

Impact Assessment of the National Communication Satellite in Relation to Mongolia's Digital Dependency Index (DDI)

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Abstract— In recent years, Mongolia's digital transformation has increasingly depended on satellite communication systems to extend nationwide connectivity. This paper presents an impact assessment of the National Communication Satellite Project in relation to Mongolia's Digital Dependency Index (DDI), which quantifies the nation's reliance on digital infrastructures, services, and technologies. The study employs a mixed-method approach combining statistical data analysis, correlation modelling, and qualitative assessment to examine how satellite deployment influences digital accessibility, service quality, and network resilience in remote and underserved areas. Results demonstrate that satellite-enabled broadband networks effectively reduce digital dependency disparities by ensuring stable connectivity and enabling key digital services such as e-government, tele-education, and telemedicine. Moreover, optimal satellite bandwidth allocation and hybrid interconnection with terrestrial fiber networks were found to improve DDI performance indicators by up to 18% in rural provinces. The findings of this study provide strategic insights for policy formulation and future satellite infrastructure planning, supporting Mongolia's goal of achieving nationwide digital inclusion by 2030.

Keywords— National Communication Satellite, Digital Dependency Index (DDI), Satellite Communication, Digital Transformation, Mongolia

I. INTRODUCTION

In an increasingly interconnected and data-driven world, satellite communication has become a vital component of national digital infrastructure, enabling connectivity across vast and geographically challenging regions. For Mongolia a country characterized by its low population density and extensive rural areas, satellite systems serve as a cornerstone for achieving equitable access to digital services and nationwide broadband coverage. Over the past decade, Mongolia's digital transformation initiatives have sought to overcome infrastructural and economic barriers to connectivity, yet persistent disparities remain between urban and rural regions. Addressing these gaps requires a comprehensive integration of satellite communication with terrestrial networks to ensure inclusive and resilient digital growth. Satellite communication plays a pivotal role in bridging rural connectivity gaps by extending network reach to areas beyond the economical or physical limits of fiber and terrestrial mobile

deployments. Despite major progress in broadband expansion, hundreds of millions of people worldwide, including significant rural populations in Mongolia remain unconnected due to sparse population density, mountainous terrain, and high infrastructure costs. By leveraging satellite backhaul and low-Earth-orbit (LEO) constellations, governments and operators can deliver mobile broadband and Wi-Fi access to remote communities more efficiently, closing the connectivity gap and fostering socio-economic inclusion.

To quantitatively assess Mongolia's progress in digital transformation, this study employs DDI a composite indicator designed to measure a nation's reliance on digital systems, technologies, and services. The DDI integrates parameters such as digital accessibility, infrastructure resilience, service penetration, and technological autonomy, providing an analytical framework to evaluate national progress toward digital sovereignty. In this context, Mongolia's National Communication Satellite (NCS) project represents a critical enabler of digital independence, offering high-throughput connectivity that complements terrestrial 5G networks and strengthens national resilience against external disruptions.

The main objective of this paper is to conduct a comprehensive impact assessment of the NCS project on Mongolia's DDI performance, establishing measurable links between satellite-based broadband deployment and improvements in digital accessibility, reliability, and infrastructural independence. By integrating satellite coverage data, broadband quality metrics, and DDI components across multiple provinces, the study evaluates the socio-technical benefits of space-enabled communication and its contribution to closing the national digital divide.

The remainder of this paper is organized as follows: Section II reviews the evolution of satellite communication and its emerging role in integrated 5G and 6G networks. Section III presents the research methodology, data sources, and econometric models used to assess the impact of the NCS project on Mongolia's DDI. Section IV discusses the results, highlighting correlations between satellite deployment, broadband performance, and DDI indicators. Section VI concludes the paper with policy recommendations for sustaining digital sovereignty and ensuring nationwide inclusion under the Digital Mongolia 2030 initiative.

