



MODELING VEHICLE TYRES DEPENDING ON THE DEGREE OF CHANGE IN EXTERNAL FACTORS

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Abstract:

This article presents a model for assessing the behaviour of vehicle tyres depending on variations in external factors, with a specific focus on the continuous feedback system that informs drivers and maintenance personnel about real-time tyre pressure. Accurate monitoring of current tyre pressure significantly reduces deviations from the average threshold, enhancing vehicle safety and operational efficiency. The proposed approach demonstrates how controlling pressure variations minimizes tyre wear and reduces unnecessary fuel consumption linked to improper inflation levels, ultimately contributing to economic and environmental benefits.

Keywords: Regularity, value, pressure, weight, tyre, load, transport.

Introduction

Based on the resulting models, it will be possible to predict tyre life when operating at different pressures, weight loads, and routes. This will help to:

- Finding out that tyre s are losing life due to abnormal pressure;
- Setting tyre resource standards for specific routes and bus operation;

Resource adjustment based on the average number of passengers on the route;
Estimation of economic losses during operation of the wheels with abnormal pressure.

The average pressure in tyres used by buses at the auto plant was 7.47 bar, and the standard pressure was 8.5 bar. The standard pressure is considered to be the pressure at which the tyre s have the greatest resource during technical operation.



However, in this case, the maximum level of change in the pressure factor obtained during the passive experiment was 8.2 bar. Since the regression models have unpredictable behaviour outside the factor range or beyond the critical points of the levels of change of the factors, the standard pressure is taken as the value closest to the value specified by the tyre manufacturer - 8.2 bar.

Since the regression models are two-factor, in order to determine whether the resource depends only on pressure, it is necessary to assign a certain value to the tyre weight load coefficient. The choice of the value of this coefficient was determined based on the average number of people lying on the road. Accordingly, using formulas (3.7) and (3.8), the average tyre load (excluding the curb weight of the bus) for the average number of passengers is approximately 300 kg.

Using regression models, we calculate the resource for each route with the following conditions: average pressure - 7.47 bar; standard pressure - 8.2 bar, weight load on tyre s - 300 kg. Since regression models calculate the wear rate, it is necessary to recalculate the resource using formula (1). The obtained values are presented in Table 1.

Table 1. Tyre life at average and standard pressures

Route	Resource		Difference, %
	at an average pressure of 7.47 bar, a thousand km	at an average pressure of 8.2 bar, a thousand km	
Fergana-Tashkent	141,727	160,532	11.7
Fergana-Gulistan	115,661	131,481	12.0
Fergana-Karshi	127,018	134,019	5.2
Fergana-Bukhara	137,976	160,507	14.0
Average value along the route	126,192	143,267	11.8

As can be seen from Table 1, tyre pressure has a significant impact on its resources, which in practice may not exceed approximately 12% of the tyre life. The calculated tyre life at standard pressure has a factor of zero (300 kg) weight load. This means that the values obtained are averaged over the weight load on



the tyre s. To predict the resource taking into account the effect of weight load on the tyre, it is necessary to calculate the resource at the minimum and maximum load, without leaving the area of the factor location. In this case, the minimum load corresponds to 203 kg, and the maximum - 409 kg, which corresponds to an average of 17 and 30 people. The standard tyre life interval for each route was determined taking into account the standard pressure (8.2 Bar) and the change in weight load on the tyre s for each route. The calculation result is given in Table 2.

Table 2. Standard tyre life at a standard pressure of 8.2 Bar, taking into account the weight load on the tyre s.

Route	Normative resource interval, thousand km.		
	Left border		
Fergana-Tashkent	149,051		
Fergana-Gulistan	124,046	135,614	157,850
Fergana-Karshi	131,613	134,804	139,969
Fergana-Bukhara	152,711	164,692	187,413
Average value along the route	140,905	153,767	176,068

When performing the same calculation, the actual loss of resources is estimated by two factors, which is 7.5 bar for the average statistical pressure in the enterprise.

Table 3. Average tyre life at 7.5 bar pressure, taking into account the weight load on the tyre s.

