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Estimating Empirical Equation for Train Movement Using Operational Data

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Abstract : Train safety and operational efficiency are enhanced by the ability to understand the behavior of trains under varying conditions. The aim of the research is to describe a method to develop empirical formula to calculate four railway dynamic concepts: Rolling and air resistance, Curve resistance, Coefficient of friction between wheel and rail, and coefficient of friction between wheel and braking shoes using operational data.

To realize this goal, field survey and data were collected for track profile, rolling stock characteristics, train composition and the download of Automatic Train Control disc for some trips for different lines at different train types (passenger – empty and loaded freight) during the four seasons (summer , fall , winter and spring).

In the present paper, investigation of passenger train runs on Cairo- Alexandria Railway line were applied as a case study, using operational data from trains in regular service.

Keywords:
Railway Dynamic, Rolling stock, Rolling and Air resistance Curve resistance, Grade resistance, coefficient of adhesion, coefficient of friction, Automatic Train Control(ATC).

I. Introduction

A Train movements from point of initiation to final destination requires a few activities which include acceleration and braking over various kinds of train under different climatic conditions

To insure the best train operation at a particular speed, sufficient tractive force should be provided to overcome the various forces resentencing train movement.

This study describes how to estimate four railway dynamic concepts:

1-Rolling and air resistance (R_{r+a}) is the summation of journal resistance, flange resistance and air resistance [1].

2- Curve resistance (R_c) is additional resistance on curve caused by friction between wheel flange and rail, and wheel slippage on the rails [2].

3- Coefficient of friction between wheel and rail (μ) is defined as the ratio of horizontal adhesion force to the vertical wheel load, it depends mainly on weather conditions and train speed [2].

4- Coefficient of friction (ef) developed on the wheels by the pressure of metal or synthetic shoes during braking [2].

These concepts are important to insure the best train performance design, planning of speed profiles, analyzing of energy consumption [3] and also considered as means of inspection, examine and comparison of different types of train operations and track conditions which help the decision maker to take the correct and suitable action for safely and economic train movement.

II-Methodology and Implementation details

To realize the objective of the study, five steps are proposed:

1-Collecting data which include, data from Automatic Train Control (ATC), track alignment details (including gradient (g) and horizontal curve radius (r_h)), rolling stock characteristics.

2- Classify the output of (ATC) data into the four following groups

3- Appling the following equations [4]:

3-1-Relation between (R_{r+a}) and relative speed (S)

(For speed more than 30 km/hr and straight lines)

$$F_{a1} = \frac{4.2(S_2^2 - S_1^2)}{La} \quad (1)$$

$$F_{a2} = \frac{30.28(S_2 - S_1)}{Ta} \quad (2)$$

$$F_{a\,av} = \frac{F_{a1} + F_{a2}}{2} \quad (3)$$

$$S_{av} = \frac{S_1 + S_2}{2} \quad (4)$$

$$R_{r+a} = \frac{270\,HP}{S_{av} * W} - F_{a\,av} - R_g \quad (5)$$

$$R_{r+a}\ (\text{approximate Indian}) = 2.2 + 3\left(\frac{S_{relative}}{100}\right)^2 \quad (6)$$

Where:

S_1: Initial speed (km/hr)
S_2: Final speed (km/hr)
L_a: Accelerated distance (m)
T_a: Accelerated time (sec)
$F_{a\,av}$: Acceleration force (kg/ton)
W: Train weight (ton)
R_{r+a}: Rolling and air resistance (kg/t)

3-2-Relation Curve resistance (R_c) versus radius of curve (R_h)

(For speed more than 30 km/hr and curved lines)

$$R_c = \frac{270\,HP}{S_{av} * W} - F_{a\,av} - R_{r+a(new)} - R_g \quad (7)$$

$$R_c(\text{Eurpean}) = \frac{500}{r_h} \quad (8)$$

Where:

R_c: Curve resistance (kg/t)
r_h: Radius of curve (m)

3-3-Relation between coefficient of friction adhesion (μ) and relative speed (S)

(For speed less than 30 km/hr)

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$$\mu = (F_\mu + R_{r+a} + R_c + R_g) * \frac{W}{W_{L2}} \quad (9)$$

$$\mu \text{ (kother)} = (\frac{9000}{42+s} + 116) \quad (10)$$

Where:
W_{L2}: Driving wheel of locomotive weight (ton)
μ: Coefficient of friction between wheel and rail

3-4-Relation between coefficient of friction between wheel and shoe (ef) and relative speed (S)

