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Theoretical Traffic Loads and Classification of Turkish Railway Network according to the Track Maintenance

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Various kinds of rail vehicles are running on a railway track such as; passenger vehicles, freight vehicles, main-line locomotives, shunting engines. The algebraic sum of the vehicle loads cannot give an accurate picture of the running load, because it does not take into account the way in which the load is applied, the running speed, so on. Therefore, a complex parameter giving an accurate estimate of the passing traffic load is necessary. Union Internationale de Chemins de Fer, UIC, proposed a method to calculate the theoretical traffic load for this purpose. In this study, initially, the theoretical traffic loads for Turkish Railway Network are calculated with the help of train loads, speeds and tonnage for 2003. At the second stage, the classification of lines for the purpose of track maintenance is made by using these traffic loads.

Keywords: Theoretical traffic loads, classification of lines, Turkish Railway Network, track maintenance

1. Introduction

Traffic loads are one of the key factors that have a direct bearing on track maintenance. In order to facilitate economic studies and comparisons between the different railways, lines are classified into several groups depending on the type of traffic and on the loads they carry [1].

Railway tracks form a very critical part of any rail company's asset base, as it provides them with the required business operability. The safety and hence the need for maintenance of this rail resource cannot be over stated.

Track maintenance refers to the comprehensive set of activities involved in ensuring that the railway tracks meet the required safety and quality standards. This includes inspection, track-data collection and possible renewals. With increasing pressure on rail operators to increase operational efficiency, track maintenance is required to be cost-effective too.

Track maintenance (as compared to vehicle maintenance) is a rather complex activity due to the geographical spread of the asset. Unlike vehicles which can be brought to sheds or other common points for inspection; for tracks any inspection, repair or data collection requires physical movement of man and material, adding to the cost and time involved in the task [2].

After the various railway system components start operating, wear begins to appear and, after a certain time, maintenance becomes necessary. Track maintenance decisively affects both train safety and passenger comfort. Track maintenance expenses represent a significant percentage of total railway network expenses.

Therefore, track maintenance expenses should be kept as low as possible while ensuring, for a specific operation speed, that running safety and passenger comfort remain acceptable at all times. With respect to safety, maintenance should be preventive; regarding comfort, maintenance should be corrective; and, finally, as regards the financial aspects of the matter, an optimum solution should be sought, so as to ensure a satisfactory safety margin and prevent an irreparable degradation of track quality.

The requirements for bearing strength and quality of the track depend to a large extent on the load parameters:

- axle load: static vertical load per axle,
- tonnage borne: sum of the axle loads,
- running speed.

The static axle load level, to which the dynamic increment is added, in principle determines the required strength of the track. The accumulated tonnage is a measure of the deterioration of the track quality and as such provides an indication of when maintenance and renewal are necessary.

Table 1
Load categories according to UIC.

Category	Axle load (kN)	Weight/m (kN/m)
A	160	48
B1	180	50
B2	180	64
C2	200	64
C3	200	72
C4	200	80
D4	225	80

The dynamic load component which depends on speed and horizontal and vertical track geometry also plays an essential part here.

2. Line classification

The UIC (International Union of Railways), which is the organization for railway cooperation and which counts standardization among its tasks, makes a distinction between load categories according to UIC leaflet 700; these categories are shown in the Table 1.

Tracks are usually classified in four categories, depending on train speed, as follows:

- High speed tracks (V > 200 km/h),
- Rapid speed tracks (140 km/h < V < 200 km/h)
- Medium speed tracks (100 km/h < V < 140 km/h)
- Low speed tracks (V < 100 km/h)[3]

Table 2
The values of the coefficients S_v and S_m according to the train speed[1].

Coefficients	Value	Speed Interval (km/hr)
S_v and S_m	1.00	$V \leq 60$
S_v and S_m	1.05	$80 < V \leq 100$
S_v	1.25	$100 < V \leq 130$
S_v	1.35	$130 < V \leq 160$
S_v	1.40	$160 < V \leq 200$
S_v	1.45	$200 < V \leq 250$
S_v	1.50	$250 < V$

Table 3
The classification of lines according to the notional traffics [3].