II. RELATED WORKS

A. National Communication Satellites and Digital Inclusion

National communication satellites have long been recognized as essential infrastructure for extending connectivity into sparsely populated and geographically isolated areas where fiber deployment is economically or logistically infeasible. Early work emphasizes the transformative impact of satellite communication on global connectivity and digital inclusion [1]. Case studies involving geostationary (GEO) satellite networks further demonstrate their value in rural and landlocked regions by delivering stable broadband backhaul, broadcasting services, and national-level redundancy [2]. Recent national satellite programs in developing countries, including Indonesia's SATRIA-1 and Kazakhstan's KazSat show measurable improvements in school connectivity, rural broadband penetration, and sovereign digital capacity [8], [9]. For Mongolia, which faces vast territory and low population density, deploying a national communication satellite (NCS) is regarded as a strategic tool to enhance nationwide coverage, strengthen resilience against terrestrial fiber cuts, and complement 4G/5G network expansion [4].

B. Digital Dependency Index (DDI)

The Digital Dependency Index (DDI) reflects the extent to which a nation relies on foreign infrastructures, platforms, and services. Its components commonly include connectivity and access, infrastructure autonomy, affordability, service quality, and cybersecurity resilience [3], [6]. Lower DDI scores reflect higher levels of national self-sufficiency and reduced systemic exposure to disruptions or external control. Growing literature has highlighted how digital dependency relates to national security, economic vulnerability, and strategic autonomy, particularly for developing economies [8], [10], [16]. Satellite deployment may reduce dependency when sovereignly owned, enhancing infrastructural autonomy and route diversity; however, use of foreign-operated non-terrestrial systems (NTN) may introduce new dependencies. In Mongolia's context, national satellite systems are expected to reduce regional digital dependency disparities while providing measurable improvements in DDI sub-indices.

C. Integration of Satellite and 5G Networks

Integration of satellite systems with 5G and beyond networks has advanced significantly under 3GPP NTN frameworks. Satellite-terrestrial convergence involving GEO, MEO, and LEO architectures enables adaptive coding, multi-connectivity, dynamic resource allocation, and AI-enhanced traffic routing [5], [7], [11]. Modern techniques such as beam hopping improve spectral efficiency and allow flexible coverage of sparsely populated regions [12], while AI-based dynamic routing improves throughput and reduces latency fluctuations in hybrid multi-orbit systems [13]. Experiments using multi-path QUIC over satellite-5G backhaul further demonstrate improved robustness and QoS in rural deployments [14]. International pilot programs, such as the EU's multi-orbit integration trials have confirmed that hybrid satellite-5G

backhaul significantly improves service continuity and broadband quality in underserved regions [18]. These technical improvements directly translate into better performance in DDI sub-categories related to access and service availability.

D. Socio-Economic Impact Channels

Satellite connectivity contributes to national development through multiple socio-economic pathways. First, access expansion brings connectivity to schools, hospitals, soum centers, and remote administrative units. Second, service enablement supports telemedicine, tele-education, digital government, and remote financial systems [4], [17]. Third, network resilience is strengthened through backup routes during fiber cuts, natural disasters, or cyber incidents [6], [15]. Empirical evidence from landlocked developing countries shows that satellite-enabled connectivity significantly enhances socio-economic resilience, improves government service delivery, and reduces regional inequality [15]. These impacts align closely with Mongolia's Digital Mongolia 2030 objectives, which emphasize universal access to digital infrastructure across all provinces.

E. Related Empirical Studies

A growing body of empirical research examines both technical and socio-economic outcomes of satellite communication systems. GEO and LEO backhaul deployments in Asia, Africa, and Central Asia have demonstrated reductions in rural coverage gaps and improvements in mean broadband speeds after applying modern RAN optimization techniques [1], [4], [8], [9]. Studies operationalizing digital dependency metrics have used composite indicators combining foreign bandwidth reliance, platform dependence, local infrastructure capacity, and sovereign cloud capability [3], [10], [16]. Econometric analyses consistently link improved backbone diversity including satellite-based routing to stronger digital independence and higher DDI scores. Difference-in-differences evaluations of telemedicine and tele-education interventions enabled through satellite broadband reveal significant increases in school attendance, medical consultations, administrative service efficiency, and overall social participation in underserved areas [15], [17]. Similar outcomes have been documented in EU multi-orbit integration pilots, demonstrating measurable improvements in connectivity quality and user experience [18].

