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Evaluating Autonomous Vehicle Companies' Strength — An Analytic Hierarchy Process Approach

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Abstract *: The development of autonomous vehicles has brought significant advancements in transportation technology, yet the capabilities of companies in this field vary widely. This study applies the Analytic Hierarchy Process (AHP) to objectively evaluate and rank the comprehensive strength of leading autonomous vehicle companies. By focusing on key factors—brand reputation, technological advancement, safety, and user experience—the study captures a structured view of how companies like Waymo, Tesla, and Apollo Go differ. These criteria, organized in a hierarchical framework, reflect each company's distinct advantages across varied geographical markets, regulatory environments, and stages of technological development. The results indicate that Tesla prioritizes safety features, Waymo excels in both technology and customer satisfaction, and Apollo Go commands strong brand recognition within China. This study offers valuable insights for stakeholders in the autonomous driving industry, providing a reference for strategic decision-making and future technology investments.*

Keywords: *autonomous vehicles, ranking, analytic hierarchy process(AHP)*

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I. Introduction

In recent years, autonomous vehicles have rapidly evoled, transforming the transportation landscape and drawing significant attention from both the public and private sectors. Major technology companies, such as Google's Waymo, Baidu's Apollo Go, and Tesla's Cybercab, are actively developing autonomous driving systems with varying degrees of technological advancement and market presence. However, the progression of autonomous vehicle technology differs substantially among companies due to geographical and regulatory factors, making a fair and objective comparison challenging.

Evaluating autonomous vehicle companies requires looking beyond their technical capabilities alone; aspects like brand influence, adherence to safety standards, and overall user experience are also essential in building public trust and encouraging adoption. Although autonomous driving has sparked significant interest, few studies have taken a comprehensive approach to assess and rank these companies across both qualitative and quantitative dimensions. To fill this gap, we use the Analytic Hierarchy Process (AHP) as a structured, multi-criteria evaluation model, examining four main dimensions: brand reputation, technology strength, safety performance, and user satisfaction.

The AHP method is particularly suited for this analysis, as it allows for the incorporation of both quantitative data and expert judgment, providing a robust framework for comparing companies with diverse characteristics and strengths. By establishing a hierarchy of evaluation criteria and weighting them according to their relative importance, this study aims to objectively rank leading autonomous vehicle companies, highlighting their unique advantages and areas for improvement. This approach offers valuable insights for industry stakeholders, guiding strategic planning and technology investments in the growing autonomous driving sector. The structure of this paper is as follows: Section 2 outlines the AHP methodology, Section 3 analyzes the main evaluation factors, Section 4 presents the results, and Section 5 discusses limitations and conclusions.

II. Methodology

We employ the Analytic Hierarchy Process (AHP) to evaluate the comprehensive strength of autonomous vehicle companies. AHP is a multi-criteria decision-making tool that enables the systematic assessment of complex decision problems by structuring them into a hierarchical model, facilitating the comparison of qualitative and quantitative factors. This methodology involves several key steps, outlined below.

2.1 Constructing the Judgment Matrix

To begin, a judgment matrix was created based on four primary evaluation factors: brand, technology, safety, and user experience. Each factor was compared pairwise in terms of its relative importance, using a scale from 1 to 9, where, 1 indicates equal importance, 3 indicates slight importance,5 indicates strong importance,7 indicates very strong importance, and 9 indicates absolute importance.

Figure 1 provides a visual representation of the factors influencing the evaluation of autonomous driving, including specific sub-criteria under each primary factor, such as advertising and operational cities for brand, or accident rate and regulation compliance for safety.