Route	Resource range with average statistical pressure, thousand km		
	Left border	Middle of the interval	Right border
Fergana-Tashkent	133,787	145,582	167,285
Fergana-Gulistan	115,876	118,293	127,432
Fergana-Karshi	131,446	141,036	158,450
Fergana-Bukhara	127,996	139,567	152,574
Average value along the route	121,100	136,119	151,435



Since the average number of passengers on the bus is not known in advance, it is necessary to indicate the interval at which the residual height of the tyre s reaches 2 mm. To accurately determine the average number of passengers on the bus, you can use the methodology of the theory of experiments and multiple regression analysis, which allows you to predict the resource over a very small operating time interval.

The middle of the interval is the mathematical expectation of the calculated resource at several weight loads (203 kg, 237 kg, 306 kg, 340 kg,). Since the dependence of the resource on the weight load on the tyre s is nonlinear (Fig. 2), the mathematical expectation shifts to some limits (to the left or to the right).

The average difference in resources when operating tyre s with a pressure of 7.5 bar and 8.2 bar was 18,187 thousand km or 12%.

Economic efficiency of using a monitoring system

The economic benefit depends on the fact that the monitoring system constantly informs the driver and maintenance personnel about the actual tyre pressure. Accordingly, knowing the actual pressure at a given time significantly reduces the deviation from the average for the tyre pressure situation. This prevents the loss of tyre life and excessive fuel consumption associated with pressure fluctuations. In general, the economic benefits of fuel economy and increased tyre life are as follows.

$$E = E_Y + E_{sh} \quad (1)$$

The economic efficiency of tyre s is calculated based on the difference in resources during operation with the average tyre pressure at the enterprise (7.5 bar) and standard pressure (8.2 bar).

$$E_{sh} = Z_{sh} - Z'_{sh} \quad (2)$$

where, - the price of tyre s, when operating with an average pressure of 7.5 bar; - 8.2. $Z_{sh} Z'_{sh}$

Tyre prices when operating at full pressure.

According to the standard method [13, 56, 41], the cost of tyres for one car can be found from the formula.

$$Z_{sh} = 0.01 \cdot L \cdot N_{sh} \cdot H_{sh} \cdot n_{sh} \quad (3)$$



where, L - annual mileage of the car, L=120,000 km; T_{sh} - the cost of one tyre, $T_{sh}= 2192174$ sum; p_{sh} - number of tyre s on the bus, $p_{sh}= 6$; H_{sh} - the level of cost determination found by this formula.

$$H_{sh} = \frac{90\%}{I} \quad (4)$$

Pricing level for tyre s operating at 7.5 bar

$$H_{sh} = \frac{90}{127982} = 0.000703.$$

Pricing level for tyre s operating at 8.2 bar

$$H_{sh} = \frac{90}{146169} = 0.000616.(5)$$

The cost of tyre s when operating at a pressure of 7.5 bar is as follows.

$$\begin{aligned} Z_{sh} &= 0.01 \cdot 120000 \cdot 2138250 \cdot 0.000703 \cdot 6 \\ &= 10826413.1 \text{ soums/bus} \cdot \text{year} \end{aligned}$$

When operating at a pressure of 7.5 bar, the cost of tyre s is as follows:

$$\begin{aligned} Z'_{sh} &= 0.01 \cdot 120000 \cdot 2138250 \cdot 0.000616 \cdot 6 \\ &= 9479342.64 \text{ soums/bus} \cdot \text{year} \end{aligned}$$

Using the formula (3), the economic efficiency of increasing the tyre resource was determined

$$E_{sh} = 10826413.1 - 9479342.64 = 1347070.46 \text{ soums/bus} \cdot \text{year}$$

In general, the economic effect of fuel economy is as follows:

$$E_Y = Z_Y - Z'_Y(6)$$

here,

Z_Y - fuel costs when operating buses with an average pressure of 7.5 Bar;

Z'_Y - fuel costs when operating buses with a pressure equal to 8.2 Bar.

The annual fuel cost for one bus was determined as follows:

$$Z_Y = \frac{L \cdot q \cdot C_m}{100} = \frac{120000 \cdot 27,35 \cdot 4600}{100} = 150972000 \text{ soums}$$

where, L - average annual mileage, km; q - average fuel consumption for ISUZU HD 50 and ISUZU NP 37 buses, l/100 km; C_m - the price of one litre of fuel, soums.