UIC Group	Daily Traffic (Grosstonne)
1	>120,000
2	120,000-85,000
3	85,000-50,000
4	50,000-28,000
5	28,000-14,000
6	14,000-7,000
7	7,000-3,500
8	3,500-1,500
9	<1,500

3. Objective

The aim of this study is to determine the classification of Turkish railway lines for the purpose of track maintenance by using UIC standarts. In order to classify the railway lines, the analogue of the Passenger Vehicle Unit (PVU) of traffic engineering is used. The loads of the various trains are converted into the equivalent passenger train loads to determine the traffic load (or tonnage) on a track .

4. Calculation of the theoretical traffic loads

A notional traffic value, allowing for the speed factor and the relative wear effect of axle-loads, shall be used. The method used for calculating the notional traffic value for tracks over a particular line section and the classification adopted are specified below.

Line classification shall be determined on the basis of a theoretical traffic load T_f expressed by Eq.(1):

$$\begin{aligned} T_f &= S_v \times \ (T_v \times \ K_t \times \ T_{tv}) \\ &+ \ S_m \times \ (K_m \times \ T_m + K_t \times \ T_m) \end{aligned} \quad (1)$$

where;

T_v : the mean daily passenger tonnage in gross tonnes hauled.

T_m : the daily freight tonnage in gross tonnes hauled.

T_{tv}: the mean daily tonnage of tractive units used in passenger traffic, in tonnes.

T_{tm}: the mean daily tonnage of tractive units used in freight traffic, in tonnes.

Table 4
Annual passenger and freight traffics on the Turkish railway network in 2003

Line Sections	Traffic (Gross tonnes)			Line Sections	Traffic (Gross tonnes)		
	Passenger	Freight	Total		Passenger	Freight	Total
Sirkeci-Halkalı	868,027	815,232	15,126,997	Gaziantep-Karkamış	30,837	695,304	727,935
Halkalı-Pehlivanköy	810,223	1,818,980	2,635,279	Karkamış-Hudut	25,503	531,251	556,883
Haydarpaşa-Gebze	5,070,188	1,325,988	15,641,747	Boğazköprü-Ulukışla	398,934	4,400,866	4,847,364
Gebze-Arifiye	5,037,937	2,377,921	7,421,726	Ulukışla-Yenice	978,029	6,149,569	7,129,929
Arifiye-Eskişehir	2,843,363	3,331,636	6,182,838	Yenice-Adana	3,085,255	5,248,937	8,382,420
Eskişehir-Polatlı	2,467,248	2,819,171	5,297,258	Adana-Toprakkale	550,849	5,243,399	5,836,995
Sincan-Polatlı	2,727,944	2,601,379	5,342,520	Malatya-Yolçatı	610,417	1,895,259	2,512,633
Marşandiz-Sincan	2,646,263	2,695,098	18,076,003	Yolçatı-Elazığ	317,665	1,267,771	1,606,803
Ankara-Marşandiz	4,058,530	2,375,655	16,230,876	Elazığ-Tatvan	179,661	828,522	1,020,998
Ankara-Kayaş	1,263,817	2,949,217	16,049,957	Yolçatı-Maden	287,648	660,971	965,579
Kayaş-Irmak	1,305,722	3,042,919	4,397,210	Maden-Batman	250,159	436,417	708,058
Irmak-Karabük	56,241	4,216,377	4,280,961	Batman-Kurtalan	208,967	169,809	380,910
Karabük-Zonguldak	853,277	1,688,104	2,585,704	Eskişehir-Alayunt	2,065,949	2,849,149	4,922,040
Irmak-Boğazköprü	1,247,736	5,963,120	7,229,562	Alayunt-Afyon	1,188,139	3,144,772	4,336,719
Boğazköprü-Kayseri	1,150,167	6,203,878	7,375,911	Afyon-Konya	932,833	2,454,215	3,388,050
Hanlı-Kayseri	1,002,106	5,265,805	6,292,348	Konya-Ulukışla	653,513	2,076,739	2,730,390
Hanlı-Bostankaya	0	2,940,223	2,940,223	Alayunt-Balıkesir	941,497	2,618,957	3,563,622
Bostankaya-Çetinkaya	1,070,062	5,918,226	7,009,250	Soma-Balıkesir	927,126	1,126,006	2,053,131
Kalın-Hanlı	1,025,403	2,045,614	3,102,575	Manisa-Soma	952,024	956,444	1,908,816
Sivas-Bostankaya	1,074,028	3,196,831	4,294,156	Çiğli-Manisa	1,298,862	943,844	2,244,098
Sivas-Kalın	1,066,703	2,811,893	3,911,096	Halkapınar-Çiğli	1,355,828	1,090,346	2,831,457
Kalın-Samsun	156,631	1,592,291	1,752,370	Alsancak-Halkapınar	2,542	758,052	991,106
Çetinkaya-Divriği	598,694	4,258,474	4,868,370	Alsancak-Şirinyer	176,394	534,990	1,152,080
Divriği-Erzurum	555,202	1,780,693	2,347,360	Şirinyer-A.Menderes	996,584	566,990	1,699,267
Erzurum-Kars	431,404	775,694	1,220,284	A.Menderes- Goncalı	787,852	497,839	1,287,855
Kars-Doğukapı	184,885	7,212	210,871	Goncalı-Karakuyu	470,458	631,304	1,108,289
Hekimhan-Çetinkaya	480,566	3,216,137	3,712,841	Karakuyu-Eğridir	135,974	233,325	371,246
Malatya-Hekimhan	468,601	2,845,686	3,386,490	Bandırma-Balıkesir	153,279	1,567,467	1,720,833
Malatya-Narlı	139,987	1,752,286	1,919,725	Afyon-Karakuyu	433,952	1,251,967	1,693,655
Fevzipaşa-Narlı	234,221	2,709,607	2,944,665	Alaşehir-Manisa	436,867	248,024	685,684
Toprakkale-Fevzipaşa	324,053	3,519,363	3,855,670	Dumlupınar-Alaşehir	296,023	298,027	594,758
Toprakkale-Iskenderun	207,857	3,412,208	3,621,564	Afyon-Dumlupınar	238,284	395,393	634,900
Narlı-Gaziantep	90,077	1,089,162	1,182,964				

