MAINTENANCE SOURCING, FLEET AVAILABILITY AND HUMANITARIAN PREPAREDNESS: A 48-MONTH BRAZILIAN MILITARY CASE

FORNECIMENTO DE MANUTENÇÃO, DISPONIBILIDADE DE FROTA E PREPARAÇÃO HUMANITÁRIA: UM CASO MILITAR BRASILEIRO DE 48 MESES

ABASTECIMIENTO DE MANTENIMIENTO, DISPONIBILIDAD DE FLOTA Y PREPARACIÓN HUMANITARIA: UN CASO MILITAR BRASILEÑO DE 48 MESES

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ABSTRACT

This study examines changes in fleet availability and a recorded unit-cost indicator following the transition of vehicle maintenance from an external contractor to an organic Brazilian Air Force maintenance unit, with particular attention to implications for humanitarian preparedness. The analysis covers a 35-vehicle fleet over 48 months, comprising equal 24-month periods before and after the January 2023 transition. Monthly availability, target attainment, and inflation-adjusted unit-cost data were assessed descriptively and through exploratory segmented regression with Newey–West standard errors; monetary values were converted to December 2024 Brazilian reais using the national IPCA consumer price index. Mean fleet availability increased from 62.4% in 2021–2022 to 81.1% in 2023–2024, while the proportion of months meeting the 70% availability target rose from 37.5% to 79.2%. The mean IPCA-adjusted recorded unit-cost indicator was 20.9% higher in the post-transition period. However, because availability was already improving before the transition, segmented regression identified no statistically significant level or slope change attributable to January 2023. Availability nevertheless averaged 85.9% and remained above the 70% target from May through December 2024, coinciding with a period of major flood-response and recovery activities. These findings should therefore be interpreted as descriptive rather than causal. The absence of a comparison fleet, reliance on aggregated monthly data, potential concurrent organizational changes, limitations in cost comparability, and the lack of utilization and mission-output measures constrain causal inference. The study contributes to sustainment and humanitarian logistics research by showing how maintenance-sourcing decisions can be evaluated through mission criticality, asset substitutability, availability, and accounting comparability, while emphasizing that fleet availability represents only one component of broader operational and humanitarian response capacity.

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Keywords: Humanitarian Logistics. Military Logistics. Maintenance Sourcing. Fleet Availability. Disaster Preparedness. Brazil.

RESUMO
Este estudo examina mudanças na disponibilidade da frota e um indicador de custo unitário registrado após a transição da manutenção de veículos de um contratante externo para uma unidade de manutenção orgânica da Força Aérea Brasileira, com atenção particular às implicações para a preparação humanitária. A análise abrange uma frota de 35 veículos ao longo de 48 meses, compreendendo períodos iguais de 24 meses antes e depois da transição de janeiro de 2023. Disponibilidade mensal, alcance de metas e dados de custo unitário ajustados pela inflação foram avaliados de forma descritiva e por meio de regressão segmentada exploratória com erros-padrão de Newey–West; valores monetários foram convertidos para reais brasileiros de dezembro de 2024 usando o índice de preços ao consumidor IPCA nacional. A disponibilidade média da frota aumentou de 62,4% em 2021–2022 para 81,1% em 2023–2024, enquanto a proporção de meses que atingiram a meta de disponibilidade de 70% aumentou de 37,5% para 79,2%. O indicador de custo unitário registrado ajustado pelo IPCA foi 20,9% mais alto no período pós-transição. Porém, como a disponibilidade já estava melhorando antes da transição, a regressão segmentada não identificou mudança de nível ou inclinação estatisticamente significativa atribuível a janeiro de 2023. A disponibilidade, contudo, apresentou média de 85,9% e permaneceu acima da meta de 70% de maio a dezembro de 2024, coincidindo com um período de principais atividades de resposta e recuperação de enchentes. Esses achados devem, portanto, ser interpretados como descritivos e não causais. A ausência de uma frota de comparação, a dependência de dados mensais agregados, possíveis mudanças organizacionais concorrentes, limitações na comparabilidade de custos e a falta de medidas de utilização e resultado de missão restringem a inferência causal. O estudo contribui para a pesquisa em logística humanitária e de sustentação ao demonstrar como decisões de fornecimento de manutenção podem ser avaliadas por meio da criticidade de missão, substituibilidade de ativos, disponibilidade e comparabilidade contábil, enfatizando que a disponibilidade da frota representa apenas um componente da capacidade operacional e de resposta humanitária mais ampla.

