission)

Average environment temperature (°C)	0	5	10	15	20	30
Average asphalt temperature (°C)	3	9	15	21	27	39
Elasticity modulus (kg/cm^2)	16,311	9,843	5,906	3,094	2,250	1,266

Table 3. Loading Pattern

Axle name	Axle load (t)	Axle wheels (number)	Wheel load (t)
Single axle with single tires	6.00	2	3.00
Single axle with dual tires	13.00	4	3.25
Tandem axle with dual tires	20.00	8	2.50
Tridem axle with single tires	18.00	6	3.00
Standard axle	8.20	4	2.05

Analysis Method

The simplest way to characterize the behavior of a pavements under wheel loads is to consider it as a homogeneous half-space (Yoder and Witczak 1975). However, a flexible pavements is a layered system with better materials on top and cannot be represented by a homogeneous mass, so the use of the Burmister's layered theory is more appropriate. Burmister (1958) first developed solutions for a two-layer system and then extended them to a three-layer system. With the advent of computers, the theory can be applied to a multilayer system with any number of layers (Haung 1993). The governing differential equation to be satisfied in an n-layer system is a fourth-order differential equation. For solving this equation and computing the stresses and displacements in this system, the KENLAYER computer program (Haung 1993) is used. The backbone of this program is the solution for an elastic multilayer system under a circular loaded area (Zafir et al. 1994). Solutions for elastic multilayer systems under a single load can be extended to cases involving multiple loads by applying the superposition principle.

Effective Parameters on Pavements Damage

Before discussing the effects of overloading on the operational life of flexible pavements, it is necessary to investigate the main parameters having considerable influences on the rate of the pavements deterioration. The possible effective parameters include asphalt layer thickness, pavements temperature, subgrade condition California bearing ratio (CBR), and vehicle speed. Sensitivity analyses of the pavements model were made in order to evaluate the effect of each parameter on the pavements stresses induced by the wheel loads. The loading pattern is based on a standard axle load with a contact pressure of 690 kPa (100 psi) according to the AASHTO method (AASHTO 1993).

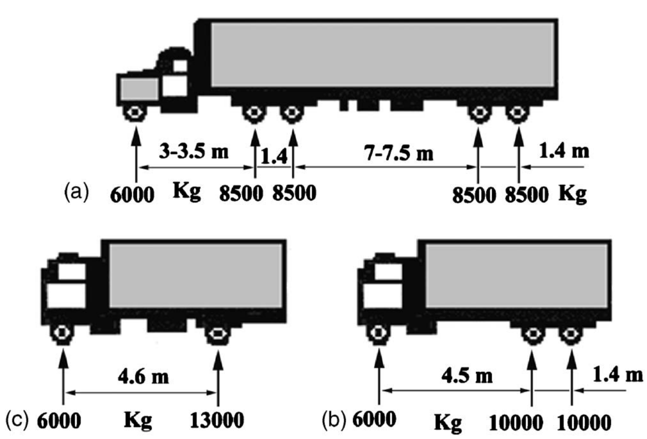

Fig. 2. (a) Five-axle trailers; (b) three-axle trucks; and (c) two-axle trucks

Table 4. Referenced Values Considered for Parameters in Sensitivity Analyses

Asphalt thickness	Pavements temperatures	Subgrade CBR	Vehicle speed
15 cm	15(°C)	10	75 km/h

To conduct the sensitivity analyses, all parameters except one were considered to have constant values as presented in Table 4. Then, the effect of the changing parameter on the analysis results was investigated. The values in Table 4 were considered as reference values for the parameters. The range of changes in the parameters are: (1) the asphalt layer thickness: from 5 to 30 cm; (2) the pavements temperature: from 0 to 30°C; (3) the subgrade CBR: from 2 to 10%; and (4) the speed of vehicle: from 0 to 100 km/h.

For most of the cases, the allowable number of load repetitions related to the tensile strain ε_t at the bottom of the asphalt layer (N_f) is smaller than those related to the compressive strain at the top of the subgrade (N_d). Hence N_f is more critical than N_d. However, the allowable number of load repetitions related to the compressive strain ε_c at the top of the subgrade (N_d) is more critical when the asphalt layer is very thin (less than 7 cm) or its temperature is high (higher than 25°C). The results of the sensitivity analyses are illustrated in Figs. 3–6. In these figures, T_a=pavements temperature; H=asphalt thickness; and CBR=California bearing ratio of the subgrade.