K_m: a coefficient allowing both for the influence of the load and wear effect of freight bogies:

- normally corresponds to the following value: Km=1.15 and,
- for tracks handling heavy loads :
  - Km=1.30, for traffic based primarily on 20t axle-loads (> 50% of traffic) or for a significant proportion of traffic with 22.5 t axle-loads (> 25% of traffic).
  - Km=1.45, for traffic based primarily on 22.5t axle-loads (> 50% of traffic) or for traffic largely consisting of 20 t or heavier axle-loads (> 75% of traffic).

K_t: a coefficient that allows for the traction-motor axle wear factor, and is equal to 1.40

S_v and S_m are coefficients that allow for train running speeds. S_v relates to the speed of the fastest passenger trains. S_m relates to the speed of ordinary freight trains. S_v and S_m coefficients shall be assigned at the Table 2.

Table 5
The average speed of passenger trains according to the line sections [5-13]

Line	Speed (km/hr)	Line	Speed (km/hr)	Line	Speed (km/hr)
Sirkeci-Halkalı	85	Çetinkaya-Divriği	65	Batman-Kurtalan	65
Halkalı-Pehlivanköy	90	Divriği-Erzurum	65	Eskişehir-Alayunt	80
Haydarpaşa-Gebze	90	Erzurum-Kars	65	Alayunt-Afyon	80
Gebze-Arifiye	105	Kars-Doğukapı	65	Afyon-Konya	85
Arifiye-Eskişehir	90	Hekimhan-Çetinkaya	75	Konya-Ulukışla	85
Eskişehir-Polatlı	95	Malatya-Hekimhan	75	Alayunt-Balıkesir	80
Sincan-Polatlı	105	Malatya-Narlı	85	Soma-Balıkesir	85
Marşandiz-Sincan	105	Fevzipaşa-Narlı	85	Manisa-Soma	85
Ankara-Marşandiz	65	Toprakkale-Fevzipaşa	70	Çiğli-Manisa	85
Ankara-Kayaş	85	Toprakkale-Iskenderun	80	Halkapınar-Çiğli	65
Kayaş-Irmak	75	Narlı-Gaziantep	65	Alsancak-Halkapınar	60
Irmak-Karabük	75	Gaziantep-Karkamış	60	Alsancak-Şirinyer	65
Karabük-Zonguldak	75	Karkamış-Hudut	60	Şirinyer-Adnan Menderes	90
Irmak-Boğazköprü	85	Boğazköprü-Ulukışla	90	Adnan Menderes-Goncalı	85
Boğazköprü-Kayseri	75	Ulukışla-Yenice	85	Goncalı-Karakuyu	65
Hanlı-Kayseri	70	Yenice-Adana	85	Karakuyu-Eğridir	65
Hanlı-Bostankaya	-	Adana-Toprakkale	90	Bandırma-Balıkesir	85
Bostankaya-Çetinkaya	85	Malatya-Yolçatı	65	Afyon-Karakuyu	65
Kalın-Hanlı	75	Yolçatı-Elazığ	65	Alaşehir-Manisa	80
Sivas-Bostankaya	95	Elazığ-Tatvan	70	Dumlupınar-Alaşehir	80
Sivas-Kalın	80	Yolçatı-Maden	55	Afyon-Dumlupınar	80
Kalın-Samsun	60	Maden-Batman	60		