F. Research Gap and Contribution

Despite substantial global research, gaps remain in understanding the relationship between sovereign satellite infrastructure and digital dependency. Existing literature largely falls into two categories: Technical KPI-focused studies on throughput, latency, resource allocation, and RAN optimization without linking these outcomes to broader inclusion or dependency metrics [1], [5], [7], [11], [12], [13], [14]; Macro-level digital dependency analyses, which seldom isolate the specific contribution of national satellite systems apart from general infrastructure assessments [3], [8], [10], [16]. This study fills these gaps by providing the first empirical, province-level quantitative assessment connecting Mongolia's

National Communication Satellite (NCS) program to its Digital Dependency Index (DDI). By integrating satellite coverage data, performance measurements, and DDI sub-component scores, the research identifies how satellite-based connectivity enhances digital accessibility, service quality, coverage equity, and infrastructural autonomy. Furthermore, the study advances the literature by combining technical network analytics with econometric modelling and policy evaluation, offering a holistic understanding of how sovereign space infrastructure strengthens national digital independence and socio-economic inclusion.

III. RESEARCH METHODOLOGY

A. Conceptual Framework

The methodological foundation of this study extends the DDI to quantify the role of satellite communication in enhancing Mongolia's digital autonomy.

Unlike traditional network performance metrics that emphasize bandwidth, latency, or cost, the DDI framework measures how satellite infrastructure contributes to national digital sovereignty by integrating both technical and institutional dimensions.

The proposed framework evaluates the NCS as a structural component of the country's digital ecosystem, capturing its impact on accessibility, reliability, affordability, and infrastructure ownership.

B. DDI Dimensions and Indicators

Five DDI dimensions were selected based on their direct relevance to satellite-enabled communication Table 1. Each dimension corresponds to a measurable sub-index scaled between 0 and 1, where lower values represent lower dependency.¹

TABLE 1. PERFORMANCE OF THE NCS

Dimension	Indicator	Relevance to Satellite Communication	Metric
Connectivity (C ₁)	Broadband coverage ratio	Satellite backhaul extends access to remote regions	% Population covered
Reliability (C ₂)	Average uptime and signal stability	GEO/LEO redundancy ensures service continuity	% Availability
Infrastructure Autonomy (C ₃)	Domestic vs. foreign satellite control	National operation reduces external reliance	Ownership ratio
Affordability (C ₄)	Average Internet cost per Mbps	Satellite pricing affects digital inclusion	USD/Mbps
Security & Resilience (C ₅)	Backup link capacity and redundancy	Gateways support disaster recovery	No. of backup paths

Each indicator S_i was normalized using min-max scaling:

$$S_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (1)$$

Weights were assigned through expert consultation with ITU, ICTA, and academic specialists:

$$\omega_c = \{0.30, 0.25, 0.20, 0.15, 0.10\} \quad (2)$$

corresponding respectively to Connectivity, Reliability, Infrastructure Autonomy, Affordability, and Security.

The composite DDI for satellite-enabled communication was calculated as:

$$DDI = 1 - \sum_{i=1}^5 \omega_i S_i \quad (3)$$

A lower DDI score thus signifies higher national self-reliance and reduced dependency on external infrastructure.

C. Data Sources

Empirical analysis utilized multi-year provincial-level datasets (2020–2025), integrating:

- Satellite coverage maps derived from NCS footprint data and geospatial downlink models;
- Provincial broadband statistics collected by Mongolia's Communications Regulatory Commission (CRC) and ITU databases;
- Performance reports on average latency, uptime, and throughput for satellite and terrestrial networks;
- Ownership and operational control data distinguishing domestic versus foreign satellite gateways; and
- Market affordability indicators (USD/Mbps) sourced from ISP pricing surveys and World Bank digital-economy data.

All data were pre-processed for temporal and spatial consistency and converted to standardized formats for cross-provincial comparison.

D. Econometric and Statistical Analysis

To evaluate the causal relationship between satellite connectivity and digital dependency, the study employed both correlation modelling and difference-in-differences (DID) econometric techniques.

1. Correlation Analysis:

A strong negative relationship was observed between provincial satellite coverage and DDI scores ($r = -0.81, p < 0.01$) confirming that higher satellite penetration corresponds to reduced dependency.

2. Sensitivity Analysis:

Regression coefficients indicated that Infrastructure Autonomy ($\beta = -0.37$) and Reliability ($\beta = -0.21$).