The results obtained from the sensitivity analyses were used to draw a coefficient for each parameter indicating the effects of the parameter on the number of allowable load repetitions. The coefficients named C_1, C_2, C_3, and C_4=functions of asphalt layer thickness, pavements temperature, subgrade CBR, and vehicle speed, respectively.

As shown in Fig. 3, the allowable number of load repetitions is highly influenced by the asphalt layer thickness. This indicates the important role of asphalt thickness in affecting the operational life of pavements. The same findings have been obtained in practice (Sadeghi and Fathali 2005). Based on the obtained results, an equation for C_1 was developed using the method of least squared errors as follows

$$C_1 = 1.1885 \times 10^{-2} \times e^{0.2955H} \tag{3}$$

in which C_1=coefficient signifying the impact of changes in the asphalt thickness on the number of load repetitions; and H=asphalt thickness (cm). As stated in Table 4, the referenced value for the thickness of the asphalt layer is 15. C_1 would have a value of one for the referenced value. Any changes in the asphalt thickness results in a different value for C_1, influencing the number of allowable load repartitions.

Fig. 4 presents subgrade quality (CBR) against allowable number of load cycles. Further information supporting these results is presented in the writers' previous experimental work (Sadeghi and Fathali 2005). Considering 10 as a referenced value for the CBR, C_2 can be obtained with the same manner as for C_1

$$C_2 = 6.7638 \times 10^{-1} \times e^{0.0391C} \tag{4}$$

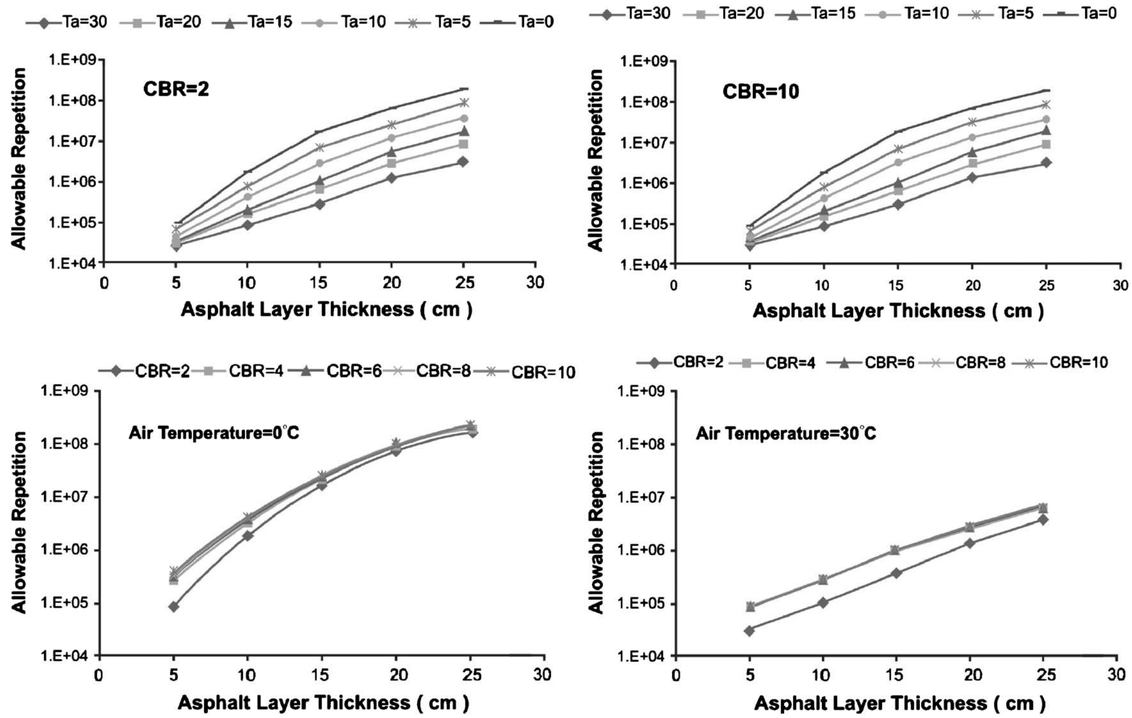

Fig. 3. Asphalt layer thickness versus allowable repetition (for standard axle)

in which C_2=coefficient representing the impact of changes in subgrade quality (CBR) on the number of load repetitions; and C=CBR for subgrade.