Palavras-chave: Logística Humanitária. Logística Militar. Fornecimento de Manutenção. Disponibilidade de Frota. Preparação para Desastres. Brasil.

RESUMEN
Este estudio examina cambios en la disponibilidad de la flota y un indicador de costo unitario registrado tras la transición del mantenimiento de vehículos de un contratista externo a una unidad de mantenimiento orgánica de la Fuerza Aérea Brasileña, con particular atención a las implicaciones para la preparación humanitaria. El análisis abarca una flota de 35 vehículos durante 48 meses, que comprenden períodos iguales de 24 meses antes y después de la transición de enero de 2023. La disponibilidad mensual, el cumplimiento de objetivos y los datos del costo unitario ajustados por inflación se evaluaron de forma descriptiva y mediante regresión segmentada exploratoria con errores estándar de Newey–West; los valores monetarios se convirtieron a reales brasileños de diciembre de 2024 utilizando el índice de precios al consumidor IPCA nacional. La disponibilidad media de la

flota aumentó del 62,4% en 2021–2022 al 81,1% en 2023–2024, mientras que la proporción de meses que cumplieron el objetivo de disponibilidad del 70% aumentó del 37,5% al 79,2%. El indicador de costo unitario registrado ajustado por IPCA fue 20,9% más alto en el período posterior a la transición. Sin embargo, debido a que la disponibilidad ya estaba mejorando antes de la transición, la regresión segmentada no identificó ningún cambio de nivel o pendiente estadísticamente significativo atribuible a enero de 2023. No obstante, la disponibilidad promedió 85,9% y se mantuvo por encima del objetivo del 70% de mayo a diciembre de 2024, coincidiendo con un período de principales actividades de respuesta y recuperación de inundaciones. Estos hallazgos deben, por lo tanto, interpretarse como descriptivos y no causales. La ausencia de una flota de comparación, la dependencia de datos mensuales agregados, posibles cambios organizacionales concurrentes, limitaciones en la comparabilidad de costos y la falta de medidas de utilización y resultados de misión restringen la inferencia causal. El estudio contribuye a la investigación en logística humanitaria y de sostenimiento al demostrar cómo se pueden evaluar las decisiones de abastecimiento de mantenimiento a través de la criticidad de la misión, la sustituibilidad de activos, la disponibilidad y la comparabilidad contable, enfatizando que la disponibilidad de la flota representa solo un componente de la capacidad operacional y de respuesta humanitaria más amplia.

Palabras clave: Logística Humanitaria. Logística Militar. Abastecimiento de Mantenimiento. Disponibilidad de Flota. Preparación para Desastres. Brasil.

1 INTRODUCTION

An emergency fleet may exist on paper and still be unavailable when it is needed. Its serviceability is built in ordinary months, through routine decisions about repairs, parts, technical knowledge and people. Humanitarian logistics research has greatly improved understanding of prepositioning, allocation and coordination, and recent process models explicitly recognise asset follow-up and maintenance (Balcik and Beamon, 2008; Balcik *et al.*, 2010; Saïah *et al.*, 2023). Fleet research also identifies maintenance, governance and alignment with mission needs as practical and scholarly priorities (Schaumann *et al.*, 2024). What remains less well understood is the governance behind serviceability: who can decide, who retains fleet knowledge and who controls staff, parts and infrastructure before demand rises.

The issue is especially important when defence organisations support civilian emergency networks. Aircraft, trucks and handling equipment may be listed as available capacity, but their contribution depends partly on whether maintenance has left them serviceable; it also requires availability for command tasking. This distinction is relevant to the 2024 floods in Rio Grande do Sul, during which defence organisations supported a large civilian emergency network. Extreme rainfall affected most of the state's municipalities, displaced large populations and damaged transport, health, energy and water infrastructure (Souza *et al.*, 2026). Under Operation Taquari II, the Brazilian armed forces worked alongside civil-defence bodies, governments, firms and volunteers. Official accounts describe strategic and tactical airlift as well as extensive multimodal cargo flows. This activity also involved ground-side collection, marshalling, loading and distribution (Agência Gov, 2024; Força Aérea Brasileira, 2024a, 2024b).

