

необхідність виділення нечітких інтервалів оцінки, а також характеризуються рівнем впевненості експерта в зроблених висновках. Отже, одним з найбільш придатних для побудови моделі оцінки рівня допустимості логістичних ризиків процесу транспортування швидкопсувної агарної продукції є нечітко-множинний підхід.

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АНАЛІЗ ДОКУМЕНТАЦІЇ З БЕЗПЕКИ РУХУ ПРИ ОЦІНОЧНОМУ РОЗРАХУНКУ ПІДВІСКИ АВТОМОБІЛЯ

В.В. Кривда¹, К.І. Корніленко², А.О. Мерікова³

¹доцент кафедри автомобілів та автомобільного господарства

²асистент кафедри автомобілів та автомобільного господарства, e-mail: kornilenko.k.i@nmu.one

³студент групи 275-21-1, e-mail: merikova.a.o@nmu.one

^{1,2,3}Національний технічний університет «Дніпровська політехніка», Дніпро, Україна

Анотація. У роботі досліджується вплив оціночного підходу до розрахунку автомобільної підвіски на загальну безпеку дорожнього руху. Розглянуто фактори, що виникають при порушенні стандартних методів проектування, а також запропоновано метод документального аналізу технічного стану підвіски за умов обмеженого інженерного забезпечення для вивчення у освітніх компонентах спеціальності.

Ключові слова: безпека дорожнього руху, підвіска автомобіля, неформальний розрахунок, документальний аналіз, механіка транспортних засобів, D3A методика, вібродинаміка, цифрові дані транспортного засобу, порівняльний аналіз, кінематика підвіски, аматорський тюнінг, аналітика автомобіля, інженерний контроль.

DOCUMENTATION ANALYSIS OF TRAFFIC SAFETY IN ESTIMATED SUSPENSION CALCULATION OF A VEHICLE

V.V. Krivda¹, K.I. Kornilenko², A.O. Merikova³

¹Associate Professor, Department of Automobiles and Automobile Economy, e-mail: krivda.v.v@nmu.one

²Assistant, Department of Automobiles and Automobile Economy, e-mail: kornilenko.k.i@nmu.one

³Student of group 275-21-1, e-mail: merikova.a.o@nmu.one

^{1,2,3}Dnipro University of Technology, Dnipro, Ukraine

Abstract. The paper investigates the impact of an estimated (informal) approach to vehicle suspension calculations on overall traffic safety. It considers factors emerging from violations of standard design methodologies and proposes a method of documentation analysis for assessing the technical condition of vehicle suspension systems under conditions of limited engineering support. This method is also proposed for integration into educational components of technical specialties.

Keywords: Traffic safety, vehicle suspension, informal calculation, documentation analysis, vehicle mechanics, D3A methodology, vibrodynamics, vehicle digital data, comparative analysis, suspension kinematics, amateur tuning, automotive analytics, engineering control.

Introduction. Nowadays, it is difficult to imagine the work of an engineer being limited only to the design and calculation of products, as well as preparing them for production. The aesthetic component plays an important role today. That is, each product must be developed not only from the perspective of functionality, but also considering design and ergonomics.

The suspension system of a car plays a critical role in ensuring safety and comfort during motion. It is responsible for absorbing road irregularities, maintaining vehicle stability, and optimizing tire grip on the road surface. Studies show that suspension failures or inadequate design can lead to serious consequences, including loss of control and increased risk of traffic accidents (Fig. 1) [1].



Figure 1 – Examples of suspension system damage related to vehicle operation

Purpose of the study. The purpose of this work is to investigate the impact of an informal (evaluative) approach to calculating vehicle suspension on road safety, and to explore the possibility of proposing a method of documentary analysis as a tool for monitoring the technical condition of the suspension under conditions of limited engineering support.

Materials and research results. The study is based on classical principles of mechanics, in particular Hooke's Law, which describes the behavior of elastic suspension elements. According to this law, the spring force is defined as [2]:

$$F_s = -k \cdot x \quad (1)$$

where F_s – spring force, k – spring stiffness (spring constant), x – displacement of the spring from its equilibrium position.