(For braking operation)

$$F_{b1} = \frac{4.2(s_1^2 - s_2^2)}{L_b} \quad (11)$$

$$F_{b2} = \frac{30.28(s_1 - s_2)}{T_b} \quad (12)$$

$$F_{b\,av} = \frac{F_{b1} + F_{b2}}{2} \quad (13)$$

$$ef = (F_{b\,av} - R_{r+a(new)} - R_{c(new)} - R_g) * \frac{W}{2000\eta W eb} \quad (14)$$

$$ef \text{ (Schrader)} = 5.8\left(\frac{s}{1000}\right)^2 - 1.7\left(\frac{s}{1000}\right) + 0.2289 \quad (15)$$

Where:
L_b: Brake distance (m)
T_b: Brake time (sec)
W: Train weight (ton)
W_{eb}: Effecting braking weight (ton)
Ƞ: coefficient of passenger train (taken=o.45)

4-Analyzing result obtained from step (3)
5-Develop empirical equations for estimate R_{r+a}, R_c, μ, ef
The proposed methodology can be summaries as shown Fig (1)

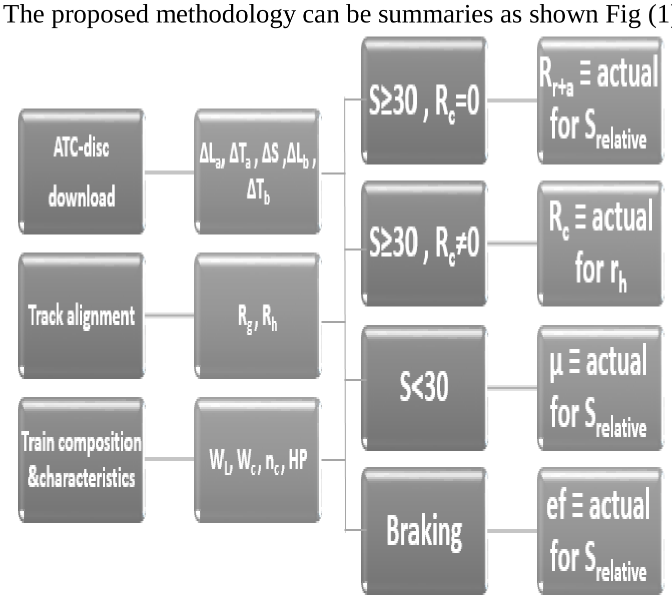

Figure 1: Flowchart for the proposed methodology

Case study:

Apply the proposed methodology in Egyptian national railway (ENR) using data of the passenger trains runs on Cairo-Alexandria railway line

1- Down load of automatic train control (ATC) of passenger train trip runs on Cairo – Alex trip at 30/1/2018 as shown in Fig (2)
2- A part of Cairo –Alexandria railway lines including gradient (g) and horizontal curve radius (r_h) as shown in table (1) and (2) respectively.

DEUTA-WERKE ADS3: Table view (date of print: 30/01/2018)

File name: ADS3 Rowdata - [C:\...\30880101.dat] - All values - Short-term memory 1
Engine No.: 3088 Start: 31.12.2017 - 06:59:20 -0.563 km Markerdiff.: 00:00:00h
Customer ID: ENR EGYPT End: 01.01.2018 - 12:39:14 892.124 km 0.000 km
Manual data correction: -0.564;, Wheel diameter from 905 to 973 mm

V1 Speed [km/h]
Ms Message

P Sp16, O Sp15, N Sp14, M Sp13, L Sp12, K Sp11, J Sp10, I Sp09
H Sp08, G Sp07, F Sp06, - E Sp05, D Sp04, C Sp03, B Sp02, A Sp01

Position/km	Time	V1	Ms	P O N M L K J I	H G F E D C B A
0.001	31.12.2017 - 08:08:12	0	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.001	31.12.2017 - 08:09:14	---	222	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.028	31.12.2017 - 08:09:15	3	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.055	31.12.2017 - 08:09:27	8	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.082	31.12.2017 - 08:09:37	10	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.108	31.12.2017 - 08:09:44	12	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.135	31.12.2017 - 08:09:52	13	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.162	31.12.2017 - 08:09:58	15	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.162	31.12.2017 - 08:10:04	---	---	-- -- -- -- -- -- -- --	-- -- -- E -- -- -- --
0.189	31.12.2017 - 08:10:04	16	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.216	31.12.2017 - 08:10:10	16	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.243	31.12.2017 - 08:10:16	17	---	-- -- -- -- -- -- -- --	-- -- -- -- -- -- -- --
0.270	31.12.2017 - 08:10:21	19	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.297	31.12.2017 - 08:10:26	20	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.323	31.12.2017 - 08:10:31	21	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.350	31.12.2017 - 08:10:35	22	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.377	31.12.2017 - 08:10:39	23	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.404	31.12.2017 - 08:10:43	24	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.431	31.12.2017 - 08:10:47	25	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.458	31.12.2017 - 08:10:51	26	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.485	31.12.2017 - 08:10:54	27	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.512	31.12.2017 - 08:10:58	27	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.539	31.12.2017 - 08:11:01	29	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --
0.565	31.12.2017 - 08:11:04	30	---	-- -- -- -- -- -- -- --	-- -- -- -- D -- -- --

