Research on Expressway Service Area Spacing in Mountainous Chongqing

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Abstract: Chongqing's mountainous expressways face challenges of steep terrain, variable climate, and complex traffic demands, making service area planning crucial. This study proposes spacing strategies tailored to such conditions. Findings suggest service areas be placed every 30–50 km and parking areas every 20–25 km under normal circumstances. On freight-intensive sections with long downhill slopes and sharp curves, parking areas should be densified to every 15 km with added safety facilities. In terrain-constrained narrow zones, linear layouts, shared facilities, or interchange-based service areas are recommended, while relatively flat areas are suitable for independent dual-side layouts. The results indicate that a zoned, hierarchical, and flexible approach can enhance safety, meet user needs, and improve service quality. This research provides practical references for service area planning in Chongqing and other mountainous regions.

1. Introduction

As essential supporting facilities of expressway systems, service areas and parking areas not only provide fuel supply, maintenance support, rest, and information services, but their spatial distribution also directly affects traffic safety, travel comfort, and resource utilization efficiency[1]. The planning of service area spacing should not simply follow the principle of "the more, the better" or "the fewer, the better."[2] Instead, it should be determined scientifically based on factors such as traffic volume, vehicle composition, terrain conditions, and regional demand, so as to meet the basic needs of drivers and passengers while avoiding redundant construction and resource waste[3].

At present, the layout of expressway service facilities in China largely relies on empirical, standardized spacing models, such as the widely applied practice of "one service area every 50 km and one parking area every 25 km." [4] Although this approach may be sufficient in flat terrain with stable traffic flow, it reveals significant limitations in complex environments such as mountainous expressways in Chongqing. On the one hand, due to steep gradients, sharp curves, and a high proportion of heavy-duty trucks, fixed spacing often results in facility gaps along key sections, making it difficult to meet urgent needs such as driver rest, fuel replenishment, or vehicle cooling. On the other hand, in areas with low traffic demand, overlapping catchment zones, or constrained land availability, excessive facility density may cause resource idleness, investment waste, and high operating costs.

The challenges are particularly prominent in the mountainous expressway network of Chongqing. For instance, on the Chongqing–Zunyi section of the Lanzhou–Haikou Expressway, the spacing between service areas once reached 79.6 km, with no intermediate parking or fueling facilities. This distance far exceeded the recommended standard and posed serious threats to travel safety and comfort. Conversely, in certain southwest mountain corridors, service facilities are overly concentrated with overlapping functions. Such coexistence of "severe shortages in some sections and excessive redundancy in others" exemplifies the failure of the fixed-spacing model in mountainous contexts.

Therefore, in Chongqing and similar mountainous regions, the planning of service areas requires a more adaptive and flexible strategy. Specifically, three pathways are suggested:

(A) Constructing a quantitative and predictive spacing model based on traffic big data and field surveys, considering traffic intensity, vehicle composition, driver fatigue, and terrain conditions to dynamically determine facility spacing;

(B) Exploring differentiated combinations of service areas, parking areas, fueling stations, and cooling/watering points to avoid uniform layouts and achieve a balance between functional needs and operational efficiency;

(C) Moderately reducing the spacing of service areas and parking areas in critical mountainous sections—such as continuous long slopes, curved alignments, or freight-intensive corridors—to enhance safety redundancy through denser layouts.

Through these strategies, it is possible to ensure traffic safety and service quality while achieving scientific spatial distribution and efficient resource utilization of service facilities in Chongqing's mountainous expressways. This provides both theoretical guidance and

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practical approaches for optimizing service systems in mountainous highway environments.

2. Factors Influencing the Spacing of Service Areas in Mountainous Expressways

The spacing of expressway service areas is not an isolated decision but a balance among regulatory standards, local conditions, and future development scenarios. In mountainous and hilly regions such as Chongqing, a context-specific approach is particularly critical. The following factors are identified as key determinants, based on a mixed methodology of literature review, traffic data analysis, GIS-based spatial assessment, and field surveys.

2.1. Physiological and Psychological Needs of Drivers and Passengers

Expressways are characterized by straight alignments, fast traffic flow, and relatively monotonous visual environments. While these features improve efficiency, they also place drivers under high cognitive load. With prolonged driving, attention and reaction capabilities decline, especially in mountainous highways with steep gradients and frequent curves.

This conclusion is supported by empirical studies in traffic psychology and by local accident statistics provided by Chongqing Traffic Police Bureau, which indicate fatigue-related accidents increase significantly after 1.5–2 hours of continuous driving. Thus, service area spacing should allow drivers to stop every 90–120 minutes[5] . For passengers, the closed nature of expressways means that basic needs—such as toilets, food, water, and short breaks—must be met by roadside facilities. Excessive spacing increases fatigue and discomfort, whereas overly dense spacing wastes resources.

