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# ANALYTICAL EVALUATION OF AUTOMOTIVE SUSPENSION PERFORMANCE USING STABILITY, ROAD ADHESION, ENERGY ABSORPTION AND COMFORT INDICATORS

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**Abstract**

This paper presents an IMRAD-based analytical evaluation of automotive suspension system performance using four comparative indicators: stability coefficient, road adhesion coefficient, energy absorption capacity and ride comfort score. The study focuses on three suspension layouts: independent suspension, semi-independent suspension and rigid axle suspension. The analysis is based on a structured technical assessment of suspension elements, dynamic response to road irregularities, energy absorption through elastic and damping components, and the influence of suspension layout on vehicle safety and comfort. The results show that the independent suspension has the highest overall performance, with a stability coefficient of 0.85, road adhesion coefficient of 0.90, energy absorption of 75% and comfort score of 9 out of 10. The semi-independent suspension provides an intermediate solution, while the rigid axle suspension demonstrates lower comfort and dynamic adaptability but remains useful where simplicity, strength and load capacity are required. The article expands the initial material into a complete academic format and provides practical recommendations for design selection and service optimization.

**Keywords:** automotive suspension; independent suspension; semi-independent suspension; rigid axle; stability coefficient; road adhesion; energy absorption; ride comfort; vehicle dynamics; technical service

## 1. Introduction

The suspension system is one of the key mechanisms that determine vehicle stability, comfort, road holding and safety. It connects the vehicle body with the wheel assemblies through elastic, damping and guiding elements. When the vehicle moves over irregular road surfaces, the suspension absorbs part of the impact energy and prevents excessive vibration from being transferred to the body. At the same time, it must maintain continuous tire-road contact, because the effectiveness of braking, acceleration and steering depends on the normal force acting on the tire contact patch.

Different suspension layouts are used in different vehicle categories. Independent suspension systems are common in modern passenger cars because each wheel can move with relatively little influence from the wheel on the opposite side. Semi-independent systems are widely used in compact vehicles because they are relatively inexpensive and simple while providing acceptable dynamic performance. Rigid axle or dependent suspension systems are generally used in trucks, buses, off-road vehicles and commercial vehicles where strength, durability and load-carrying capacity are more important than maximum ride comfort.

A scientific evaluation of suspension systems should consider not only their construction but also their dynamic indicators. Stability, road adhesion, energy absorption and comfort are among the most important criteria. These indicators are interrelated: better energy absorption usually improves passenger comfort, while higher road adhesion improves braking and cornering safety. However, a design that maximizes comfort may not always provide the best handling. Therefore, comparative assessment is needed to select a suitable suspension system for a given vehicle type.

The objective of this article is to analyze the performance of three suspension layouts using a set of comparative indicators and to provide engineering recommendations for improving suspension efficiency, safety and durability. The original Uzbek-language article was expanded, reorganized and translated into English according to the IMRAD structure.

## 2. Materials and Methods

The research was carried out as a comparative analytical study. The main object of analysis was the vehicle suspension system, including springs, shock absorbers, stabilizers, control arms and additional elastic elements. The study examined how these elements influence stability, wheel-road contact, vibration absorption and ride comfort. The analysis was organized into constructional, experimental, mathematical and analytical stages.

At the constructional stage, the material, geometry, elastic behaviour and functional role of the main suspension elements were considered. At the experimental stage, the expected performance of suspension systems under road excitation was interpreted through indicators such as wheel movement, body vibration and energy absorption. At the mathematical modelling stage, the suspension was considered as a dynamic system in which the sprung mass, unsprung mass, spring stiffness and damping coefficient determine the response to road inputs. At the analytical stage, the suspension types were compared using numerical indicators taken from the source material.

For the comparative evaluation, four indicators were used: stability coefficient, road adhesion coefficient, energy absorption percentage and comfort score. The coefficients are interpreted as dimensionless comparative values: the closer the coefficient is to 1.0, the better the expected performance. Energy absorption is expressed as a percentage, and comfort is scored on a scale from 1 to 10. These values should be understood as analytical comparative indicators rather than universal experimental constants.

| No. | Research stage | Content of analysis | Expected engineering output |
|---|---|---|---|
| 1 | Constructional analysis | Study of springs, dampers, stabilizers and elastic joints | Identification of the influence of each component |
| 2 | Dynamic response assessment | Evaluation of wheel trajectory, vibration response and load transfer | Understanding of ride and handling behaviour |
| 3 | Mathematical modelling | Use of simplified dynamic relations and comparative indicators | Prediction of suspension response under different conditions |
| 4 | Analytical evaluation | Comparison of stability, road adhesion, energy absorption and comfort | Selection of the most suitable suspension type |

| | | | |
|---|---|---|---|
| 5 | Safety and service assessment | Consideration of braking stability, tire contact and maintenance needs | Recommendations for operation and diagnostics |