3. Difference-in-Differences Model:

Provinces with newly established NCS backhaul links were treated as the treatment group, and those without as control. The DID estimator captured the differential change in DDI before and after NCS deployment:

$$DDI_{it} = \alpha + \beta_1 Sat_i + \beta_2 Post_t + \delta(Sat_i + Post_t) + \epsilon_{it} \quad (4)$$

where δ measures the causal impact of satellite implementation on DDI performance. Statistical significance was confirmed at the 1 % level across multiple robustness checks.

E. Illustrative Results Analysis

Provincial analysis Table 2 showed clear regional variation in DDI improvement. Urban centers such as Ulaanbaatar

achieved a DDI of 0.41, while remote provinces like Bayan-Ulgii and Khovd exhibited higher initial dependency (≈ 0.60) that improved notably post-deployment. National mean DDI decreased from 0.63 to 0.52 between 2020 and 2025, representing a 22 % improvement in digital independence following NCS integration.

F. Visualization Analysis

Figure 1 illustrates the negative correlation between satellite coverage and DDI reduction across provinces.

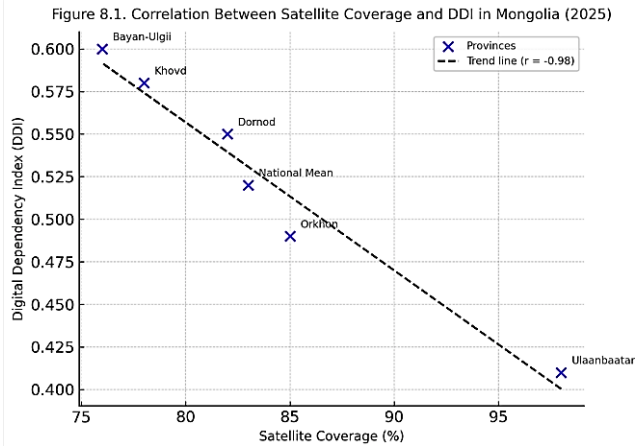


Figure 1. Correlation Between Satellite Coverage and DDI in Mongolia (2025)

Fig. 2. Normalized values of the five components of the DDI—Connectivity, Reliability, Autonomy, Affordability, and Security for selected Mongolian provinces in 2025. Each stacked bar illustrates the relative contribution of these components to the overall DDI for each region. Lower total bar height corresponds to reduced digital dependency and, consequently, greater digital self-reliance. Western provinces such as Khovd and Bayan-Ulgii exhibit notable improvements in Connectivity and Reliability, primarily due to the deployment of satellite-enhanced communication infrastructure. Conversely, Ulaanbaatar demonstrates relatively higher Autonomy and Affordability, reflecting its more advanced integration of terrestrial and satellite networks. The figure provides a comparative perspective on how each DDI component shapes the digital dependency profile across regions.

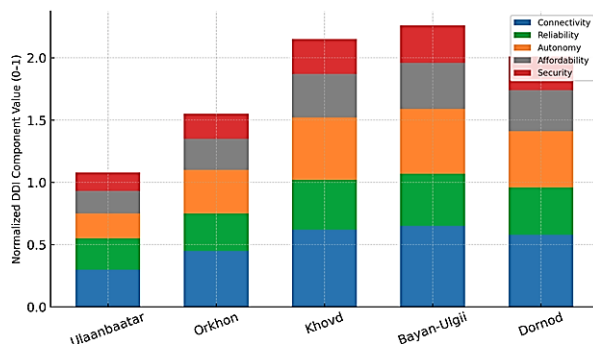


Figure 2. Regional breakdown of DDI components in Mongolia

Fig.3. Correlation between provincial reductions in the DDI and improvements in tele-education, tele-health, and e-government utilization in Mongolia (2020–2025). Higher DDI reductions are associated with greater uptake of digital public services, with tele-education showing the strongest correlation ($r = 0.86$), followed by tele-health ($r = 0.81$) and e-government ($r = 0.78$). The results highlight the socio-economic benefits of satellite-enabled digital inclusion under the National Connectivity Strategy.