According to various literary sources, a decrease in tyre pressure by 10% leads to an increase in fuel consumption by 4-6%, respectively, an average fuel

consumption reduction of 5% and a repetition of the calculation of fuel costs is required.

$$Z'_Y = \frac{0.95 \cdot L \cdot q \cdot C_m}{100} = \frac{120000 \cdot 27,35 \cdot 4600}{100} = 143423400 \text{ soums}$$

Then, using formula (4.3), we obtain the economic effect of reducing fuel consumption per year for a bus.

$$E_Y = 150972000 - 143423400 = 7548600 \text{ soums}$$

Using the formula (2), the overall economic benefit from fuel economy and increased resources was determined

$$E = 1347070.46 + 7548600 = 8895670.46 \text{ soums}$$

Accordingly, the amount of savings per year for all considered buses of the ISUZU HD 50 and ISUZU NP 37 brands (49 buses) is 435,887,853 soums.

Assessing the effectiveness of investments to implement a monitoring system. The monitoring system is a set of pressure sensors, an information unit and various auxiliary peripherals. Figure 1 shows a typical set of the Carax TPMS CRX-1061 tyre pressure monitoring system based on internal pressure sensors. A feature of the Carax TPMS CRX-1061 monitoring system is that it has two amplified antennas, which allow the system to be used on buses and cars, as well as internal wheel sensors mounted on the rim instead of the valve shown (in Figure 1).



1 - receiving unit; 2 - mounting bracket with suction cup; 3 - internal pressure sensors; 4 - valves; 5 - antenna; 6 - power adapter; 7 - auxiliary devices, 8 - antenna cable splitter; 9 - antenna with bracket

Figure 1. Carax TPMS CRX-1061 tyre pressure monitoring kit based on internal pressure sensors

A monitoring system with internal wheel sensors allows you to protect them from damage during movement, as well as from environmental influences.

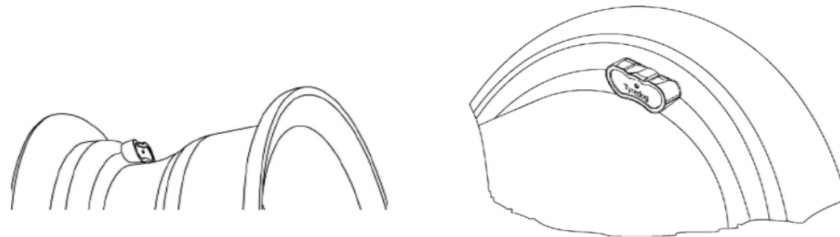


Figure 2. Internal tyre pressure sensor installation diagram

Figure 2 shows options for laying antenna cables and installing antennas,

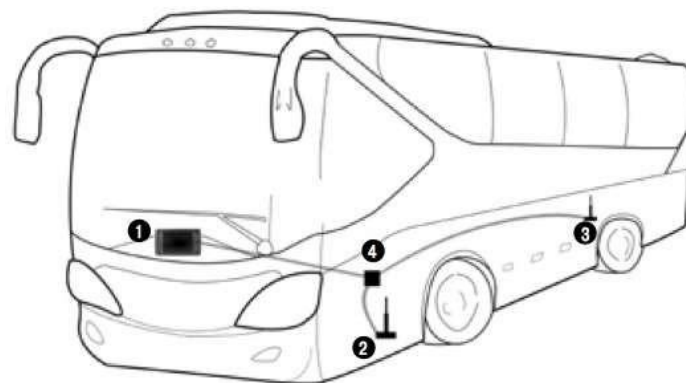


Figure 3. Possibility of laying antenna cables and controlling antennas

1 - reception control; 2 - antenna for the front axle; 3 - antenna for the rear axle; antenna cable splitter.

The principle of the system is as follows. In a normal situation, the sensors on each wheel detect the temperature and pressure every 3 seconds and transmit information to the receiving device every 30 seconds. If the pressure or temperature readings are outside the specified limits, the sensor sends 10 signals to the receiving unit within 6 seconds, and the receiving unit informs the driver about this with sound and light indicators. This warns the driver to carry out a wheel check, which is displayed by the receiving unit. If the pressure changes by 3 Pa (0.2 bar) for 3 seconds, this sensor switches to an alarm, which allows you to respond in a timely manner to tyre damage and pressure leakage.