As indicated in Fig. 5, increasing the pavements temperature causes a substantial reduction in allowable load repetitions. This agrees with what has been found in practice (Sadeghi and Fathali 2005). Again the coefficient C_3 can be obtained based on the method of least squared errors

$$C_3 = 4.7660 \times e^{-0.1041T} \tag{5}$$

in which C_3=coefficient representing the impact of changes in the pavements temperature on the number of load repetitions; and T=asphalt temperature measured in °C.

Fig. 6 demonstrates that the allowable number of load repetitions increases as the vehicle speed increases. Karimizadeh has demonstrated the same finding in practice (Karimizadeh and

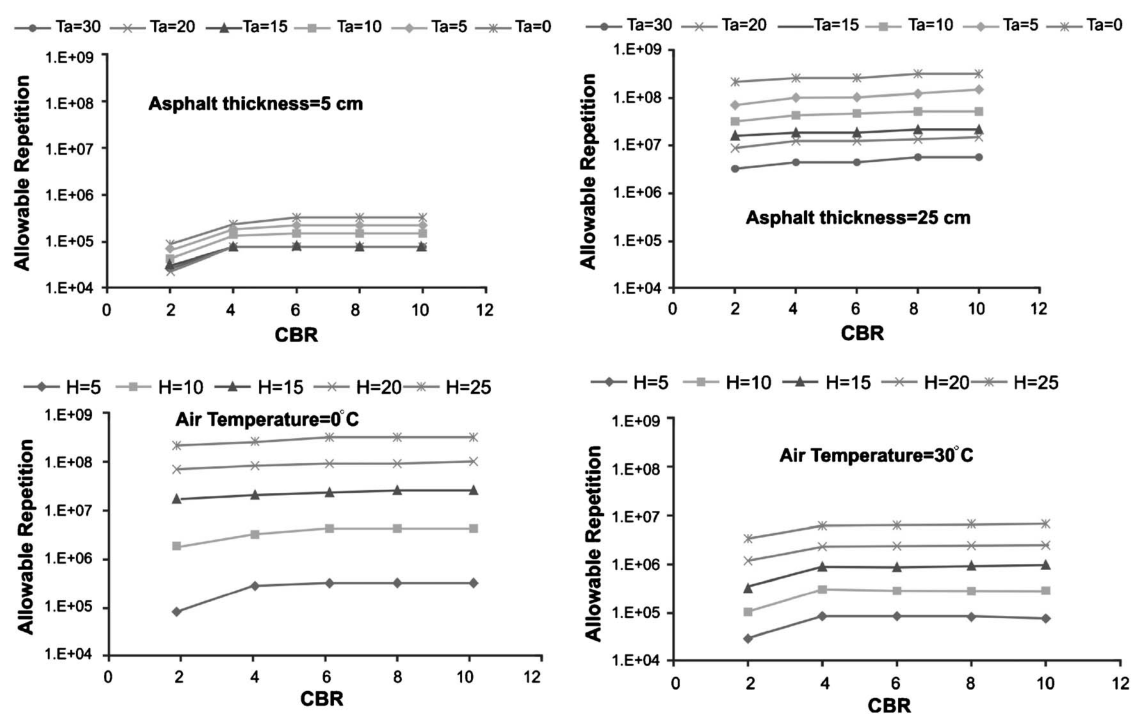

Fig. 4. Subgrade CBR versus allowable repetition (for standard axle)