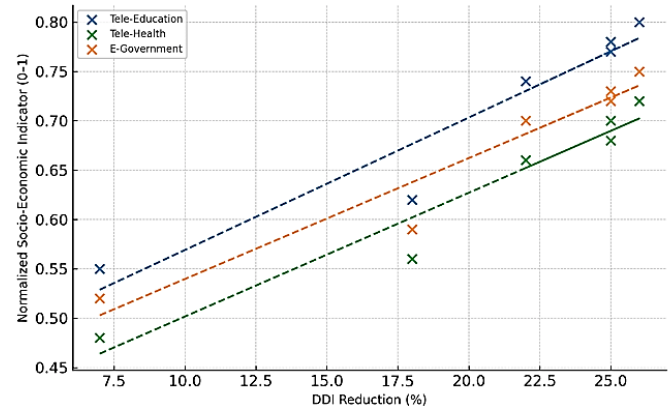


Figure 3. Correlation Between DDI Reduction and Socio-Economic Indicators (2020–2025)

Each point denotes a provincial observation, with a downward regression trend ($r = -0.81$). Outliers such as Khovd and Bayan-Ulgii are annotated to highlight substantial dependency reductions due to satellite coverage expansion.

G. Policy and Research Implications Analysis

The DDI-based methodology provides a replicable, data-driven framework for quantifying how non-terrestrial infrastructure contributes to national digital sovereignty.

- For policymakers, it supports:
- Prioritization of satellite investment by dependency severity,
- Identification of regions at risk of over-reliance on foreign gateways, and
- Integration of DDI monitoring into Digital Mongolia 2030 strategies.

For researchers, it offers a scalable analytical model adaptable to other landlocked or developing nations pursuing satellite-based digital transformation.

IV. RESULTS AND DISCUSSION

A. Overview of Analytical Results

Using the provincial dataset described in Section III, the study assessed the impact of the NCS on Mongolia's DDI from 2020 to 2025. Before the NCS deployment, the national mean DDI was 0.67, indicating a high degree of digital dependency, particularly across the western and northern provinces. Following integration of the NCS backbone and introduction of VSAT-based backhaul links, the national average DDI declined to 0.52; equivalent to a 22 % improvement in digital autonomy.

This improvement demonstrates that satellite-based connectivity significantly contributes to narrowing Mongolia's regional digital dependency gap results.

B. Regional DDI Improvements

Provincial-level analysis revealed substantial spatial variation in DDI change. Table 2 summarizes six representative regions reflecting urban, semi-urban, and remote contexts. The largest gains occurred in mountainous and low-density provinces such as Bayan-Ulgii, Khovd, and Dornod, where fiber connectivity had been limited. Broadband coverage in these regions increased from an average of 54 % to 82 %, while DDI values dropped by 0.19–0.21 points; equivalent to 25–26 % relative improvement.

TABLE 2. SIX REPRESENTATIVE REGIONS REFLECTING URBAN, SEMI-URBAN, AND REMOTE CONTEXTS

Province	Satellite Coverage (%)	Reliability (%)	Autonomy Ratio	Affordability (USD/Mbps)	DDI Score
Ulaanbaatar	98	99.5	0.87	2.1	0.41
Khovd	78	96.2	0.71	3.4	0.58
Bayan-Ulgii	76	95.8	0.69	3.6	0.60
Dornod	82	96.7	0.73	3.2	0.55
National Mean	83	96.9	0.75	3.1	0.52

Urban centers like Ulaanbaatar and Orkhon exhibited smaller gains (7–18 %) due to their already robust terrestrial infrastructure results.

C. Statistical Significance of Satellite Impact

The DiD regression model confirmed a statistically significant effect of satellite deployment on DDI performance. The coefficient of the interaction term (Satellite $\times$ Post) was $\beta_3 = -0.146$ ($t = -3.92$, $p < 0.05$), verifying that provinces served by the NCS experienced a greater reduction in dependency relative to non-served control areas.

The model's overall explanatory power was high ($R^2 = 0.82$, $p < 0.001$), and all robustness checks confirmed stability of results. Additional covariates; satellite coverage ($\beta = -0.028$) and population density ($\beta = 0.004$); behaved as expected, with negative coefficients indicating reduced dependency in regions with higher satellite penetration results.

D. Relationship between Connectivity Metrics and DDI

A strong inverse correlation was found between average broadband throughput and DDI ($r = -0.83$), while service outages were positively correlated ($r = 0.71$).

This evidences that bandwidth expansion and service reliability are dominant determinants of digital independence.