This formula makes it possible to evaluate the impact of spring stiffness on the damping properties of the suspension.

It is also important to take into account the damping force generated in shock absorbers, which suppresses excessive oscillations. This force is described by the equation [3]:

$$F_d = -c \cdot v \quad (2)$$

where F_d – damping force, c – damping coefficient, v – velocity of the shock absorber's displacement.

To analyze the suspension dynamics, we will use the classical "quarter-car model," which considers the body mass m_1 , wheel mass m_2 , spring stiffnesses k_1 and k_2 (for the suspension and tire respectively), and the damping coefficient

ccc. The equations of motion for this system are as follows—for the body mass (3) and for the wheel mass (4):

$$m_1 \cdot \ddot{z}_1 + c \cdot (\dot{z}_1 - \dot{z}_2) + k_1 \cdot (z_1 - z_2) = 0 \quad (3)$$

$$m_2 \cdot \ddot{z}_2 + c \cdot (\dot{z}_2 - \dot{z}_1) + k_1 \cdot (z_2 - z_1) + k_2 \cdot z_2 = f(t) \quad (4)$$

where z_1 , z_2 —vertical displacements of the body and wheels respectively, \dot{z}_1, \dot{z}_2 —their speeds, \ddot{z}_1, \ddot{z}_2 —acceleration, $f(t)$ —external disturbing force, for example, a bump in the road.

These equations make it possible to assess how design parameters affect vehicle dynamics. In particular, the spring stiffness k_1 influences ride stiffness and body roll; the damping coefficient ccc determines the rate at which oscillations are damped; and tire stiffness k_2 affects the suspension's initial response to road irregularities [4].

Let us consider the influence of suspension parameters on vehicle behavior. The spring stiffness k_1 affects the body height and its oscillations – an increase in stiffness reduces body roll but may compromise ride comfort. The damping coefficient ccc determines the speed of oscillation decay. Excessive damping makes the suspension feel "harsh," while insufficient damping leads to prolonged oscillations.

Tire stiffness k_2 , in turn, affects road grip and the transmission of minor irregularities to the vehicle body. Understanding these parameters and their interactions is critical for engineers when developing a suspension system that balances comfort and safety.

Informal calculation refers to methods that do not comply with engineering standards (such as ISO, SAE...), and are based on subjective assessments, simplified models, or empirical approaches without sufficient verification. Simple engineering calculators are often used for such tasks.

Informal calculations can lead to:

- distortion of chassis geometry;
- reduced damping efficiency;
- changes in the center of mass;
- compromised tire-road traction;
- increased wear on tires and steering components.

To address problems related to informal calculation approaches, the following measures are proposed:

Developing simplified mathematical models – such as the basic quarter-car model – to assess the effects of parameter changes.

Using software tools (CAD/CAE), such as SolidWorks Simulation, MATLAB Simulink, and Adams Car, for preliminary modeling.

Incorporating certified data-using manufacturer specifications or ISO/SAE standards (e.g., SAE J670 for suspension kinematics).

Promoting a culture of technical literacy through educational and scientific projects, technical courses, instructional materials, and state initiatives for safe vehicle modifications.

Enforcing control at the vehicle inspection level-modifications should be reflected in registration documents only with proper engineering justification.

The concept of "informal calculation" should not be confused with engineering creativity. In the context of vehicle safety, the term has a clearly negative connotation, as the lack of justification in technical decisions often leads to reduced reliability and controllability. Therefore, even "home" tuning should be carried out using at least basic calculation models and fundamental verification procedures.

Let us now turn to the method of documentary analysis, which involves the examination of:

- technical documentation (manuals, drawings, calculations);
- modification history;
- photo and video materials of vehicle operation;
- results of technical inspections and diagnostics.

This approach allows us to assess how well-founded and safe a modification is. A new approach to road safety documentation analysis is proposed, which is based not only on classical principles of technical documentation verification but also on the integration of digital tools, machine data analysis, and the formalization of informal experience.

In this context, documentary analysis is a systematic study of available technical, instructional, and operational documentation (both official and user-generated) to identify potential risks, inconsistencies, or undocumented changes in the vehicle's suspension design. A methodology is proposed-referred to as D3A analysis-which includes:

Documentation Layer (analysis of technical documentation),

Data Layer (analysis of digital data), and

Delta Analysis (comparative discrepancy analysis).