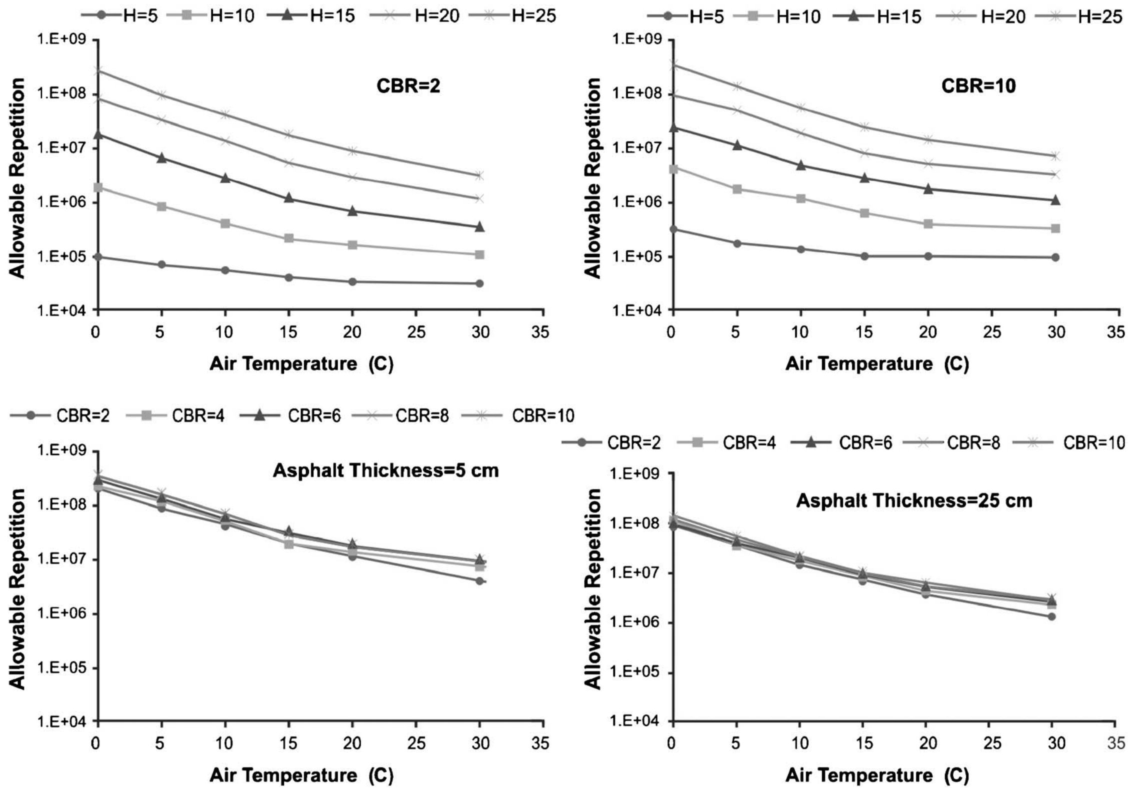

Fig. 5. Air temperature versus allowable repetition (for standard axle)

Ameri 1999). Coefficient C_4 can be obtained in the same way as for C_1-C_3, as follows

$$C_4 = 3.5790 \times 10^{-1} \times e^{0.0137V} \tag{6}$$

in which C_4=coefficient indicating the impact of changes in the vehicle speed on the number of load repetitions; and V=vehicle speed in km/h while the referenced value for the vehicle speed is 75 km/h. The results obtained from the sensitivity analyses are summarized in Table 5.

These coefficients should be taken into account when constructing a correlation between the vehicle loads and the number of load repetitions. For this purpose, first we draw a deterioration formula for a pavements with certain amounts for the asphalt layer thickness, the pavements temperature, the subgrade CBR, and the vehicle speed as indicated in Table 4. Then, we multiply the obtained formula by coefficients C_1-C_4 in order to consider the changes in those properties form one pavements to another. In other words, the final deterioration formula become as follows

$$F = C_1 C_2 C_3 C_4 f(P) \tag{7}$$

in which $f(P)$=deterioration formula for a pavements with the properties as presented in Table 4, and C_1, C_2, C_3, and C_4=coefficients which are functions of asphalt layer thickness, pavements temperature, subgrade CBR, and vehicle speed, respectively. The details of the model and the incorporation of these coefficients are discussed as follows.