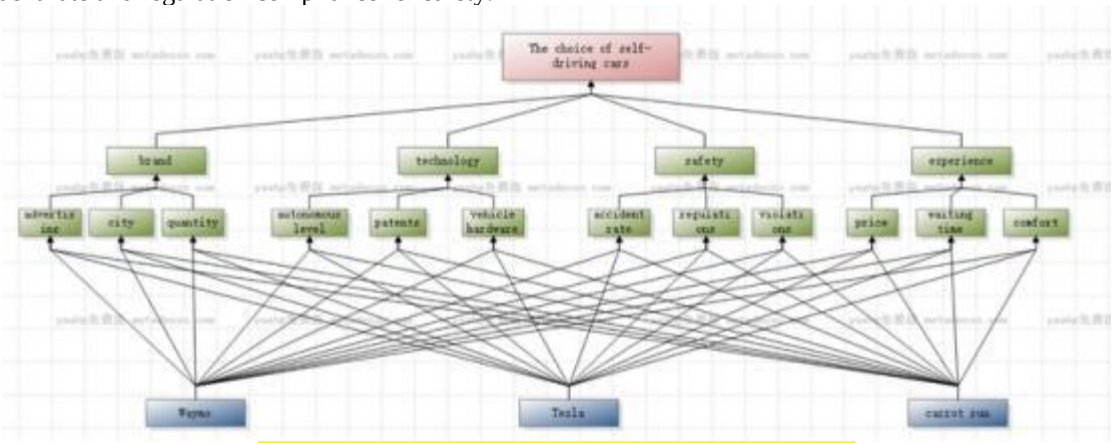

Figure 1: Analysis of factors affecting driverless driving

The reciprocal values (e.g., 1/3, 1/5) represent the inverse comparison when one factor is less important than the other. **Table 1** presents the initial judgment matrix used in this study, which reflects the pairwise comparison of these factors.

Table 1·Quantitative value and importance comparison table

Quantitative value	Factor i compare with factor j
1	Equally important
3	Slightly important
5	Strongly important
7	Super strongly important
9	Extremely important
2 , 4 , 6 , 8	The middle value of the judgment of two adjacent values
aij=1/aij	Reciprocal

2.2 Consistency Check

To ensure that the judgment matrix is logically consistent, a consistency ratio (CR) is calculated. A CR value below 0.1 indicates acceptable consistency; otherwise, the matrix must be revised. The CR calculation involves determining the maximum eigenvalue (λ_max) and the consistency index (CI) using the following formulas:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where RI is the random index, depending on the matrix order. Table 2 provides the values of RI for matrices of different orders, which are used to determine the acceptable range for CR.

Table 2: Relationship between matrix order and RI

matrix order	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this study, the consistency of the matrix was verified, ensuring that CR<0.1CR < 0.1CR<0.1, thereby confirming that the judgments were consistent.

2.3 Weight Calculation

Once consistency is confirmed, the weight of each evaluation factor is calculated by normalizing the judgment matrix. Each column of the matrix is summed and normalized to produce a priority vector, which reflects the

relative importance of each factor. The calculated weights for each factor are shown in **Table 3**, providing insight into the relative significance of brand, technology, safety, and user experience in the overall evaluation.

Table 3: Weights of factors affecting driverless driving

Self-driving car options	Brand	Technique	Safety	Experience	Wi
Brand	1	1/4	1/6	1/2	0.0695
Technique	4	1	1/2	4	0.3048
Safety	6	2	1	6	0.5270
Experience	2	1/4	1/6	1	0.0987

2.4 Comprehensive Scoring

After determining the weights, the comprehensive score of each autonomous vehicle company was calculated by multiplying each company's performance score for each factor by the respective factor weight. These scores were then summed to obtain an overall ranking for each company. Table 4 summarizes the scores and final rankings for each company, highlighting their relative strengths across the evaluated criteria.

Table 5. Comparison of brands

brand	Waymo	Tesla	Apollo Go	Wi
Waymo	1	5	1/2	0.3332
Tesla	1/5	1	1/7	0.0751
Apollo Go	2	7	1	0.5917

III. Results and Discussion

In this section, we analyze the data obtained through the Analytic Hierarchy Process (AHP) based on the factors identified: brand, technology, safety, and user experience. Each company's performance in these areas was assessed, and their relative weights (as calculated in the Methodology section) were applied to obtain a comprehensive score.

3.1 Factor Weights and Importance

The weights assigned to each factor reflect their relative importance in evaluating autonomous vehicle companies, as shown in **Figure 2**. **Safety** and **technology** received the highest weights, underscoring the priority given to passenger and pedestrian protection, as well as the technical capabilities of the vehicle. This result aligns with industry priorities, where safety is a critical concern due to regulatory standards and consumer trust, while technology showcases the company's innovative edge.