Table 1. Research methodology used for suspension performance evaluation

## 3. Results

### 3.1. Comparative performance indicators

The comparative data show that the independent suspension system provides the highest values in all selected indicators. Its stability coefficient is 0.85 and its road adhesion coefficient is 0.90. This means that the wheel can follow road irregularities more effectively while maintaining a stable contact with the road surface. The energy absorption value of 75% indicates a higher ability to reduce vibration transmitted to the vehicle body. The comfort score of 9 confirms the suitability of this suspension type for passenger cars and vehicles where ride quality is a priority.

The semi-independent suspension system demonstrates intermediate performance. Its stability coefficient is 0.70, road adhesion coefficient is 0.75, energy absorption is 60% and comfort score is 7. These values indicate that the semi-independent layout is less effective than the independent suspension but still offers acceptable performance for compact urban vehicles. The rigid axle suspension has the lowest values in this comparison: stability coefficient 0.60, road adhesion coefficient 0.65, energy absorption 50% and comfort score 6. However, it can still be technically justified in vehicles that require high strength, simple structure and load-carrying capacity.

| Suspension type | Stability coefficient | Road adhesion coefficient | Energy absorption (%) | Comfort score (1-10) |
|---|---|---|---|---|
| Independent suspension | 0.85 | 0.90 | 75 | 9 |
| Semi-independent suspension | 0.70 | 0.75 | 60 | 7 |
| Rigid axle suspension | 0.60 | 0.65 | 50 | 6 |

Table 2. Comparative indicators of automotive suspension systems

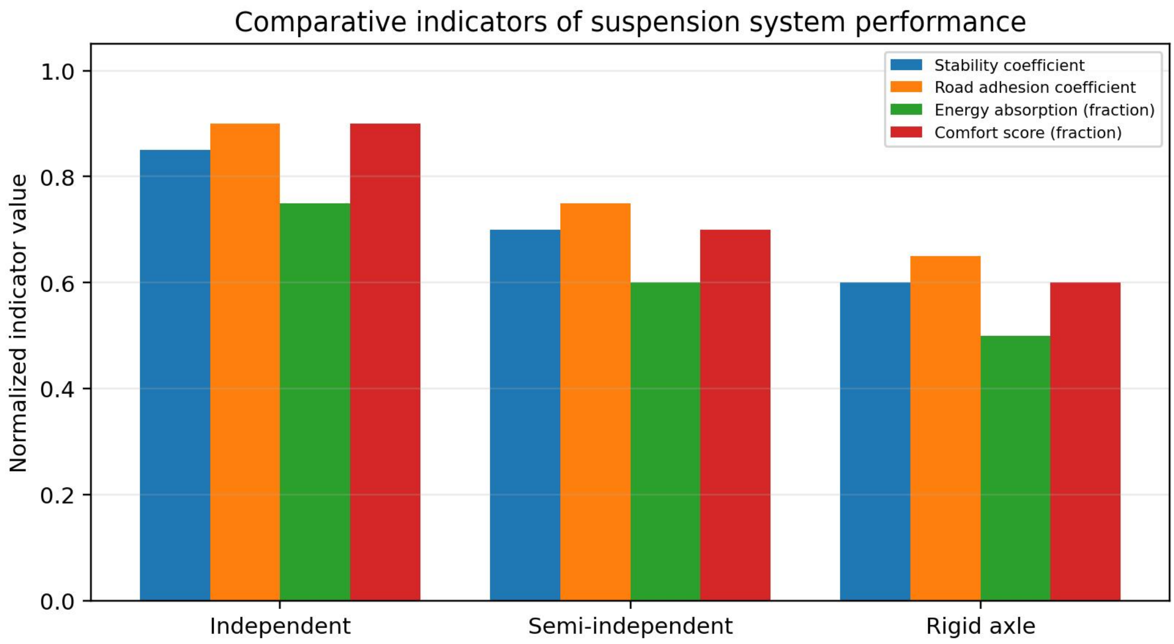


Figure 1. Comparative graph of normalized suspension performance indicators

### 3.2. Overall performance index

To make the comparison clearer, an overall performance index was calculated using normalized values of the four indicators. The stability coefficient and road adhesion coefficient were used directly. Energy absorption was divided by 100, and comfort score was divided by 10. The average of these four normalized values was taken as the overall performance index. This simple calculation is intended only for comparative evaluation and does not replace a full vehicle dynamics test.

| Suspension type | Overall performance index | Performance level |
|---|---|---|
| Independent suspension | 0.850 | High |
| Semi-independent suspension | 0.688 | Medium |
| Rigid axle suspension | 0.588 | Low |

Table 3. Calculated overall performance index

### 3.3. Interpretation of individual indicators

Stability coefficient. The independent suspension has the highest stability coefficient because each wheel can move separately and the body is less affected by the movement of the opposite wheel. This improves steering precision and reduces uncontrolled body motion on uneven roads.

