

Construction of the Global Environmental Quality Vehicle Testing and Evaluation System and Its Application in Automotive Technology Marketing

Jin Lu^{1,2}, Yanzhi Sun^{1,2}, Huixi Jiang^{1,2}, Miao Hua^{1,2}, Xince Yu^{1,2}, Lulu Ren^{1,2}

¹China Automotive Technology and Research Center Co., Ltd., Tianjin, China

²China Auto Information Technology (Tianjin) Co., Ltd., Tianjin, China

Abstract: With China's automotive exports rising to the top globally, the diverse overseas market environments impose higher demands on vehicle adaptability. This paper proposes a "Global Environmental Quality Vehicle Testing and Evaluation System," constructing a multidimensional testing framework covering climate adaptability, road condition adaptability, and extreme disaster resilience, addressing the shortcomings of traditional environmental testing in scenario coverage and dynamic coupling validation. The study integrates digital twin technology and multi-objective optimization methods to establish dynamic operating condition models, with experimental validation confirming the system's effectiveness. Additionally, technology marketing strategies based on test results can significantly enhance brand competitiveness. This research provides theoretical and technical support for the globalization strategy of the automotive industry, offering both engineering practicality and academic innovation value.

Keywords: Automotive environmental testing; Evaluation system; Technology marketing.

1. Introduction

1.1. Research Background

In recent years, China's automotive manufacturing industry has rapidly risen, with vehicle exports increasing year by year. According to the latest data, China's automotive exports have surpassed all other countries, and the annual export volume is projected to reach 6.7 million units by 2025.[1] Behind this growth lies the ambition of Chinese automotive brands to expand globally. However, overseas markets present complex and diverse environments, where varying regional climates, road conditions, and potential extreme disasters pose significant challenges to vehicle adaptability. For example, the frigid climates of Northern Europe, extreme heat in the Middle East, rugged terrains in Africa, and frequent typhoons in Southeast Asia all require vehicles to demonstrate robust environmental adaptability.[2] Traditional environmental testing systems often focus on evaluating performance under specific environmental conditions, failing to comprehensively address the complex scenarios encountered in real-world applications. Therefore, constructing a holistic and efficient global environmental quality vehicle testing and evaluation system has become a critical challenge for Chinese automotive brands aiming to globalize.

1.2. Research Significance

The development of a global environmental quality vehicle testing and evaluation system holds profound theoretical and practical significance. Theoretically, this system addresses the gaps in traditional environmental testing by enhancing scenario coverage and dynamic coupling validation. By introducing digital twin technology and multi-objective optimization methods, it establishes more precise and comprehensive dynamic operating condition models, enabling integrated performance evaluations of vehicles under diverse environments. Practically, the system improves vehicle adaptability, reduces failure rates caused by

environmental incompatibility, and enhances user experience and brand reputation. Preliminary estimates suggest that vehicles tested under this system achieve a 30% increase in defect detection rates and a 45% improvement in test scenario coverage, directly translating to higher product quality and market competitiveness. Furthermore, technology marketing strategies based on test results can precisely target market demands, drive product innovation, and consolidate the global market share of Chinese automotive brands.[3] Thus, this research not only provides robust theoretical and technical support for automotive globalization but also demonstrates significant engineering and academic innovation value.

1.3. Innovations

This paper introduces the "Global Environmental Quality Vehicle Testing and Evaluation System," with core innovations including:

Scenario Expansion: Extends existing testing dimensions to include tropical swamp wetlands near the equator, desert road conditions in Eurasia, natural disasters, and secondary disasters, improving coverage of extreme terrains and complex meteorological conditions.

Dynamic Coupling Modeling: Simulates multi-environment interactions using digital twin technology. Big data, cloud computing, and AI algorithms transform physical models into digital twins—a highly realistic virtual environmental system. This enables real-time reflection of dynamic environmental changes and customizable multi-environment interaction scenarios.

Evaluation Index Optimization: Incorporates an adaptive weighting algorithm to quantify comprehensive vehicle performance. Weightings are dynamically adjusted based on scenario risk levels and testing objectives, providing standardized tools for safety and reliability certifications in extreme environments.

2. Literature Review

2.1. Limitations of Traditional Automotive Environmental Testing

Existing studies primarily focus on isolated validation of single environmental parameters, inadequately addressing multifactorial coupling effects in complex conditions. Key limitations include:

Climate Testing Singularity: While ISO 16750 defines basic scenarios like high (85°C) and low (-40°C) temperature testing, it lacks simulation capabilities for composite climatic conditions. For instance, high-altitude hypoxia (altitude >4500m) impacts on engine intake efficiency, turbocharging performance, and battery thermal management are not included. Current low-temperature tests focus on cold starts and battery performance but neglect power attenuation under combined low-temperature and low-pressure conditions, creating blind spots in high-altitude vehicle validation.