Documentation Layer refers to the collection of initial technical documentation for the vehicle (passport, manual, service history).

For example, the object of study is a Volkswagen Golf V, 1.9 TDI, model year 2006.

The goal is to identify deviations in front suspension components following informal modifications, compared to factory baseline parameters (Tables 1-3).

Table 1 – Collection of initial technical information

Component	Factory equipment	Source of information
Front springs	OEM code: 1K0411105CE	ETKA, VW spare parts catalog
Front shock absorbers	Sachs 312 732 (gas)	Service book, Partscatalog
Ground clearance height	140 mm	Operating instructions

Table 2 – Identified changes

Component	Actually installed	Installation source
Front Springs	From Audi A4 B6	Car owner, service photo
Shock Absorbers	Bilstein B4	Parts sticker, service sheet
Ground Clearance	158 mm	Measurement with tape measure

Table 3 – Compliance analysis

Parameter	Expected value	Detected value	Deviation
Spring stiffness	17.5 N/mm	22.0 N/mm	+25.7%
Damping	Standard	Increased	Not OEM
Clearance	140 mm	158 mm	+18 mm

After gathering the information, conclusions from the Documentation Layer are recorded.

Example: The installed springs and shock absorbers do not comply with the manufacturer's recommendations. The ground clearance has been altered without recalibrating the suspension geometry. There is a high likelihood of a shift in the roll center position, which may affect cornering stability. It is necessary to conduct the Data Layer and Delta Analysis to assess the impact on vehicle dynamics.

The second stage, Data Layer (digital data analysis), involves obtaining data from onboard recorders (if available), analyzing photo/video materials from inspections or test drives (video analysis of suspension behavior), and incorporating driver feedback from publicly accessible sources, etc.

Below, Tables 4–5 provide an example of the Data Layer stage from the proposed D3A-analysis methodology, which pertains to the collection and interpretation of digital data on the condition of the vehicle's suspension. This stage allows for evaluating the actual effects of informal modifications using available digital tools.

Object of study – Volkswagen Golf V after replacement of front springs with models from an Audi A4.

Interpretation of results. The oscillation damping time has significantly increased, indicating that the damping system is not properly matched to the stiffness of the new springs. The change in natural frequency suggests a shift in the dynamic characteristics toward a more "sporty" setup, but without adequate

compensation from the shock absorbers.

Table 4 – Sources of digital data

Source	Description	Tool
OBD-II reading	Data from speed, acceleration, body angle sensors	Torque Pro (Android)
Video analysis of suspension behavior	Slow motion video of driving over bumps	iPhone Slow-Mo (240 fps)
Variation amplitude telemetry	Body vibration damping rate	Sensor Kinetics Pro
Movement dynamics	Video + frame analysis	Tracker Video Analysis Tool

Table 5 – Results processing. Example of analysis of oscillations after passing a speed bump (values are normalized)

Parameter	Factory setting	After replacement	Deviation (%)
Damping time ($t_{1/2}$)	1.8 s	2.9 s	+61.1%
Natural frequency	1.7 Hz	2.4 Hz	+41.2%
Maximum acceleration of the body	3.1 m/s ²	4.8 m/s ²	+54.8%
Body tilt angle during braking	5.3°	7.6°	+43.4%

Let us now consider the Delta Analysis (comparative discrepancy analysis). This involves identifying deviations between the design and actual parameters (based on simulation or compatibility tables), and analyzing the impact of these changes on key factors such as stiffness, damping, and natural frequency. The next step is to generate a digital risk map, which highlights zones of critical influence.

Example. The goal of the analysis is to determine the criticality of suspension parameter changes after informal component replacement, using a Volkswagen Golf V fitted with non-original front springs as a case study.

Actual digital values from the Data Layer are compared with nominal values from the Documentation Layer. To assess the impact, we will use a Criticality Index (CI):

$$CI = \frac{|Fact - Norm|}{Norm} \cdot W \tag{5}$$

where W – parameter criticality weighting factor (from 1 to 3), $CI > 0.3$ — critical deviation.