Road adhesion coefficient. Road adhesion is highest in the independent suspension because tire contact is maintained more consistently. Better road contact improves braking efficiency, lateral grip and overall safety. The lower value of the rigid axle system is related to the mechanical interconnection of wheels and greater unsprung mass.

Energy absorption. Energy absorption reflects the ability of elastic and damping elements to reduce the influence of road irregularities. The independent suspension has the highest energy absorption value, while the rigid axle system has the lowest value in the considered comparison.

Comfort score. Ride comfort depends on vertical body acceleration, vibration frequency, damping quality and the transmission of shocks to passengers. The independent suspension is rated highest in comfort, while semi-independent and rigid axle systems are evaluated lower because they transfer more road excitation to the body.

## 4. Discussion

The comparison confirms that the structural design of the suspension system has a direct influence on dynamic and comfort-related performance. Independent suspension provides better stability, road adhesion and comfort because the wheels are able to respond to road irregularities individually. This makes the system particularly suitable for passenger vehicles, where comfort, braking stability and handling precision are important. The main limitation of independent suspension is its higher design and manufacturing complexity.

The semi-independent suspension is a compromise solution. It cannot provide the same dynamic performance as a fully independent layout, but it is more compact, cheaper and easier to maintain. This makes it attractive for economy-class and urban passenger vehicles. The results suggest that semi-independent suspension may be selected when the manufacturer needs to balance performance, cost and packaging constraints.

The rigid axle suspension shows lower values in the selected indicators, but it should not be considered technically obsolete. In many commercial and off-road vehicles, load capacity, robustness and service simplicity are more important than maximum ride comfort. Therefore, the correct conclusion is not that one suspension type is always better, but that each layout must be selected according to vehicle purpose and operating conditions.

The service aspect is also important. A suspension system with high theoretical performance may become unsafe if shock absorbers, joints, rubber bushings or wheel alignment are neglected. Regular maintenance is essential for preserving the original design performance. In particular, road adhesion and braking stability can deteriorate significantly when dampers lose efficiency or when wheel geometry is disturbed.

## 5. Practical recommendations

| No. | Recommendation | Technical justification |
|---|---|---|
| 1 | Use independent suspension for vehicles where comfort and handling are priorities | It provides higher stability, road adhesion and energy absorption |
| 2 | Use semi-independent suspension when cost and compactness are important | It gives acceptable performance with simpler construction |
| 3 | Use rigid axle suspension for heavy-duty and rough-road applications | It offers durability and load-carrying capability |
| 4 | Optimize spring stiffness and damping parameters according to vehicle mass | Correct matching improves both comfort and road holding |
| 5 | Inspect shock absorbers, joints and silent blocks regularly | Wear of these parts reduces stability and increases vibration |
| 6 | Check wheel alignment after impact or suspension repair | Correct geometry reduces tire wear and improves steering response |

Table 4. Practical recommendations for design selection and technical service

## 6. Conclusion

The analytical evaluation shows that the independent suspension system has the highest comparative performance among the three considered layouts. It achieved a stability coefficient of 0.85, road adhesion coefficient of 0.90, energy absorption of 75% and comfort score of 9 out of 10.

The semi-independent suspension provides a balanced solution for compact and urban vehicles. Its indicators are lower than those of the independent suspension but higher than those of the rigid axle system in the presented comparison. Therefore, it can be recommended when cost, packaging and service simplicity are important.

The rigid axle suspension demonstrates lower comfort and dynamic adaptability, but it remains useful for commercial vehicles, buses, off-road vehicles and applications requiring high durability and load capacity.

The overall performance index confirms the ranking of the systems: independent suspension has the highest index, semi-independent suspension has medium performance, and rigid axle suspension has lower performance in comfort-oriented criteria. However, suspension choice must always be linked to vehicle function and operating environment.

Improving suspension performance requires not only correct design selection but also regular diagnostics, correct adjustment of wheel geometry, timely replacement of worn rubber-metal elements and avoidance of excessive vehicle loading.

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