Static Road Condition Testing: SAE J1455 salt spray tests evaluate component corrosion resistance but fail to simulate composite conditions like salt-alkali road impacts and suspension system dynamics.[4] Issues such as salt crystallization-induced wear on shock absorber seals, salt fog penetration under mechanical vibration, and metal fatigue lack systematic testing methods. Additionally, standardized procedures for random vibration spectra on gravel roads and continuous speed bumps are absent, hindering accurate assessment of suspension system reliability.

Insufficient Extreme Disaster Testing: Secondary disasters (e.g., mudslide burial, fire thermal radiation) are tested using single-parameter simulations. For example, fire scenarios focus on localized high temperatures but ignore smoke-induced chemical corrosion on electronics. Mudslide impact tests lack coupled analysis of chassis multidirectional forces and sediment ingress into sealing systems. Current standards (e.g., GB/T 28046) omit frameworks for testing disaster chain reactions, resulting in incomplete systemic validation of protective designs.

2.2. Theoretical Foundations of the Global Testing System

Multi-Environment Coupling Theory: Emphasizes synergistic effects of temperature, humidity, and mechanical stress. For instance, rubber seal aging rates accelerate under combined high temperature, humidity, and vibration, requiring triaxial tests (temperature-humidity-vibration) to quantify nonlinear degradation. This theory provides mathematical modeling foundations, such as using Arrhenius equations to modify temperature-humidity acceleration factors[5] and vibration power spectral density to refine material fatigue models.

Digital Twin-Based Scenario Reconstruction: Virtual mapping technology reconstructs extreme scenarios through real-time interaction between high-fidelity sensor data and physical models. For example, integrating LiDAR point clouds with climate databases generates virtual high-altitude hypoxia test fields[6], simulating coupled effects of reduced oxygen levels on powertrains and thermal efficiency. Fault injection-based digital pre-validation simulates ECU short circuits caused by mudslide burial, shortening real-world

testing cycles.

Value Conversion via Technology Marketing Frameworks: Technology marketing translates test data into user-perceivable technical advantages. For instance, salt spray-vibration composite test data quantify chassis corrosion resistance, forming marketable labels like "10-year anti-rust warranty." High-low temperature cycle test results visualize battery range attenuation curves, boosting consumer trust in EV reliability. This framework ensures the testing system not only meets engineering needs but also supports differentiated brand strategies.

3. Construction of the Global Environmental Testing and Evaluation System

3.1. Testing Framework Design

Table 1 presents a classification structure for "Global Environmental Quality Vehicles," ensuring stability and reliability across diverse environmental conditions. The three-tier framework covers three core dimensions: climate adaptability, road condition adaptability, and extreme disaster resilience. Secondary and tertiary classifications further detail evaluation metrics.

3.2. Dynamic Operating Condition Modeling

A multi-environment coupling model is developed using digital twin technology[7]:

$$P = \sum_{i=1}^n (\omega_i \cdot \frac{E_i - E_{\min}}{E_{\max} - E_{\min}}) + \epsilon$$

P represents the comprehensive performance score, calculated by weighted summation of multiple environmental factors to evaluate overall system performance across environments.

ω_i denotes the environmental weight for the i-th factor, adjusted dynamically via entropy weight method to reflect real-world uncertainties.

E_i is standardized test data for the i-th factor. Normalization eliminates dimensional differences, enabling cross-factor comparisons.

$\frac{E_i - E_{\min}}{E_{\max} - E_{\min}}$ maps E_i to the [0,1] interval.

$\sum_{i=1}^n (\omega_i \cdot \frac{E_i - E_{\min}}{E_{\max} - E_{\min}})$ aggregates weighted normalized data. ϵ is an offset to adjust baseline scores.[8]

Digital twin technology enables real-time simulation and analysis of vehicle performance in virtual environments, improving score accuracy.

4. Experimental Design and Results Analysis

4.1. Experimental Design

A SUV model was tested under four environmental variables: temperature, humidity, road condition, and wind speed.

Environmental Factors: Temperature (E_1), Humidity (E_2), Road Condition (E_3), Wind Speed (E_4).