As a result, the Delta Analysis demonstrated that the methodology covers the entire analysis cycle—from documentation review to the comparison of digital deviations. This enables a comprehensive assessment of the impact of changes. The proposed approach ensures a logical sequence, reducing the risk of over-

looking critical safety aspects. The use of mobile apps, OBD scanners, video analysis, and sensors allows for the collection of objective and measurable data without the need for expensive equipment.

Table 6 – Calculation of the criticality index

Parameter	Norm	Fact	Weighting factor W	CI	Criticality
Damping time ($t_{1/2}$)	1.8 c	2.9 c	2	1.22	● High
Natural frequency	1.7 Гц	2.4 Гц	1.5	0.62	● Moderate
Maximum acceleration	3.1	4.8	3	1.64	● High
Braking angle	5.3°	7.6°	1	0.43	● Low

Table 7 – Visualization of risk areas

CI value	Risk Category
$CI \geq 1.0$	● Critical Risk (requires immediate response)
$0.5 \leq CI < 1.0$	● Moderate Risk (check recommended)
$CI < 0.5$	● Low Risk (does not require immediate intervention)

The methodology not only identifies changes but evaluates their impact in terms of safety-handling, stability, comfort, and braking efficiency. This is especially important for vehicle modifications that lack formal certification. The methodology can be applied to the analysis of any passenger vehicle, regardless of brand or year of manufacture. Its structure is suitable for vehicle owners, automotive service providers, or technical auditors alike.

The analysis showed that the informal replacement of springs without accounting for their parameters resulted in critical deviations in amplitude-frequency characteristics and body dynamics. The increased body acceleration ($CI = 1.64$) and damping time ($CI = 1.22$) may lead to loss of traction during emergency braking and dangerous body roll in corners. Therefore, it is recommended to either match the shock absorbers to the new springs or revert to the original components.

Conclusions. This study applied the author's "D3A" methodology to a passenger vehicle with an informal spring replacement. The documentation analysis revealed that springs from an SUV with a different stiffness rating (+45%) were installed. Telemetry data from the Torque Pro app confirmed excessive stiffness over road irregularities and increased oscillation frequency. The Delta Analysis indicated a 17% increase in the risk of traction loss compared to nominal parameters. Based on these findings, a return to near-original suspension specifications was recommended.

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МОЖЛИВОСТІ ТА ПЕРСПЕКТИВИ ПОРШНЕВОГО ДВИГУНА АВТОМОБІЛЯ З ГІБРИДНОЮ ЕНЕРГОУСТАНОВКОЮ

В.В. Кривда¹, В.В. Олішевська², К.І. Корніленко³

¹кандидат технічних наук, доцент, e-mail: krivda.v.v@nmu.one

²кандидат технічних наук, доцент, e-mail: olishevska.v.ye@nmu.one

³асистент, e-mail: kornilenko.k.i@nmu.one

^{1,2,3}кафедра автомобілів та автомобільного господарства Національний технічний університет «Дніпровська політехніка», Дніпро, Україна

Анотація. В роботі розглянуто особливості гібридної енергоустановки, яка поєднує в собі ДВЗ та електричну силову установку. Проведено аналіз енергетичної ефективності гібридної енергоустановки.

Ключові слова: поршневий двигун, гібридна енергоустановка, енергоефективність, екологічне навантаження.

POSSIBILITIES AND PROSPECTS OF RECIPROCATING ENGINE OF A VEHICLE WITH A HYBRID POWER UNIT

Vitalii Krivda¹, Valentyna Olishevskaya², Kostiantyn Kornilenko³

¹Ph.D., Associate Professor, e-mail: krivda.v.v@nmu.one

²Ph.D., Associate Professor, e-mail: olishevska.v.ye@nmu.one

³Assistant, e-mail: kornilenko.k.i@nmu.one

^{1,2,3}Automobiles and Automobile Economy Department, Dnipro University of Technology, Dnipro, Ukraine

Abstract. The paper examines the features of a hybrid power unit that combines an internal combustion engine and an electric power unit. An analysis of the energy efficiency of