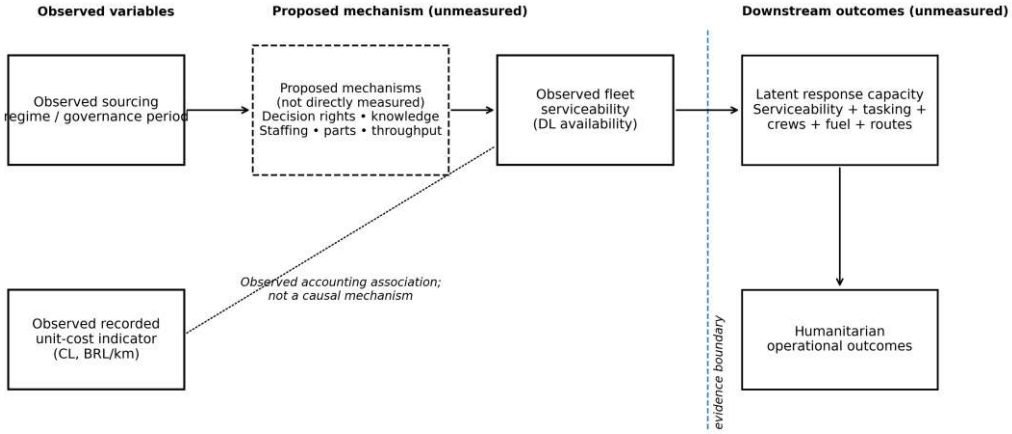
This study follows the 35-vehicle ground fleet of Brazil's National Air Mail System (Sistema de Correio Aéreo Nacional, SISCAN), operated by the Air Force Logistics Transport Centre (Centro de Transporte Logístico da Aeronáutica, CTLA). A contractor provided logistics support in 2021–2022; maintenance moved in-house in January 2023. The disclosed fleet size, core mission and institutional availability measure continued across both periods. Because the change preceded the floods, the records allow the sourcing transition to be examined over 48 months and availability to be described during the later emergency window.

No make-or-buy theory gives a universal answer. Transaction cost economics (TCE) points towards internal governance when specialised assets, uncertainty and difficult adaptation strain a contract (Williamson, 2008; Ketokivi and Mahoney, 2020). The resource-based view (RBV) asks whether knowledge, people and routines are valuable and difficult to replace (Barney, 1991, 2001). Public-sector contracting reversals reflect managerial, political and environmental conditions (Hung and Lu, 2022). In a military setting, the boundary additionally bears on mission assurance and accountability, neither of which is reducible to quoted purchase price. Outsourcing in humanitarian logistics is already a developed field of inquiry (Goßler *et al.*, 2020). The more specific question here is how a reversal in maintenance sourcing, and the governance mechanisms it may alter, relate over time to an intermediate preparedness indicator.

The study asks: **How did recorded fleet availability and the recorded unit-cost indicator evolve across the transition from contracted to in-house maintenance, and what hypotheses does the case generate about sustainment governance in humanitarian preparedness?** All 48 authorised monthly observations are retained. Cost values are converted with month-specific inflation indices, and segmented regression is used to check whether the formal transition coincided with a detectable break. That diagnostic is not treated as a causal design.

The paper adapts the defence idea of sustainment governance—coherent oversight of the policies, processes and decisions that shape lifecycle support—to humanitarian preparedness (U.S. Government Accountability Office, 2010). In this setting, the term refers to how decision rights, incentives, monitoring duties, resources and knowledge are divided between internal and external providers. It defines **latent response capacity** as the pre-event ability to place owned or accessible resources into service at short notice. Recorded fleet availability is used only as an indicator of its serviceability component; command tasking, crews, fuel, routes and network integration remain outside the measure. Applying these ideas to the 48-month series also points to what comparative research would need to measure. Empirically, availability was higher and target shortfall lower in 2023–2024, but the design cannot show that insourcing produced either the availability or cost pattern.

Figure 1. Proposed sustainment-governance pathway and the study's evidence boundary.



Source: Author's elaboration based on Williamson (2008), Barney (1991, 2001), U.S. Government Accountability Office (2010), Glas *et al.* (2013), Goßler *et al.* (2020), Hung and Lu (2022), and the analytical framework developed in this study.