Those railways which only keep statistics on aggregate tonnages (tractive units and trailing stock) T'_v and T'_m defined below, and are unable to calculate T_{tv} and T_{tm} separately, may use the Eq.(2):

$$T_f = \lambda_v \times (S_v \times T'_v) + \lambda_m \times (S_m \times K_m \times T'_m) \quad (2)$$

where;

T'_v : the daily mean passenger tonnage (tractive units and trailing stock) expressed in tonnes.

T'_m : the daily mean freight tonnage (tractive units and trailing stock), expressed in tonnes.

λ_v and λ_m are coefficients that allow for the wear effect of tractive-unit axles and of the percentage they represent in overall freight and passenger tonnages.

These coefficients shall have the following values:

- $\lambda_v = 1.08$, when the bulk of traffic is moved in hauled trains, with tractive units accounting for about 20% of the overall tonnage of passenger trains.
- $\lambda_v = 1.05$ when a significant proportion of passenger traffic is moved by motor train-sets, with the tonnage of tractive units accounting for about 12% of the overall tonnage of passenger trains.
- λ_v =1.02 when $K_m = 1.15$
- λ_v =1.00 when K_m=1.3 or $K_m = 1.45$, with the tonnage of tractive units accounting in all these cases for about 10% of the aggregate tonnage of freight trains.

The notional traffic values are used to classify the lines for the purpose of track maintenance. The class intervals determined by UIC are given in Table 3.

5. Data and Analysis

The theoretical traffic loads are calculated for the year 2003. Initially, the passenger and freight traffics, expressed in gross tonnes, are calculated for each lines. The beginning and the end points of the lines are determined according to TCDD publication [4], for which the traffic data were

Table 6
Annual passenger and freight traffics on the Turkish railway network in 2003

Line	T_f	Line Class	Line	T_f	Line Class
Sirkeci-Halkalı	5,857	7	Gaziantep-Karkamış	2,568	8
Halkalı-Pehlivanköy	9,236	6	Karkamış-Hudut	1,968	8
Haydarpaşa-Gebze	21,975	5	Boğazköprü-Ulukışla	17,032	5
Gebze-Arifiye	27,103	5	Ulukışla-Yenice	25,231	5
Arifiye-Eskişehir	21,541	5	Yenice-Adana	29,193	4
Eskişehir-Polatlı	18,436	5	Adana-Toprakkale	20,550	5
Sincan-Polatlı	19,355	5	Malatya-Yolçatı	8,647	6
Marşandiz-Sincan	19,387	5	Yolçatı-Elazığ	5,502	7
Ankara-Marşandiz	21,070	5	Elazığ-Tatvan	3,509	7
Ankara-Kayaş	14,805	5	Yolçatı-Maden	3,205	8
Kayaş-Irmak	14,894	5	Maden-Batman	2,295	8
Irmak-Karabük	15,192	5	Batman-Kurtalan	1,254	9
Karabük-Zonguldak	8,663	6	Eskişehir-Alayunt	16,566	5
Irmak-Boğazköprü	25,484	5	Alayunt-Afyon	14,892	5
Boğazköprü-Kayseri	25,669	5	Afyon-Konya	11,915	6
Hanlı-Kayseri	21,868	5	Konya-Ulukışla	9,620	6
Hanlı-Bostankaya	10,472	6	Alayunt-Balıkesir	12,253	6
Bostankaya-Çetinkaya	24,720	5	Soma-Balıkesir	7,165	6
Kalın-Hanlı	10,472	6	Manisa-Soma	6,646	7
Sivas-Bostankaya	15,041	5	Çiğli-Manisa	7,781	6
Sivas-Kalın	13,329	6	Halkapınar-Çiğli	8,096	6
Kalın-Samsun	6,135	7	Alsancak-Halkapınar	2,707	8
Çetinkaya-Divriği	17,027	5	Alsancak-Şirinyer	2,453	8
Divriği-Erzurum	8,067	6	Şirinyer-Adnan Menderes	5,411	7
Erzurum-Kars	4,103	7	Adnan Menderes-Goncalı	4,454	7
Kars-Doğukapı	600	9	Goncalı-Karakuyu	3,710	7
Hekimhan-Çetinkaya	12,948	6	Karakuyu-Eğridir	1,253	9
Malatya-Hekimhan	11,591	6	Bandırma-Balıkesir	6,104	7
Malatya-Narlı	6,717	7	Afyon-Karakuyu	5,807	7
Fevzipaşa-Narlı	10,448	6	Alaşehir-Manisa	2,241	8
Toprakkale-Fevzipaşa	13,542	6	Dumlupınar-Alaşehir	1,981	8
Toprakkale-Iskenderun	12,799	6	Afyon-Dumlupınar	2,149	8
Narlı-Gaziantep	4,159	7			