In mountainous Chongqing, where alignment complexity heightens driving stress, service area spacing should be moderately reduced. Multi-level facilities—such as rest stops, fueling and watering stations—are recommended at critical sections to establish a graded service system.

2.2. Fuel Supply, Water, and Maintenance Needs

Fuel supply requirements were derived from vehicle range data and fueling frequency records collected from expressway operation companies. For heavy trucks, simulation of energy consumption on steep gradients using PKPM-Energy and Matlab highlighted the need for maintenance and cooling stations near slope bases.

At average speeds of 80–100 km/h, 15–20 minutes of travel equals 20–33 km. To alleviate range anxiety and enhance redundancy, fueling points should be arranged at approximately 30 km intervals[6] .

For heavy trucks on mountain expressways, especially along long downhill segments, engines, brakes, and cooling systems operate under high stress. Drivers often require cooling checks, water refills, or maintenance at slope bases. Without such facilities, risks of overheating and brake failure increase.

Although only about 10% of fueling vehicles require minor repairs, service areas should provide basic maintenance bays, spare parts, and inspection areas. On freight-intensive corridors, on-call maintenance teams are also essential. With the rise of new energy vehicles, fast-charging stations, waiting areas, and grid connections must also be incorporated into the layout.

2.3. Traffic Volume and Flow Structure

Traffic volume and flow characteristics were analyzed using 10-year monitoring datasets from the Chongqing Expressway Group, combined with forecasting through SPSS regression analysis. Results confirm that volumes often double within one or two decades after opening, necessitating capacity reserves.

Vehicle mix (private cars, buses, heavy trucks, NEVs) was derived from sampling surveys at existing service areas. However, traffic forecasts remain sensitive to policy changes (e.g., toll reforms, freight regulations), which represent a methodological limitation.

2.4. Environmental Protection and Regional Integration

Service area planning intersects with ecology, landscape, and culture. In environmentally sensitive zones such as water protection areas and forests, facilities should be minimized and carefully sited to reduce ecological disruption. Elsewhere, integration with local landscapes, geomorphology, and cultural elements enhances both aesthetics and regional identity. Service areas can act as cultural windows, incorporating local architectural styles, tourism information, and cultural displays.

2.5. Construction and Operational Economics

Service areas are not purely public goods but must consider economic viability and sustainability. Under China’s market-oriented expressway system, investment returns and operating costs constrain siting decisions. Site selection should weigh land costs, construction expenses, passenger demand, and long-term benefits. New models such as smart service areas and integrated energy stations (oil, electricity, hydrogen) can improve efficiency and reduce operating costs.

2.6. Land-Use Efficiency and Spatial Layout

Site selection principles were evaluated through remote sensing analysis of land use and field verification surveys. Distributed and vertical layouts were modeled in AnyLogic for spatial optimization. Limitations include the fact that terrain modeling cannot always predict geological risks such as landslides, which require long-term monitoring.

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2.7. Topographic Constraints and Siting Challenges

Topography exerts strong constraints on service area siting in mountainous expressways. Large flat land parcels are rare, and construction requires substantial earthworks and risk management.

Strategies include: Linear (strip) layouts extending facilities longitudinally to minimize land requirements. Distributed layouts splitting functions across smaller nodes. Tiered/vertical structures leveraging natural elevation differences. Shared/interchange-based layouts with bi-directional or multi-section use. In extremely constrained corridors, conventional spacing may be infeasible; in such cases, priority should be given to fuel and safe parking functions, with flexible standards and modular structures adopted.

3. Analysis of Service Area Spacing in Chongqing

When determining the spacing of service areas and parking areas along expressways in Chongqing, it is necessary to integrate both international experience and domestic practice, while paying close attention to the region's unique topography and traffic characteristics. The discussion is organized into three dimensions: international comparison, domestic typical practices, and the specific challenges in Chongqing.

3.1. International Experience: Small Spacing and Hierarchical Layout

International cases provide valuable reference scales for service facility planning (see Table 1).

Table 1 World highway mileage and density table

country name	Types of facilities	Distance (km)	Remarks
U.S.	Parking Area	16～24 32~48	Sections with high traffic volume Sections with low traffic volume
U.K.	Service area	16～17	
Germany	Parking Area Service area	5～10 50	
France	Parking Area A Parking Area B Refueling facility service area	8～10 25～30 40～50 100	Provide short-term parking with toilets, benches, etc
Netherlands	Refueling facilities	20～30	
Hungary	Parking Area	20～30	
Proposal for the 8th International Road Conference	Parking Area Service area	5 50	

In Europe and the United States, rest areas are generally spaced at short intervals, about 5–25 km, while service areas with comprehensive functions (fuel, catering, retail) are typically set at 16–27 km, with some extreme cases extending to 100 km. In Japan, service area spacing is relatively stable, commonly controlled within 30–60 km, with a standard of 50 km. However, when combined with auxiliary facilities such as parking and refueling stations, the "functional accessibility" spacing usually falls within 15–25 km. Overall, developed countries tend to adopt a "small spacing, dense distribution" strategy, often placing rest areas within 10 km to address driver fatigue, safety redundancy, and convenience.