Mathematical Load-Operational Life Models

The allowable number of load repetitions (N_f) that causes fatigue cracking and the allowable number of load repetitions (N_d) to limit rutting for different types of loading were obtained, using the KENLAYER computer program (Haung 1993), for the referenced values detailed in Table 4. The results are presented in Table 6.

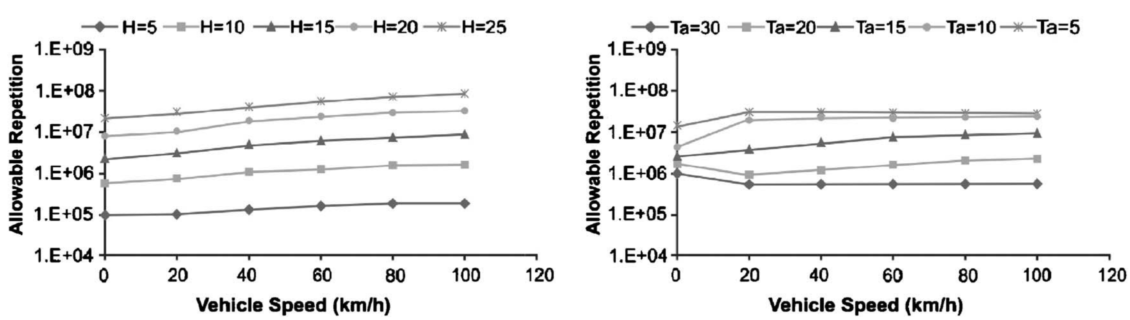

Fig. 6. Vehicle speed versus allowable repetition (for standard axle)

Table 5. Sensitivity Analyses Results

Row	Parameter	Referenced value	Coefficient
1	Asphalt thickness	15 cm	$C_1=1.1885\times10^{-2}\times e^{0.2955H}$
2	Subgrade CBR	10	$C_2=6.7638\times10^{-1}\times e^{0.0391C}$
3	Asphalt temperature	15°C	$C_3=4.7660\times e^{-0.1041T}$
4	Vehicle speed	75 km/h	$C_4=3.5790\times10^{-1}\times e^{0.0137V}$

To develop a mathematical correlation between the loading of a flexible pavements and its operational life, the axle loads against the allowable load cycles (N_f and N_d) were graphically drawn and mathematical equations for the allowable load cycles as a function of the axle load were obtained based on least squared errors. The general forms of the equations are as follows

$$N_d = K_1(P)^{K_2} \tag{8}$$

$$N_f = K_3(P)^{K_4} \tag{9}$$

in which P=axle load (t); and K_1–K_4=constant values. The amounts obtained for K_1–K_4 are presented in Table 7.

Deterioration Models

If axles, passing the road, have the allowable load of P and the allowable load repetitions of $(N)_{\text{all}}$, an increase in the axle load to $P+\Delta P$ decreases the allowable load repetition from $(N)_{\text{all}}$ to N. Thus, the reduction ratio of the allowable load repetition (indicating the operational life of the pavements) due to the incremental load of ΔP (excess load) can be demonstrated by the following formula

$$L_{LN} = 1 - \frac{N}{(N)_{\text{all}}} \tag{10}$$

where L_{LN}=reduction ratio of the allowable load repetition (i.e., the operational life reduction ratio) for the flexible pavements due to the excess load of ΔP; $(N)_{\text{all}}$=allowable load repetition when axles passing the road have the allowable load of P; and N=allowable load repetition when each axle has excess loads of ΔP (i.e., axle load of $P+\Delta P$). Hence, the operational life reduction factor (deterioration model) for any overloaded axle pass is obtained as follows

$$F = \frac{1}{N} - \frac{1}{N_{\text{all}}} \tag{11}$$

where F=operational life reduction factor for the flexible pavements when an axle with excess load of ΔP passes the pavements.