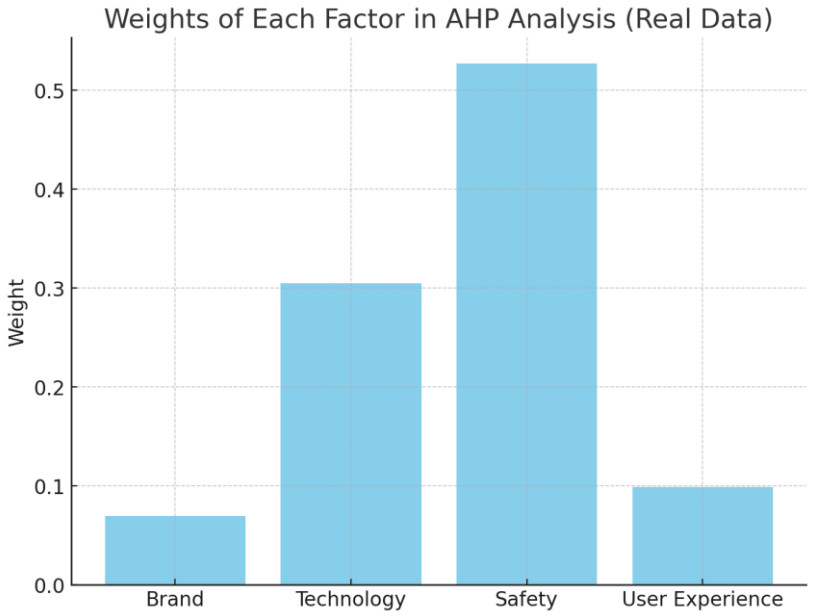

Fig2. Weights of Each Factor in AHP Analysis

3.2 Comparative Performance Analysis

Using the factor weights, we calculated the performance scores for each company. **Figure 3** presents a radar chart comparing the scores of Waymo, Tesla, and Apollo Go across each factor, while **Figure 4** provides a bar chart of company scores in each individual factor.

(1)Tesla: Tesla ranks highest in safety, with a comprehensive set of safety features and consistently low accident rates, particularly with the use of its Full Self-Driving (FSD) mode. Tesla's high score in safety suggests that its advanced driver assistance systems are robust, addressing consumer concerns and regulatory standards effectively.

(2)Waymo: Waymo excels in both technology and user experience. As a pioneer in autonomous driving research, Waymo's technology portfolio includes numerous patents and a high level of automation, evidenced by its operation of Level 4 autonomous vehicles in select cities. Waymo's user experience ratings are also strong, attributed to the comfort, reliability, and convenience of its rides, positioning it as a leader in customer satisfaction.

(3)Apollo Go: Apollo Go performs particularly well in brand recognition, especially in the Chinese market, where it benefits from substantial government support and a large user base across multiple cities. Extensive advertising and public exposure contribute to Apollo Go's strong brand score, reinforcing its visibility and appeal among local consumers.

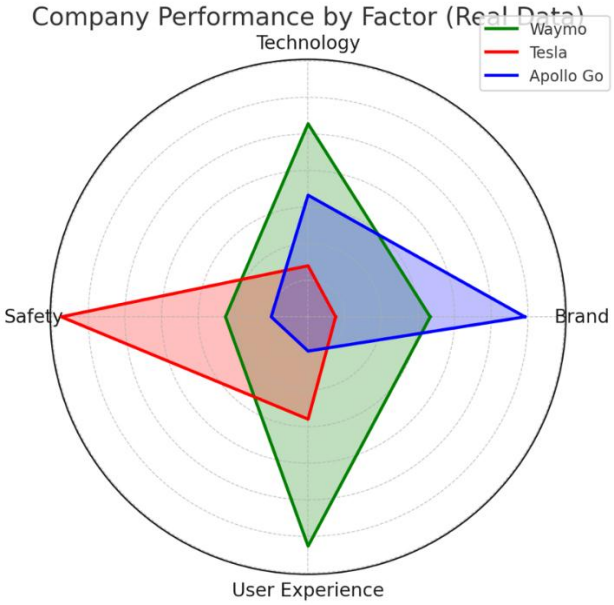

Fig 3. Company Performance by Factor

Radar chart comparing company performance by factor, showing Tesla's strength in safety, Waymo's advantages in technology and user experience, and Apollo Go's brand influence.