Nevertheless, these countries are mostly located in plains or relatively favorable terrains, where construction costs and topographical constraints are much less severe than those in the mountainous areas of Chongqing. Hence, while useful, such experiences should be adapted cautiously rather than copied mechanically.

3.2. Domestic Typical Practices

In China, the layout of service and parking areas reflects a more region-specific and adaptive approach.

Generally, service area spacing ranges between 30–60 km, and parking areas between 25–30 km. For example, the Chengdu–Chongqing Expressway (340 km in total) has 9 service areas, with an average spacing of about 40 km. On the Shanghai–Nanjing Expressway, the original plan included 3 service areas and 3 parking areas. With growing traffic demand and higher urbanization, these were later upgraded to full-service facilities, resulting in actual spacing between 33.6–45.5 km.

In Chongqing, the planning has already shown adaptation to terrain and traffic flow. For instance, the Weilon Service Area on the G5013 Chongqing–Chengdu Expressway is located in Tongliang District, about 45 km from the central city, covering 245.38 mu, and integrates catering, shopping, and rest functions.

Moreover, in the 2025 list of 12 national pilot "open-type service areas" issued by the Ministry of Transport, Banxi Service Area in Chongqing was included, highlighting its integration with local industries and tourism. These examples demonstrate that dense layouts are feasible in high-traffic and flat-terrain corridors, while in constrained or low-demand sections, a more flexible, differentiated spacing strategy is required.

3.3. Current Situation and Problems in Chongqing

In Chongqing's mountainous expressway network, the spacing of service areas faces several pressing issues:

Excessive spacing in critical segments：For example, in the Chongqing–Zunyi section of the Lanzhou–Haikou Expressway, the spacing between facilities once reached 79.6 km, far exceeding recommended safety limits. On the Chongqing–Zunyi Expressway, in the Liangfengya–Qijiang segment, the absence of service or parking areas forced heavy trucks to stop on roadsides or rely on makeshift water supply points from local residents, creating serious safety hazards (see table 2).

Table 2 Planned Spacing of Highway Service Areas in the Chongqing Region

Surveyed Route	Lanhai Expressway (Chongqing–Zunyi Section)	Chongqing–Suining Expressway	Zunyi–Jinsha Section	Suining–Mianyang Expressway	Chengdu–Chongqing Expressway
Route Length	~239 km	~148 km	~67 km	~176 km	~340 km
Service Area Spacing	~79.6 km	~29.6 km	~33.5 km	~44 km	~34 km
Comprehensive Spacing (Service Areas, Parking Areas, and Fuel Stations)	~39.8 km	~29.6 km	~22.3 km	~29.3 km	~34 km

Over-dense spacing and resource waste：In low-traffic segments or near urban nodes, overly dense facilities can lead to low utilization, inefficient operation, and redundant investment. Some service areas overlap in service radius, weakening their individual attractiveness and profitability.

Severe topographical constraints: As a typical mountainous and hilly region, Chongqing's road network is characterized by winding alignments, steep gradients, and numerous bridges and tunnels. Standardized layouts with independent bi-directional service areas are often impractical due to limited flat land, high excavation costs, and geological risks. Alternatives such as shared facilities, combined layouts, or strip-type designs are commonly employed.

Higher safety and service demands：In mountainous terrain, vehicles are subject to frequent load fluctuations during uphill and downhill driving, particularly heavy trucks that require water refilling, inspection, and cooling. Long spacing aggravates safety risks, while drivers are more prone to fatigue, impaired judgment, and reduced alertness in such conditions, intensifying the demand for timely service access.

In summary, if Chongqing's service area spacing continues to follow generic empirical standards without adjustment, it will be difficult to reconcile safety, efficiency, and cost-effectiveness. Therefore, it is necessary to conduct traffic volume surveys, topographical analyses, and scenario-based simulations to develop differentiated spacing strategies tailored to each corridor.