If we substitute Eqs. (8) and (9) into Eq. (11), the operational life reduction factor (F) is obtained as a function of the truckload. It is made for the three kinds of trucks as follows:

Two-Axle Trucks

As stated in the previous section, single axles with dual tires are critical loading patterns for two-axle trucks. Considering the allowable axle loads as indicated in Fig. 2, the operational life reduction factor is obtained as

$$F = \left[\frac{1}{N_f((19+\Delta P)-6)} - \frac{1}{N_f(13)}\right] \tag{12}$$

where ΔP=truck excess load. Substituting Eq. (9) into Eq. (12) the operational life reduction factor can be drawn as a function of the track loads. Taking into account the first row of Table 6 for K_1 and K_2, and incorporating C_1–C_4, the deterioration model (the operational life reduction factor) for the two-axle trucks is obtained as follows

$$F = 6.8561 \times 10^{-13} \times \lfloor((19+\Delta P)-6)^{3.2910} - 4634\rfloor \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)} \tag{13}$$

where ΔP=truck excess load (t); H=asphalt thickness (cm); C=subgrade CBR (%); T=asphalt temperature (°C); and V=vehicle speed (km/h).

Table 6. Number of Load Repetitions against Load

Single axle with dual tires			Tandem axle with dual tires			Tridem axle with single tires		
Load (t)	N_f	N_d	Load (t)	N_f	N_d	Load (t)	N_f	N_d
1	2.16E+12	4.00E+12	1	2.59E+11	8.90E+13	1	6.80E+11	6.00E+14
3	5.83E+08	2.70E+10	5	1.40E+09	6.60E+10	5	3.78E+09	8.00E+11
5	1.09E+08	2.60E+08	10	1.33E+08	3.00E+09	10	3.51E+08	2.00E+10
7	3.59E+07	7.21E+08	15	3.42E+07	4.88E+08	15	8.96E+07	5.45E+09
9	1.57E+07	2.45E+08	20	1.31E+07	1.35E+08	20	3.59E+07	1.10E+09
11	8.10E+06	7.95E+07	25	8.10E+06	4.96E+07	25	1.69E+07	4.88E+08
13	4.68E+06	3.99E+07	30	3.66E+06	2.19E+07	30	1.11E+07	1.80E+08
15	2.92E+07	2.19E+07	35	2.36E+06	1.10E+07	35	6.08E+06	7.95E+07
17	1.93E+06	1.10E+07	40	1.34E+06	6.05E+06	40	3.66E+06	4.96E+07
19	1.34E+06	6.97E+06	45	9.65E+05	3.57E+06	45	2.92E+06	2.65E+07

Table 7. Values Obtained for Coefficients in Eqs. (8) and (9)

Row	Axle type	K_1	K_2	K_3	K_4
1	Single axle with dual tires	4.00E+12	−4.49	2.00E+10	−3.29
2	Tandem axle with dual tires	9.00E+13	−4.47	3.00E+11	−3.28
3	Tridem axle with single tires	2.00E+15	−4.79	6.00E+11	−3.25

Three-Axle Trucks

The loading pattern of three-axle trucks is a tandem axle with dual tires as discussed in the "Loading Pattern" section. Considering the allowable front and back axle loads of the three-axle trucks to be 6 and 20 t, respectively, the operational life reduction factor for the three-axle trucks is obtained as follows

$$F = \left[\frac{1}{N_f((26+\Delta P)-6)} - \frac{1}{N_f(20)} \right] \tag{14}$$

where ΔP=truck excess load. Substituting Eq. (9) into Eq. (14), the operational life reduction factor can be drawn as a function of the track loads. Taking into account the second row of Table 6 for K_1 and K_2, and incorporating $C_1 - C_4$, the operational life reduction factor for three-axle trucks is obtained as follows

$$F = 4.5707 \times 10^{-14} \times [((26+\Delta P)-6)^{3.2820} - 18620] \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)} \tag{15}$$

All parameters are as defined earlier.

Five-Axle Trailers

Considering Fig. 2 and applying the same approach as for the two- and three-axle trucks, the operational life reduction factor for the five-axle trailers is obtained [Eq. (16)]. Due to the existence of two critical axles in the five-axle trailers, the equation is multiplied by 2

$$F = \left[\frac{1}{N_f\left(\frac{(40+\Delta P)-6}{2}\right)} - \frac{1}{N_f(17)} \right] \times 2 \tag{16}$$

Considering the third row of Table 7, and incorporating coefficients $C_1 - C_4$, the operational life reduction factor for the five-axle trailers is obtained as follows

$$F = 9.3980 \times 10^{-15} \times [((40+\Delta P)-6)^{3.2820} - 106246] \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)} \tag{17}$$

All parameters are as defined earlier.