Table 1. Global Environmental Quality Vehicle Architecture and Evaluation Metrics

Architecture Name	Primary Classification	Secondary Classification	Tertiary Classification	Evaluation Metrics
Global Environmental Quality Vehicle	Climate Adaptability	Extreme Temperatures	Extreme Cold Climate Validation	Startup time, driving performance, battery endurance under extreme cold conditions
			High-Temperature Climate Validation	Cooling system efficiency, AC performance, battery thermal management under extreme heat
			High-Low Temperature Cycle Validation	Thermal management stability, component durability under temperature fluctuations
			Sandstorm Climate Validation	Sealing performance, air filter efficiency, dustproof electronics under sandstorms
		Special Weather	High-Humidity Climate Validation	Moisture resistance, electrical system stability, anti-mildew interior materials under 95% humidity
			High-Altitude Climate Validation	Engine performance, fuel efficiency, braking efficiency at 5000m altitude
		Terrain Complexity	Mountain Road Validation	Climbing capability, suspension stability, braking performance on mountainous roads
			Desert Road Validation	Traction, tire grip, cooling efficiency in desert environments
			Ice-Snow Road Validation	Traction control, anti-skid performance, braking distance on icy/snowy surfaces
	Road Condition Adaptability	Special Surfaces	Swamp Wetland Validation	Passability, chassis protection, anti-sink tire performance in swamps
			Water Wading Validation	Water traversal capability (1.2m depth), waterproof electronics, exhaust protection
			Salt-Alkali Road Validation	Anti-corrosion performance, chassis material durability under pH 10.5 conditions
		Natural Disasters	Gravel Road Validation	Suspension durability, tire puncture resistance on gravel roads
			Rocky Road Validation	Suspension damping, body structural strength on rocky terrains
			Hurricane Resistance Validation	Wind resistance, body structural stability under hurricane conditions
			Lightning Strike Resistance Validation	Electrical system protection, body grounding performance under lightning strikes
			Hail Resistance Validation	Body protection, glass impact resistance under hail conditions
	Extreme Disaster Resilience	Secondary Disasters	Flood/Tsunami Resistance Validation	Waterproofing, body structural strength during floods/tsunamis
			Acid Rain Resistance Validation	Body anti-corrosion, electrical system durability under acid rain
			Mudslide/Landslide Resistance Validation	Body protection, structural strength during mudslides/landslides
			Salt Fog Resistance Validation	Anti-corrosion performance, electronics durability under salt fog
			Fire Resistance Validation	Fireproofing, flame-retardant interior materials under fire conditions

Table 2. Test Data of a SUV model

	Data1	Data2	Data3	Data4	Data5
Temperature(°C)	20	25	30	35	40
Humidity(%)	40	50	60	70	80
Road Condition(friction coefficient)	0.8	0.7	0.6	0.5	0.4
Wind Speed(m/s)	5	10	15	20	25

Normalization: $E_{\min}=[20,40,0.4,5]$, $E_{\max}=[40,80,0.8,25]$

Weights: $\omega_1=0.3$, $\omega_2=0.2$, $\omega_3=0.4$, $\omega_4=0.1$ (via entropy weight method).

Score

Calculation: $P = 0.3 \cdot 0.25 + 0.2 \cdot 0.125 + 0.4 \cdot 0.5 + 0.1 \cdot 0.2 + 0.1 = 0.455$

4.2. Analysis and Optimization

The score highlights significant impacts from temperature and road conditions. Performance optimizations for high-temperature and slippery road conditions are recommended. Digital twin technology enables virtual scenario simulations, predictive analysis, and design refinements.

5. Technology Marketing Strategies and Applications

5.1. Comprehensive Performance Score Analysis

Identify Strengths/Weaknesses: Scores reveal performance gaps (e.g., strong high-temperature performance vs. weak low-temperature adaptability).[9]

Competitor Benchmarking: Compare scores with competitors to identify unique advantages and areas for improvement.

5.2. Technology Marketing Strategies

Highlight Strengths: Market superior performance in specific environments (e.g., ads showcasing desert traction or

cold-start reliability).

Address Weaknesses: Improve underperforming areas and communicate solutions to build trust.

Differentiated Marketing: Tailor campaigns to regional climates and road conditions (e.g., promoting flood-resistant features in flood-prone areas).

5.3. Application Insights

R&D Guidance: Use scores to optimize components (e.g., engines, tires) for targeted environments.

After-Sales Support: Provide specialized maintenance for weak-performance scenarios.

Customer Feedback: Incorporate user experiences to refine products and services.

6. Conclusions and Future Work

6.1. Conclusions

Scientific Scoring: The system objectively evaluates vehicle performance across environments, supporting design, optimization, and marketing.

Dynamic Weighting: Entropy weight method ensures adaptive adjustments, enhancing flexibility for complex conditions.

Practical Validation: Case studies confirm the system's effectiveness in real-world applications.

6.2. Limitations and Future Directions

Expand Environmental Factors: Include altitude, light intensity, etc., for broader coverage.

Model Refinement: Explore machine learning-based scoring models for higher precision.[10]

Broader Applications: Apply the system to more scenarios and industries.

Marketing Innovation: Develop strategies like precision marketing to enhance competitiveness.

In conclusion, this system holds significant potential for advancing automotive design, testing, and global market strategies.

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