2 LITERATURE REVIEW AND THEORETICAL FRAMING

2.1 PREPAREDNESS, FLEET MANAGEMENT AND LATENT RESPONSE CAPACITY

Humanitarian logistics operates with uncertain demand, many kinds of actors and unusually serious consequences when delivery is delayed (Kovács and Spens, 2007; Holguín-Veras *et al.*, 2012). Much of the resource-management literature accordingly deals with facility location, inventories, scheduling, risk and casualty allocation across preparedness and response (Geng *et al.*, 2024). Preparedness research further shows that good supply-chain design depends on the operating setting, the products involved and the kind of disaster anticipated (Stumpf *et al.*, 2023). This work explains where resources should be placed and how they might be allocated. It says less about whether the vehicles expected to move those resources will actually be serviceable.

Recent fleet studies bring the condition of the asset into view. Vehicles provide field access, consolidation and last-mile delivery, yet weak maintenance capability, poor data and unclear governance can undermine each of those functions (Schaumann *et al.*, 2024). The Frontline Humanitarian Logistics Initiative likewise places asset follow-up and maintenance within a common humanitarian process architecture (Saïah *et al.*, 2023). Maintenance is therefore recognised in the field. Its pre-emergency governance, and especially the longitudinal consequences associated with a change in sourcing, remain much less developed.

That narrower focus sits within a broader understanding of humanitarian logistics, one that accommodates changing delivery models, local actors and commercial relationships while keeping mission performance at its centre (Kembro *et al.*, 2024).

The term **latent response capacity** is used here for the pre-event ability to place owned or accessible resources into service at short notice. Doing so requires serviceability, availability for command tasking, crews, fuel, usable routes and network coordination. The institutional measure used in the case observes only serviceability. A vehicle may be serviceable but unable to contribute because a crew, fuel, route or valid tasking is missing. An owned vehicle awaiting repair has the opposite problem: it is nominal capacity without current serviceability. Availability should therefore be read as an intermediate readiness indicator, not as readiness or humanitarian performance in its own right.

The distinction also matters for financing. Humanitarian expenditure often follows an event, but maintenance systems, trained personnel and spare-parts holdings have to be funded continuously. Their value may become visible only when disruption occurs (Van Wassenhove, 2006). Routine governance decisions can thus narrow or enlarge the options later available to commanders and civilian partners.

2.2 DEFENCE ORGANISATIONS IN HUMANITARIAN RESPONSE

Defence organisations can bring transport, engineering, communications and self-sustaining command structures at a scale few civilian actors can match. That reach does not remove the need for coordination. Studies comparing military, civilian and composite response models repeatedly find friction between different mandates and organisational cultures (Pettit and Beresford, 2005; Heaslip and Barber, 2014, 2016). European emergency networks provide a similar picture: defence organisations supplied logistics, surge resources and command-and-control capabilities, but did so within wider inter-agency arrangements (Kaneberg *et al.*, 2023).

Research on whole-of-government response and organisational ambidexterity adds another layer. Agencies must coordinate surge capacity without abandoning the reliable routines that make adaptation possible in unfamiliar conditions (Narayanan and Altay, 2024; Malhouni and Mabrouki, 2025).

Internal asset condition and civil–military coordination are complementary. Coordination cannot repair an unavailable vehicle; serviceability, in turn, creates little public value unless the vehicle is assigned to legitimate civilian priorities. Kovács and Tatham's (2009) distinction between dormant preparation and action connects the two levels: capability is configured before disruption and activated through a network afterwards. The present analysis stops at the first of those levels. It examines the evolution of recorded fleet availability, not the performance of the wider relief system.

2.3 MAINTENANCE SOURCING AS A GOVERNANCE CHOICE

TCE frames make-or-buy as a choice between governance structures rather than a simple price comparison. Specialised assets can create dependence, uncertainty increases the need for unplanned adaptation and difficult measurement weakens contractual safeguards. When these problems are pronounced, hierarchy or a plural arrangement may reduce maladaptation and monitoring costs (Williamson, 2008; Ketokivi and Mahoney, 2020).

Military maintenance contains many of these hazards. Knowledge and tools may be fleet-specific, demand can rise abruptly and a delayed repair may have consequences far beyond its invoice value. Performance-based contracts can align incentives with availability, but only when outcomes can be attributed, suppliers can influence them and risks are allocated credibly (Glas *et al.*, 2013; Alqahtani *et al.*, 2023). Contracting may still be the better choice for standard work or scarce specialist skills, particularly where the supplier market is resilient. The practical issue is which arrangement preserves adaptation and accountability at an acceptable total governance cost.