Ticketing Models

Having the above operational life reduction factors and multiplying them by the total cost of the pavements gives rise to the ticketing amount, i.e., $S = F \times L \times M$, where L=pavements length (m); M=total cost of the pavements per meter; F=operational life reduction factor due to the excess loads; and S=ticketing sum. The final results are presented in Table 8.

The scope of this research has been to develop models that predict the cost of damage to road pavements caused by overweight vehicles. To expand this research, an investigation into the damage to the road substructures such as road bridges and drainage systems etc. would be beneficial. This has been made partially by the writers elsewhere as they have studied the damages to the road bridges (Sadeghi and Fathali 2007). Incorporating the substructure costs will allow the calculation of a comprehensive fine. Moreover, the police force may add an extra charge to it due to the nature of the offense.

Table 8. Ticketing Models for Road pavements

Vehicle type	Ticketing models
Two axle	$S=6.8561\times10^{-13}\times[((19+\Delta P)-6)^{3.2910}-4{,}634] \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)}\times L\times M$
Three axle	$S=4.5707\times10^{-14}\times[((26+\Delta P)-6)^{3.2820}-18{,}620] \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)}\times L\times M$
Five axle	$S=9.3980\times10^{-15}\times[((40+\Delta P)-6)^{3.2820}-106{,}246] \times e^{(0.2955H+0.0391C-0.1041T+0.0137V)}\times L\times M$

Practical Use of Model

In practice a road check point must be established. For any vehicles of interest the following information should be determined: (1) the vehicle excess load; (2) the length of the road passed by the vehicle; (3) the average cost of the pavements per meter; and (4) the asphalt layer thickness, the pavements temperature, the subgrade CBR, the vehicle speed, and the vehicle type. Applying the ticketing models in Table 8 will calculate the fine.

A software program can perform the calculations. The average values for the asphalt layer thickness, the pavements temperature, and the subgrade CBR can be imported to the software as defaults for each road. The software can be linked to a digital truck scale, importing any excess load automatically. The input data thus becomes the vehicle type, the average vehicle speed, and the length of the road passed by a truck. Once these data are manually entered the total fine can be obtained.

Part of the research conducted for this paper involved testing the models on vehicles driving the 100-km-long road between Isfehan and Tehran (central Iran). The payable ticket sums for the three kinds of vehicles were expressed in two ways: (1) in percentage of total road cost; and (2) in United States currency (USD) (Fig. 7) where the estimated pavements construction cost in Iran is currently USD 1,450/m (CPMO 2004). A comparison of the fines obtained for the three types of vehicle indicates that the damage made by two-axle trucks is much higher than that

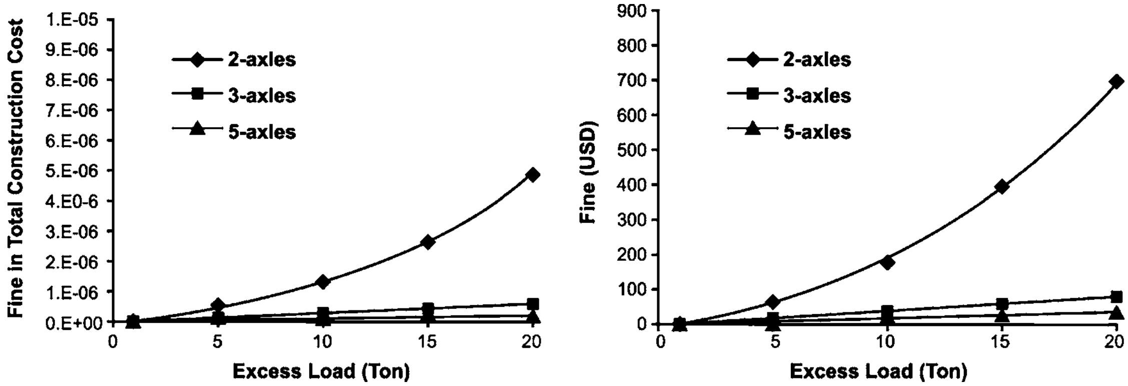

Fig. 7. Ticketing sums at Isfehan–Tehran road block

caused by three- and five-axle vehicles. This is due to the distribution of the excess load. That is, in a two-axle vehicle, the load is spread over two axles only while for the three- and five-axle vehicles the excess load is distributed to three and five axles, respectively. This agrees with what has been found in practice (Maheri and Akbari 1993).