4. Spacing Strategies for Service Areas in Chongqing

In the mountainous expressway network of Chongqing, the spacing of service areas and parking areas must balance multiple objectives, including safety, service accessibility, economic efficiency, and environmental sustainability. Based on the influencing factors discussed earlier, a differentiated, hierarchical, and flexible strategy is proposed as follows:

4.1. Standard Spacing for Regular Sections

In relatively flat segments with moderate traffic and sufficient land resources, a 30–50 km spacing for service areas combined with 20–25 km spacing for parking areas is recommended. This arrangement aligns with national guidelines (average spacing not exceeding 50 km, maximum spacing within 60 km), ensures accessibility of essential services, and optimizes construction and operational costs.

4.2. Densified Layout for High-Risk or Critical Sections

For freight-intensive corridors with long downhill slopes, frequent sharp curves, or complex road conditions, the spacing of parking areas should be reduced to about 15 km. Such nodes should be equipped with water supply, cooling points, and light maintenance facilities to enhance safety. Additional small-scale rest stops or rapid refueling points may be introduced to mitigate driver fatigue and vehicle risks, especially under high traffic volumes.

4.3. Flexible Layouts in Terrain-Constrained Sections

In mountainous valleys, gorges, or areas with difficult earthwork conditions, conventional bi-directional, independent service areas may be infeasible. Flexible alternatives include:

Linear strip layout: distribute service functions along the expressway corridor, minimizing the need for large flat parcels.

Shared facilities: adopt bi-directional shared service areas or interchange-based shared facilities to reduce land and cost requirements.

Vertical or tiered layout: leverage elevation differences by stacking functions (parking, fueling, catering, rest) in a three-dimensional form.

Functional segmentation: split services into smaller nodes (e.g., fueling, water supply, or micro-rest areas) and distribute them strategically to form a service network.

In extreme terrain, priority should be given to fueling and safe parking, even if service area standards must be relaxed temporarily.

4.4. Full-Scale Layouts in Favorable Sections

In relatively flat areas with abundant land, independent, bi-directional service areas should be established, equipped with complete functions (fueling, catering, shopping, repair, charging). Expansion space must be reserved for future demand growth. These areas can be upgraded into high-level service hubs, enhancing commercial value and supporting smart and diversified operations.

4.5. Integrated Strategy and Siting Principles

The balance between service areas and parking areas should be maintained, with service areas providing comprehensive functions and parking areas serving as supplementary nodes. Site selection should adhere to the principles of minimal land acquisition, reduced demolition, lower earthwork, proximity to the mainline, and scalability. Distribution must avoid overlapping catchment areas and ensure network-wide connectivity. Facilities in constrained terrain should be sited near summits or upper slopes to minimize vehicle braking or climbing challenges.

Furthermore, considering the shift toward electric and hydrogen vehicles, service areas and parking nodes should pre-plan charging facilities, grid connections, and multi-energy integration.

Through this “primary service area + auxiliary parking area + supplementary micro-node” approach, Chongqing can establish a multi-level service facility network that ensures accessibility, enhances safety, and avoids redundant investment.

5. Conclusions and Prospects

5.1. Limitations of Fixed-Interval Models

The conventional “one service area every 50 km and one parking area every 25 km” model proves insufficient for Chongqing’s mountainous expressways. Based on GIS spatial analysis, traffic flow monitoring, and field survey data, it was found that this rigid approach cannot adapt to complex topography, differentiated safety requirements, and supplementary functional demands.

5.2. Necessity of Multi-Factor Integration

Quantitative decision-making must integrate traffic volume, vehicle types, human factors, terrain conditions, land availability, and economic efficiency. This study employed multi-criteria evaluation and scenario simulation to demonstrate that single-factor spacing standards often result in either excessive resource input or inadequate service coverage.

5.3. Zonal Differentiation and Flexible Deployment

The analysis of segmented corridors indicates that regular spacing is feasible in favorable terrain, but high-risk sections require denser deployments. In terrain-constrained corridors, flexible layouts are more appropriate. The adopted analytical framework—combining spatial clustering and accessibility evaluation—provides a practical tool for such differentiated planning.

5.4. Existing Practices and Areas for Improvement

Case studies of Rulong, Tongliang, and Daguan service areas show efforts in functional upgrades and integration of local features. However, survey data and utilization statistics reveal problems such as uneven spacing, shortages in certain corridors, and unbalanced efficiency. These issues highlight the limitations of relying solely on empirical practices without systematic, data-driven evaluation.

5.5. Future Directions: Scalability and Energy Transition

Looking ahead, service areas and parking nodes must anticipate rising vehicle ownership and the transition toward electrification and hydrogen mobility. Planning should include capacity reservation for expansion, charging infrastructure, and smart energy systems. Future work should employ dynamic simulation and life-cycle cost analysis to assess scalability and sustainability. Integrating renewable energy and intelligent operation will be critical for supporting long-term regional development.

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