RBV asks a different but complementary question: which capabilities need to remain under organisational control? For a public military organisation, mission assurance plays a role analogous to competitive advantage. Fleet-specific tacit knowledge, authorised personnel and routines integrated with command may be hard to replace during a surge, even when individual repair jobs are technically contestable (Barney, 1991, 2001). Bringing work in-house does not, however, create those capabilities by itself. It can just as readily add fixed cost, bureaucracy or skill erosion. Studies of public contracting reversals therefore point to prior performance, political and environmental conditions, and the need to revisit the boundary over time (Hartman *et al.*, 2017; Da Silva *et al.*, 2019; Hung and Lu, 2022).

Humanitarian-logistics outsourcing research arrives at much the same caution: sourcing decisions need to account for risk, coordination and capability as well as transactional efficiency (Goßler *et al.*, 2020). This case carries that discussion into a maintenance-sourcing reversal within a defence organisation that also supports humanitarian operations.

Table 1. Governance considerations for emergency-fleet maintenance

Decision criterion	TCE logic	RBV/preparedness logic	Sourcing implication
Mission criticality	Failure has asymmetric operational consequences.	Capability value is revealed under crisis demand.	Retain stronger internal or plural control as criticality rises.
Asset specificity	Fleet-specific tools, knowledge and routines increase bilateral dependence.	Tacit and integrated resources may be hard to imitate.	Safeguard configuration knowledge and diagnostic capability.
Uncertainty and adaptation	Incomplete contracts are stressed by unprogrammed surge.	Command integration can accelerate recombination of resources.	Test supplier and internal adaptation under realistic contingencies.
Substitutability under surge	Market capacity can disappear when demand is correlated.	Non-substitutability supports mission assurance.	Evaluate substitutes in crisis conditions, not only in routine markets.
Total governance cost	Price omits monitoring, transition and maladaptation costs.	Capability building carries fixed and learning costs.	Compare lifecycle cost with serviceability, mission assurance and control.

Source: Developed from Williamson (2008), Barney (1991), Glas *et al.* (2013), Hartman *et al.* (2017), Hung and Lu (2022), and Ketokivi and Mahoney (2020).

2.4 INTEGRATED FRAMEWORK AND PROPOSITIONS

Figure 1 marks the boundary between what the records show and what the theory proposes. Governance period, monthly availability and the recorded unit-cost indicator are observed. Decision speed, knowledge retention, staffing, parts access and supplier dependence are not, nor are humanitarian outcomes attributable to individual vehicles. The arrows linking these elements should therefore be read as propositions for later testing.

Taken together, the framework suggests three relationships worth testing. Where missions are time-critical, assets or knowledge are specialised and substitute suppliers become scarce during a surge, arrangements that retain internal or shared control should be associated with more reliable serviceability. If sourcing matters for availability, the link should run through observable changes in decision rights, qualified labour, fleet knowledge, parts and repair throughput; the label “make” or “buy” is too crude on its own. Finally, higher availability should add to latent response capacity only when the serviceable assets are available for command tasking and matched with crews, fuel, routes and mission



requirements. The empirical analysis below addresses a narrower question: whether the series shows a level or slope break at the formal sourcing date.

3 METHOD

3.1 RESEARCH DESIGN AND CASE SELECTION

This is a longitudinal single-fleet case study with embedded quantitative analysis and official documents establishing the operational context. Following Ketokivi and Choi (2014), the case is used to refine constructs, identify plausible mechanisms and propose boundary conditions. The design cannot estimate an average treatment effect.

The unit of analysis is the SISCAN ground fleet operated by CTLA. Every disclosed month covers 35 vehicles, among them trucks, crane trucks, tractor units and semi-trailers used for cargo collection, delivery, positioning at air bases and loading support. Contract logistics support covered January 2021 to December 2022. Internal military personnel and organisational infrastructure covered January 2023 to December 2024. The formal sourcing date thus divides the series into two 24-month periods.

The series covers all 48 monthly observations supplied for the operational fleet, but the organisation chose to bring maintenance in-house under its own conditions. There was no exogenous assignment. The author also assumed command of CTLA in November 2022, two months before the formal sourcing transition. Planning, parts acquisition, staffing, leadership attention or other changes may therefore have started before January 2023 and influenced availability independently. The analysis treats that timing as a rival intervention.