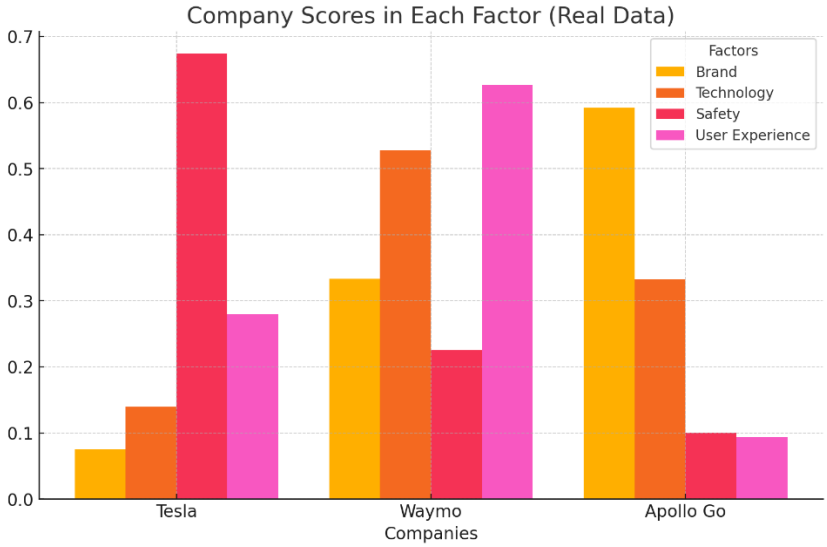

Fig 4. Company Scores in each factor

Bar chart of company scores across factors, providing a clear view of each company's strengths and weaknesses in brand, technology, safety, and user experience.

3.3 Analysis of Factor Contributions to Rankings

Each factor's contribution to the overall ranking provides insight into what drives competitive advantages in the autonomous vehicle industry. The following analysis highlights the implications of each factor:

Safety's High Priority: Safety, as the most weighted factor, significantly impacts the rankings. Tesla's leading position in this area emphasizes the role of safety in gaining consumer trust and regulatory approval. The high safety weighting suggests that advancements in safety technology, such as collision avoidance and emergency response, are essential for establishing a competitive edge.

Technological Advancements as a Differentiator: Waymo's high score in technology underscores the competitive advantage that comes with early entry and continuous innovation in autonomous driving. The emphasis on technology demonstrates the importance of R&D investments, patent acquisition, and progress towards higher automation levels.

Brand Influence and Market Presence: Apollo Go's strong brand performance, particularly in China, indicates that regional market penetration and brand visibility are powerful assets. This factor suggests that companies aiming for a robust market presence should consider strategic branding efforts and local partnerships, especially in markets with strong government support for autonomous vehicles.

3.4 Implications for the Industry

The AHP analysis highlights several strategic insights for industry stakeholders, providing valuable guidance on competitive priorities and areas of potential growth in the autonomous vehicle sector.

Firstly, **safety and technology remain top priorities**. As autonomous vehicles must meet stringent regulatory standards and ensure public trust, companies that excel in safety are positioned to lead in both consumer acceptance and regulatory approval. Safety enhancements, such as advanced collision avoidance, real-time hazard detection, and emergency response systems, are essential. Continuous investment in R&D to improve these aspects will help companies maintain a competitive edge, especially in markets with rigorous safety requirements.

Secondly, **user experience is emerging as a key differentiator**. Positive user feedback on aspects like ride comfort, convenience, and wait times can enhance brand loyalty and influence consumer choice. In a competitive market, a superior user experience not only improves customer retention but also attracts new customers through word-of-mouth. Companies that prioritize usability, including intuitive app interfaces, seamless booking processes, and responsive customer support, are more likely to gain a loyal user base. Furthermore, user data analytics can be leveraged to personalize experiences and tailor services to specific user needs, fostering a deeper connection with customers.