Table 4 presents the main technical characteristics of the internal pressure sensors of the Carax TPMS CRX-1061 monitoring system.

Table 4. Technical characteristics of internal pressure sensors

Parameter	Unity
measured pressure range	0-203 psi (0-14 Bar)
measurement error	±3 psi
temperature measurement error	±4 C
transmitter frequency	433.92MHz
power supply	3.6V/500mA
power supply life	about 7 years old
sensor weight	30 ± 1.5g
price according to the manufacturer	400,000 soums

The cost of implementing a pressure monitoring system was estimated.

In general, the costs of implementing the equipment are as follows:

$$C_u = C_m + C_q \quad (7)$$

where, C_m - the cost of installing the equipment; C_q - the cost of purchasing and depreciation of the equipment.

Equipment installation costs

$$C_m = C_{n-s} \cdot n \cdot t, \quad (8)$$

where, t - labor intensity of equipment installation, balancing and tyre pumping, $t = 1.43$ man-hours; C_{n-s} - standard hourly rate, $C_{n-s} = 21500$ sum; n - number of tyres in service

The price of the tyre pressure monitoring system, according to the manufacturer's website, is 4,000,000 soums. However, the manufacturer does not indicate the service life of the system or its individual components, except for batteries. It can be assumed that the pressure monitor equipment is sufficiently reliable and needs to be replaced every 7 years. At the same time, the equipment is still subject to physical wear and tear, as well as the second type of wear - as a result of the emergence of more economically and technically advanced systems (for example, battery-free systems). It is necessary to form a depreciation fund in case of sudden failure of the equipment components or their wear.



Enterprises independently determine the useful life of fixed assets at the date of commissioning of a particular facility based on the classification of fixed assets established by the Republic of Uzbekistan. The pressure control system can be included in the fourth depreciation group, that is, the useful life is from 5 to 7 years.

The service life is calculated from the sum of the useful life numbers of the equipment.

$5+4+3+2+1=15$ years.

Next, there will be a depreciation percentage.

Year 1: $5/15 = 33.3\%$;

Year 2: $4/15 = 26.7\%$;

Year 3: $3/15 = 20\%$;

Year 4: $2/15 = 13.3\%$;

Year 5: $1/15 = 6.7\%$.

Equipment purchase and depreciation costs for the 1st year of operation of the monitoring system

$$C_h = C_m + C'_u + u \quad (9)$$

where, C'_u -this is the price of the monitoring system package, $C'_u = 4000000$ soums;

u -depreciation in the first year of operation. In subsequent years, the costs are equal to amortization.

Using the formula (4.10), the costs of implementing a monitoring system were determined.

For one bus

$$C_h = 1.43 \cdot 21500 \cdot 6 + 4000000 + 1370000 = 5554470 \text{ soums} \quad (10)$$

For 49 buses

$$C_h = 49(1.43 \cdot 21500 \cdot 6 + 4000000 + 1370000) = 272169030 \text{ soums}$$

The assessment of investment efficiency is determined in the form of a payback period.

$$W = \frac{C_h}{E} D \quad (11)$$

here, C_h - investments for the implementation of monitoring systems;

I - economic impact from fuel economy and increased tyre life;



D is the number of days in the year.

Table 5. Depreciation allowances for the monitoring system

Order of years	Annual depreciation allowances, %	Annual depreciation allowances for 1 bus, soums	Annual depreciation allowances for 49 buses, soums
1st year	33.3	1372000	67228000
2nd year	26.7	1097600	53782400
3rd year	20	823000	31936800
4th year	13.3	557200	26891200
5th year	6.7	274400	13445600
Amount	100	4 124 200	201684000

Accordingly, the project will have a payback period.

$$W = \frac{272169030}{435887853} 365 = 228 \text{ day} \quad (11)$$

Based on the payback period, investments in implementing a tyre pressure monitoring system can be considered effective and relevant.

Conclusions

The article concludes that economic efficiency depends on the fact that the monitoring system constantly informs the driver and maintenance personnel about the actual tyre pressure. Accordingly, knowing the actual pressure at a given time significantly reduces the deviation from the average for the tyre pressure situation. This is shown to save on tyre life and excessive fuel consumption associated with pressure fluctuations.

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