The records identify the two maintenance regimes, but not the organisational processes through which either regime might influence performance. Table 2 makes that evidence boundary explicit. TCE and RBV guide interpretation; neither is tested as a mediation model.

Table 2. Governance transition and evidence boundaries

Dimension	Contracted period	In-house period	Evidence status / limitation
Formal regime and provider	External contract, Jan 2021–Dec 2022	Military personnel, Jan 2023–Dec 2024	Observed at period level; contract and organisational instruments were not disclosed.
Fleet, mission and indicator	35 vehicles; SISCAN logistics support; DL	Same disclosed fleet size, core mission and DL	Observed in the supplied monthly series.
Personnel and facilities	Contract logistics support	Internal personnel and organisational infrastructure	Known only at high level; staffing, qualifications, capacity and workload were not supplied.
Contract design and decision rights	Not supplied	Not supplied	Scope, service levels, incentives, monitoring, escalation and authority cannot be compared.
Parts, tools and knowledge	Not supplied	Not supplied	Inventory, tooling, supplier structure and knowledge-transfer mechanisms were not measured.
Planning and implementation	Pre-transition activity may have occurred	Formal start: Jan 2023	Planning, handover and stabilisation dates are unavailable; command changed in Nov 2022.

The records identify the maintenance regime, but not the TCE/RBV mechanisms proposed in the paper. A regime label should not be read as a measured governance process.
Source: Author's elaboration based on the authorised institutional records used in this study.

3.2 DATA AND MEASURES

The outcome, logistics availability (DL), is an institutional measure normalised to 30 days. For month m:

$$DL_m\ (\%) = [\Sigma_i\ d_{im} / (30\ n)] \times 100 \qquad (1)$$

Here, d_{im} is the number of available days recorded for vehicle i, n = 35 throughout the disclosed series and multiplication by 100 expresses DL as a percentage. The 30-day denominator is used in February as well as in 31-day months, so DL is not an unadjusted share of actual calendar fleet-days. The supplied material does not state how vehicles entering or leaving overhaul were treated, how missing status entries were handled or how values were rounded to whole percentages.

Across both periods, the records use 70% as the operational target. The analysis treats it as an ex ante institutional benchmark, although no separate policy instrument confirming its authority was provided. The 48 monthly observations come from the Air Force's integrated logistics system (Sistema Integrado de Logística de Material e de Serviços, SILOMS).

Two biennial summary counts were also supplied from daily records: 274 of 730 records at or above target in 2021–2022 and 578 of 730 in 2023–2024. The underlying dates and daily values were unavailable, as was any explanation of missing-day status. Because

2023–2024 contains 731 calendar days, its denominator of 730 may represent an omitted date or an institutional convention. The two counts are used only as unaudited supplementary summaries, not as 1,460 observations or as independent confirmation of the monthly series.

The source reports CL ("logistics cost") in BRL/km. It describes the ratio as a maintenance-and-supply cost centre divided by kilometres travelled, but neither the monthly cost numerator nor the kilometre denominator was supplied. Across 48 rows, CL takes only eight distinct values, each repeated for six months. The documentation does not reveal whether they are monthly tariffs, semester aggregates carried into each monthly row or separately calculated ratios that happened to be constant. For that reason, the paper refers to CL as an **institutional recorded unit-cost indicator**. It is not a measure of full economic cost, lifecycle cost or cost efficiency.

Nominal CL was converted to December 2024 purchasing power with the official monthly IPCA number index published by the Brazilian Institute of Geography and Statistics (IBGE, n.d., 2022, 2023, 2024, 2025):

$$CL_m^{Dec2024} = CL_m \times (P^{Dec2024} / P_m) \qquad (2)$$

P_m is the month-end index for month m, and PDec2024 is the December 2024 index. IPCA measures general consumer-price inflation rather than the prices of maintenance inputs. The conversion places the reported ratios in common purchasing-power terms, but it cannot reconcile an unknown accounting boundary. Contractor payments may not be comparable with internal military labour, facilities, depreciation, inventories, pensions, overhead and contract-management costs.

Air Force and federal-government communications supply the operational context. A CTLA release, for example, reports that 15 tractor-trailers and trucks from the centre were mobilised to Brasília from 20 May 2024 for relief logistics (Força Aérea Brasileira, 2024b). The documents establish CTLA's participation and describe the wider operation. They contain no vehicle-specific journeys, kilometres, maintenance workload, cargo attributable to the 35-vehicle analytical fleet or humanitarian outcomes.