Additionally, **strong branding and regional adaptation strategies** enable companies to effectively penetrate diverse markets, as demonstrated by Apollo Go's success in China. By focusing on local market preferences and government partnerships, companies can strengthen their market presence and ensure regulatory compliance. For example, forming alliances with local authorities or integrating culturally specific features into the service can make autonomous vehicles more appealing to regional users. Companies should also consider customized advertising strategies and partnerships with local organizations to reinforce brand visibility and trust within specific markets.

Moreover, as the industry grows, **collaborative innovation between companies could accelerate advancements**. Partnerships, joint ventures, or alliances with technology firms, automotive manufacturers, or even city governments can help companies expand their capabilities, share costs, and pool resources to address complex challenges. Collaborative efforts can also drive standardization across the industry, leading to broader adoption of autonomous driving technologies.

Finally, **sustainability and environmental considerations** are becoming increasingly relevant. With growing global emphasis on reducing carbon emissions, autonomous vehicle companies that focus on eco-friendly technologies—such as electric and hybrid vehicles—will likely appeal to environmentally conscious consumers and align with international environmental standards. Companies can further differentiate themselves by committing to green practices, such as energy-efficient routing, eco-driving modes, and renewable energy sourcing for vehicle operations.

In summary, the future growth and success of autonomous vehicle companies will rely on a balanced approach that combines safety, technological innovation, enhanced user experiences, targeted branding, regional adaptation, collaboration, and sustainability. These strategies will not only address current industry challenges but also pave the way for long-term competitive advantages in a rapidly evolving market.

IV. Limitations and Conclusion

4.1 Limitations

This study has several limitations that should be considered when interpreting the results. Firstly, the analysis relies on publicly available data, which may not fully capture recent advancements, proprietary technologies, or regional performance nuances of each company. As a result, emerging technologies or new safety protocols that have not been disclosed might not be reflected in this evaluation.

Secondly, the qualitative nature of certain factors, such as brand reputation and user experience, introduces an element of subjectivity. While AHP provides a structured approach for weighting these factors, the assessment of brand perception or comfort levels in user experience inherently depends on subjective judgment and may vary across different demographics or regions.

Moreover, the study focuses on a limited set of companies, factors, and data points, which might not encompass all variables influencing autonomous vehicle performance and market success. Other factors, such as regulatory compliance costs, ethical considerations in decision-making algorithms, and infrastructure readiness, were not included but could significantly impact a company's operational effectiveness. Future studies could incorporate a broader range of factors or use alternative methodologies to provide a more comprehensive analysis.

Finally, the study's findings are based on a snapshot in time, and the autonomous vehicle industry is highly dynamic. Rapid technological advancements and evolving regulatory standards could alter the relative standings of companies in the near future. Longitudinal studies or real-time data integration could address this limitation by capturing industry trends more effectively.

4.2 Conclusion

In conclusion, this study employs the Analytic Hierarchy Process (AHP) to conduct a comparative analysis of leading autonomous vehicle companies, evaluating their strengths in brand, technology, safety, and user experience. The findings reveal Tesla's strong positioning in safety, Waymo's technological leadership, and Apollo Go's brand influence in the Chinese market. This multi-dimensional evaluation provides valuable insights for industry stakeholders, illustrating the varied strategies and unique strengths of each company in the competitive landscape of autonomous driving.

By identifying the primary factors contributing to competitive advantage, this study offers practical guidance for companies aiming to improve their market standing. The analysis underscores the importance of continuous safety and technology improvements, as well as the potential benefits of focusing on user experience and targeted branding strategies.

Ultimately, as the autonomous vehicle industry progresses, companies that adapt to technological innovations, prioritize safety, enhance user satisfaction, and strategically position their brand will likely succeed. This study contributes to a deeper understanding of the factors that shape the future of autonomous driving, and it offers a foundation for future research to build upon, potentially expanding the evaluation model to include additional companies, emerging technologies, and regional perspectives.

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