The current method of calculating a fine issued by the Iranian road authorities is based on a linear relationship between the excess load and the fine. The relationship is based on the averaging of the personal judgments of expert road authority officials over a period of 10 years (CTTO 2005). A comparison of the proposed fine obtained by using the method illustrated in this paper with those currently issued by the road authorities is presented in Fig. 8. The comparison demonstrates that the results obtained in this research are in agreement with what is currently issued by the Iranian road authorities if the excess loads are less than 20% of the allowable vehicle loads. However, as the excess load increases the differences between the results obtained here and those currently used in practice increase. In other words, the results obtained here are higher than the revenue from fines currently collected by the road authorities in Iran if the magnitude of the excess load is more than 20% of the vehicles allowable loads. According to the model the owners of overloaded vehicles are not paying adequate compensation for the pavements damage they are causing.

Conclusions

This paper presents some models that describe the behavior of flexible pavements under overloaded vehicles and the determination of related ticketing sums. To investigate the pavements damage under overloaded vehicles, fatigue and rutting criteria were considered. The theoretical models for flexible pavements were developed. Using these models, sensitivity analyses were conducted to study the influences of asphalt layer thickness, pavements temperature, subgrade condition (CBR), and vehicle speed on the deterioration rate of pavements. Mathematical correlations between the allowable number of load cycles and the magnitude of axle loads were developed, incorporating the main factors influencing the pavements behavior and taking into account the load conditions. Using these constructed correlations, the operational life reduction factors (deterioration models) due to the excess loads for the overloaded vehicles were obtained. These deterioration models were then used to develop a model for ticketing the overweight vehicles. To show the capability and applicability of the models, a numerical example was presented. The fines obtained from the numerical example were compared with those currently issued by the Iranian road authorities. The results indicate that the revenue collected from fines by the road authorities is inadequate compensation for the pavements damages predicted by the model, particularly if the magnitude of the excess load is more than 20% of the vehicles allowable loads.

Construction of this ticketing model is based on only the cost of road pavements damage. To complete this study the costs of damage to the road substructures (such as bridges and drainage systems etc.) caused by overloaded vehicles should also be examined. Incorporating both the total damage cost to the road and its substructures due to vehicle overloading will lead to a comprehensive ticketing model. Research in this field is in progress.

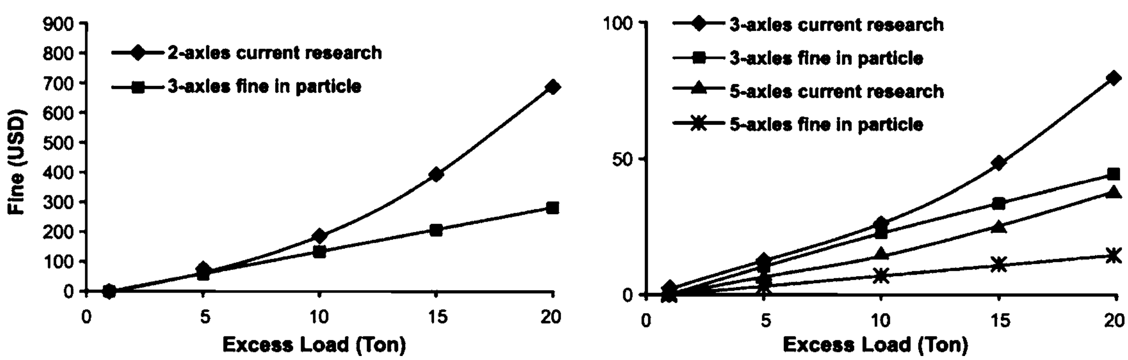

Fig. 8. Comparison of ticketing sums at Isfehan–Tehran road block with currently collected fines

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