present. Lines and their traffic values are given in Table 4

The traffic values presented in Table 4 are in aggregate tonnages. In other word, they are the summation of the tractive units and trailing stock weigths. Thus, the theoritical traffic values will be calculated with Eq. (2).

Secondly, the coefficients related with the wear effect of tractive-unit axles, λ_v and λ_m, are determined. The analysis of the weigths of passenger and freight trains showed that, the bulk of traffic is moved in hauled passenger trains, with tractive units accounting for about 20% of the overall tonnage. Thus, for passenger trains, λ_v is determined as 1.08. For freight trains as the traffic is based on 20 tonnes axle-loads, the coefficient allowing both for the influence of the load and wear effect of freight bogies, K_m, and λ_m are taken as 1.30 and 1.00 respectively.

Thirdly, the speeds of passenger and freight trains are examined [5-13]. The average speeds for passenger trains are given for each line in Table 5. On the other hand, the average speeds for freight trains determined as 60 km/hr or less for all lines.

At the next step, the speed coefficient of passenger trains, S_v, is calculated for each line by using Table 1 and 4. As the speed of freight trains are less or equal to 60 km/hr, the speed coefficient, S_m, is equal to 1.00.

Finally, the theoritical traffic values are calculated with Eq. (2) for each line seperately. These values are used for the classification of lines for the purpose of track maintenance according to UIC standards. Line classes and theoritical traffic values are given in Table 6.

6. Conclusions

In this study, the theoretical traffic loads and the classification of lines for track maintenance are determined for the year 2003 with respect to the UIC standards. According to the analysis, the lines are identified between Class 4 and 9. When the lenght of the lines is taken into account, the distribution of lines class is obtained such as; 2.8% in Class 4, 29.4% in Class 5, 29.2% in Class 6, 24.6% in Class 7, 10.6% in Class 8, and 3.4% in Class 9. The line classification shows also the strength of a railway network. The average line class of Turkish Railway Network is 6.2.

The main reason of this result is the lowness of applied speed. The low speed also decraeses the capacity of a line. However, an increasing at the train speed can only realized if the track is convenient.

On the other hand, the UIC maintenance formula (Eq. (2)) is not an overall evaluation of the maintenace class. This formula is not adequately sensetive to speed and traffic changes. For instance, at the zone "Sirkeci-Halkalı", the average speed of passenger trains is 85 km/hr. Increasing speed by 50% which means the average speed will be 127.5 km/hr, will increase the theoretical traffic load, T_f. The present value of T_f, which is 5,857 t, will be 6,114 t. However, the maintenance class will be the same (Class 7). In that, for T_f between 3,500 and 7,000 t, the maintenance class is 7. It is not realistic to claim that, the increase of speed from 85 km/hr to 127.5 km/hr will not change the need of maintenance. The speed augmentation will affect the centrifugal force in the curves. When the balance between centrifugal and centripital forces change, the superstructure will be deformed mare rapidely. Thus, the frequency of maintenance must be changed when a speed raise is applied.

Similarly, at the same zone, the the increase of passenger traffic value by 35% will increase the T_f value but will not change the maintenance class. (The present T_f value will be 6,891 t).

Finally, the UIC maintenance formula is a general approach for maintenance classification. It can not be accepted as an adequate solution to determine the maintenance frequency when the operation conditions, such as speed and carried tonnage, change.

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