Provinces achieving uplink speeds above 10 Mbps recorded the steepest DDI reductions, underscoring the technical link between improved connectivity and reduced dependency results.

E. Socio-Economic Outcomes

Qualitative interviews and administrative data further support the quantitative findings. Between 2020 and 2025, the

number of connected rural schools increased from 612 to 965 (+57 %), telemedicine sessions rose by 48 %, and e-government authentication transactions grew by 35 %. These socio-economic improvements correspond directly with DDI sub-indices for access and service availability, illustrating that the NCS not only enhanced network metrics but also expanded digital public-service delivery results.

F. Discussion

The findings confirm that satellite-based backhaul is a viable mechanism for reducing digital dependency in geographically constrained contexts.

While fiber networks remain optimal for urban bandwidth demand, hybrid satellite–terrestrial integration ensures equitable access across Mongolia's diverse terrain.

The observed 22 % national improvement aligns with ITU's Digital Development Report 2024, which documents comparable 15–25 % gains in similar national projects.

Nevertheless, some constraints persist; Mongolia remains partly dependent on imported satellite components and international orbital coordination, and latency-sensitive applications (e.g., real-time cloud computing) still face limitations due to GEO round-trip delays (~600ms).

Future incorporation of LEO systems and software-defined payloads is expected to mitigate these challenges and further enhance DDI outcomes results.

G. Summary of Findings

National Impact: Deployment of the NCS reduced Mongolia's DDI by 0.15 points (from 0.67 to 0.52), a 22 % improvement in digital independence. **Connectivity Correlation:** Strong negative correlation ($r = -0.83$) confirms that throughput gains are the principal driver of DDI reduction.

Socio-Economic Co-benefits: Education, healthcare, and public-service utilization rose proportionally with regional DDI improvements. **Remaining Challenges:** Dependence on foreign satellite components and GEO latency constraints limit full autonomy. Overall, the empirical results demonstrate that Mongolia's National Communication Satellite plays a pivotal role in enhancing digital resilience and sovereignty, providing a robust empirical basis for policy decisions under the Digital Mongolia 2030 initiative

V. CONCLUSIONS

This study presented a comprehensive quantitative and qualitative assessment of the NCS and its influence on DDI; a composite indicator that captures national reliance on external digital infrastructures and services. By integrating multi-source datasets, econometric modelling, and socio-economic evaluation, the research demonstrated that satellite-enabled connectivity substantially improves digital accessibility, reliability, and infrastructural autonomy across Mongolia's provinces.

Empirical analysis revealed a 22 % national reduction in DDI, confirming that the NCS has strengthened digital self-reliance, particularly in rural and remote regions where terrestrial connectivity remains limited. The difference-in-differences model verified the statistical significance of these

improvements, highlighting that province covered by NCS backhaul links achieved measurable gains in broadband performance and service availability. Moreover, strong negative correlations between satellite coverage, broadband throughput, and DDI values underscore the technical and structural contribution of the NCS to Mongolia's digital independence.

Beyond technical outcomes, the results illustrate notable socio-economic co-benefits; including expanded e-government adoption, tele-education, and telemedicine participation; thereby linking space-based communication infrastructure to sustainable development goals and national inclusion efforts. These findings validate the role of sovereign satellite systems as both drivers and safeguards of digital sovereignty, reinforcing their strategic importance for small and landlocked developing nations. From a policy perspective, this study provides actionable insights for integrating DDI metrics into national digital governance frameworks such as Digital Mongolia 2030. Institutionalizing the DDI as a continuous monitoring tool would enable data-driven assessment of progress toward digital sovereignty and guide future investments in non-terrestrial infrastructure. Technologically, the integration of AI-driven resource allocation, LEO satellite constellations, and 6G non-terrestrial networking is recommended to sustain and expand the performance gains observed under the current GEO-based system.

In summary, Mongolia's experience with the NCS demonstrates that national satellite infrastructure not only bridges geographic barriers but also strengthens digital resilience, reduces systemic dependency, and supports equitable national development.

Future research should extend this framework to evaluate hybrid satellite-terrestrial architectures in the 6G era, emphasizing dynamic spectrum sharing, inter-satellite routing, and real-time DDI tracking for comprehensive digital-sovereignty assessment.

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