Figure 2: Part of download of Automatic train control (ATC)

Table 1: Part of Cairo –Alexandria railway lines showing the gradient (g)

Cairo-Assiut			
FROM	**TO**	**g**	**R_g**
3.475	3.675	417	2.398
3.675	3.775	zero	zero
3.775	4.425	-721	-1.387
4.425	5.075	zero	zero
5.075	5.325	-714	-1.401
5.325	5.550	zero	zero
5.550	6.150	-1000	-1.000
6.150	6.250	zero	zero
6.250	6.500	-625	-1.600
6.500	7.000	zero	zero
7.000	7.500	1200	0.833
7.500	7.750	zero	zero
7.750	8.350	1200	0.833
8.350	9.550	zero	zero
9.550	10.000	1500	0.667
10.000	10.300	zero	zero
10.300	10.800	2500	0.400
10.800	11.950	zero	zero

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Table 2: part of Cairo –Alexandria railway lines showing the horizontal curve radius (r_h)

Cairo-Alexandria(curves)		
From	**To**	**r_h**
0.178	0.323	550
0.658	1.000	1000
1.000	1.280	1300
1.280	1.727	1100
2.317	2.337	1500
2.442	2.475	1000
2.995	3.045	1000
3.095	3.145	1000
4.641	4.829	1666
4.905	5.250	855
5.444	5.624	1320
5.699	5.875	893
8.794	8.873	2200
9.775	9.875	1000
10.435	10.525	1500
10.620	10.695	1500
44.949	45.086	4000
45.100	45.180	474

III-Results

By applying the equation 5,7,9,14 and using regression analysis technic the following empirical equation are obtained:

1- $R_{r+a} = 0.0003S^2 + 0.0012S + 2.159$ (16)
2- $R_c = 3E\text{-}08\ rh2 - 0.0003rh + 0.8069$ (17)
3- $\mu = 0.1661\ S^2 - 9.4707\ S + 365.68$ (18)
4- $ef = 0.0009\ S^2 - 0.0444\ s + 0.6347$ (19)

The figures (3,4,5,6,7) shows the relation between rolling and air resistance and relative speed ,compression between European and proposed equation for curve resistance, compression between kother's equation and the proposed one for coefficient of friction (µ),compression between Schrader's equation and the proposed equation for coefficient of friction (ef) and relation between horsepower and cross ponding speed in straight and curve .

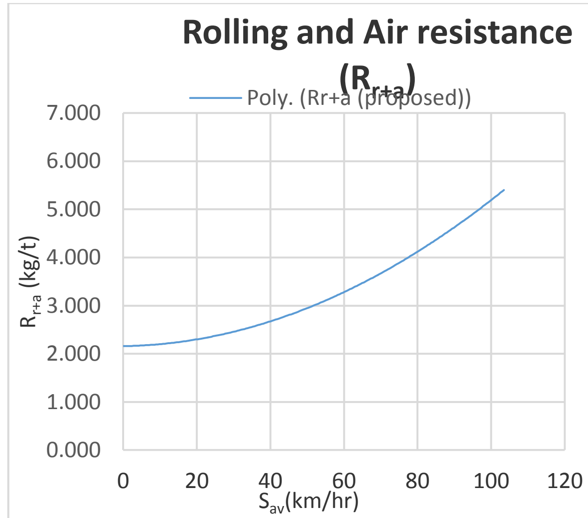

Figure 3: Proposed empirical equation of (R_{r+a})

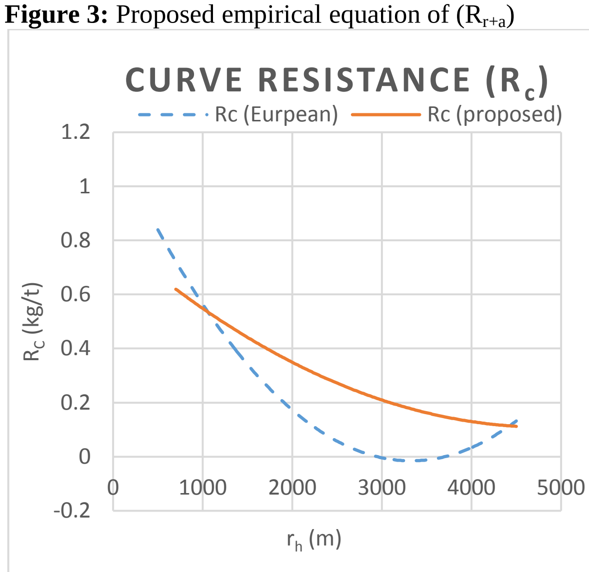

Figure 4: European and proposed equation for curve resistance

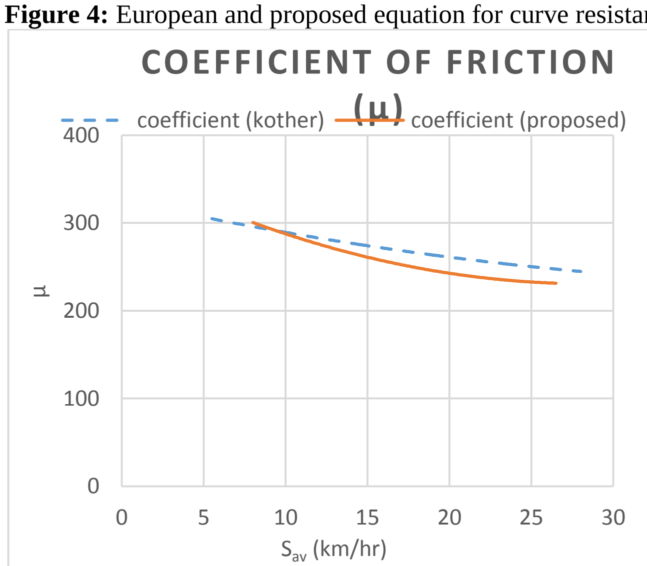

Figure 5: Kother and proposed equation for coefficient of friction

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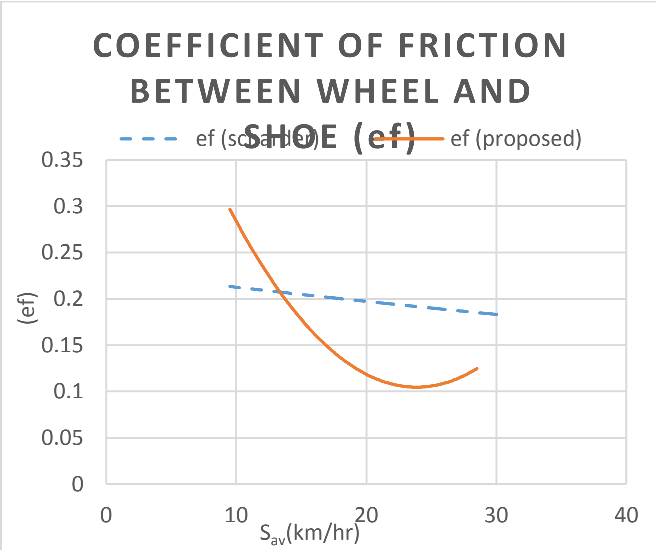

Figure 6: Schrader and proposed equation for coefficient of friction (ef)

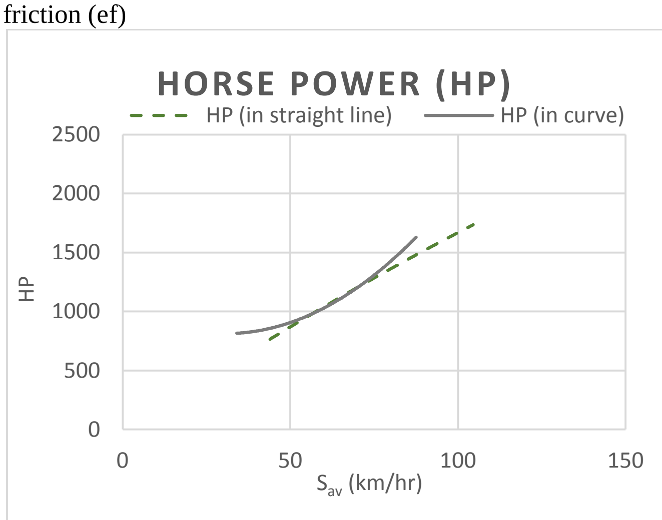

Figure 6: HP versus relative speed for straight and curved line

From above figures Posed running and air resistance (R_{r+a}) complies nearly with approximate general for passenger train and horsepower on curves is more than on straight line.

IV- Conclusions:

A method has be proposed to calculate dynamic concepts (rolling and air resistance, curve resistance, coefficient of friction between wheel and rail, coefficient of friction) using operational data from ATC disc.

When apply this method on ENR, we obtain equations can be used in speed control and also as indicators for the quality of track and rolling stock and braking system

In the future, the more extensive the use of operating train data will make it possible to conduct the four dynamic concept analyses, these analyses will allow getting more precise equation under more accurate conditions.

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