Table 3. Data sources, granularity and analytical use

Measure/source	Available evidence	Period/granularity	Analytical qualification
Availability (DL)	48 monthly values	Jan 2021–Dec 2024	SILOMS; n = 35 and 70% target in the disclosed series.
Daily target attainment	Two biennial summary counts	2021–2022; 2023–2024	No dates or microdata; 730 denominator in each period, although 2023–2024 has 731 days.
Recorded CL	48 rows; eight distinct steps	Each supplied value appears in six monthly rows	BRL/km numerator and denominator not separately available; accounting boundary unreconciled.
IPCA	48 monthly number-index values	Jan 2021–Dec 2024	Official IBGE/SIDRA series; month-end conversion to December 2024 purchasing power.
Operational context	Official communications	May–Jun 2024 sources; May–Dec window	Documents wider response and CTLA participation; does not validate fleet utilisation or relief outcomes.

Appendix A reproduces the monthly series. Daily summaries are supplementary and are not treated as independent observations for inference.
Source: Author's elaboration based on SILOMS, authorised operating-organisation records, official Brazilian Air Force communications, and IBGE data.

3.3 ANALYTICAL STRATEGY

Availability was summarised by period and by year using the mean, median, standard deviation, range and proportion of months meeting the 70% target. Monthly target shortfall, calculated as max(0, 70 − DL), describes the depth of underperformance on the original percentage-point scale.

The cost comparison uses equal-weighted means of the 24 reported BRL/km observations in each period, in nominal and IPCA-adjusted terms. Without monthly kilometres, these means are not pooled cost-per-kilometre ratios. No cost–availability correlation is reported because the eight stepped cost values co-trend with time and would invite pseudo-replication rather than reveal a meaningful marginal relationship.

To examine whether January 2023 coincides with a discontinuity, the study estimates an exploratory segmented regression (Lopez Bernal *et al.*, 2017, 2021; Linden, 2015):

$$Y_t = \beta_0 + \beta_1 CenteredTime_t + \beta_2 Insourced_t + \beta_3 PostTime_t + \varepsilon_t \qquad (3)$$

$CenteredTime_t$ is defined as t − 25, placing zero at January 2023. $Insourced_t$ equals one from that month onwards, while $PostTime_t = \max(0, t - 25)$, giving the first post-transition month a value of zero. With this coding, β_0 is the level predicted for January 2023 by the pre-transition trend, β_1 is the monthly pre-transition trend, β_2 is the immediate January level change and β_3 is the change in slope. The post-transition slope is $\beta_1 + \beta_3$.



Newey–West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors use three lags, selected by L = floor[4(T/100)^(2/9)] for T = 48, with the n/(n − k) finite-sample correction (Newey and West, 1994). Confidence intervals use the normal approximation. Robustness checks vary the HAC lag from one to six, fit a Prais–Winsten AR(1) model, add calendar-month indicators and use logit-transformed availability. These models indicate whether a break is detectable in the series; unmeasured concurrent changes remain uncontrolled.

Availability from May to December 2024 is reported separately to place the series alongside the flood response and recovery. This eight-calendar-month window is descriptive. It contains neither a measure of utilisation intensity nor a contracted counterfactual and is not a second intervention test.

3.4 VALIDITY, INTEGRITY AND POSITIONALITY

The same institutional definition, target and information system were used in both periods, which supports construct consistency. Appendix A reproduces every supplied monthly DL and nominal CL value and the corresponding inflation conversion. Maturation, anticipation, leadership, resourcing, utilisation, seasonality and the lack of a comparison fleet remain threats to internal validity. The binary regime indicator also leaves the proposed governance mechanisms unmeasured.

The author's command role provided access and operational knowledge, but it also creates interpretive risk and represents a concurrent organisational change. The paper addresses this risk through disclosure of the complete monthly analytical series, restricted use of official documents for contextual evidence and explicit separation of observed variables from proposed mechanisms. The study used aggregate operational records and public documents; it involved no human participants and processed no personal data.

4 RESULTS

4.1 AVAILABILITY AND TARGET ATTAINMENT

Mean availability was 62.4% in 2021–2022 and 81.1% in 2023–2024, an 18.7 percentage-point difference. The median rose from 63.5% to 84.5%. Standard deviations

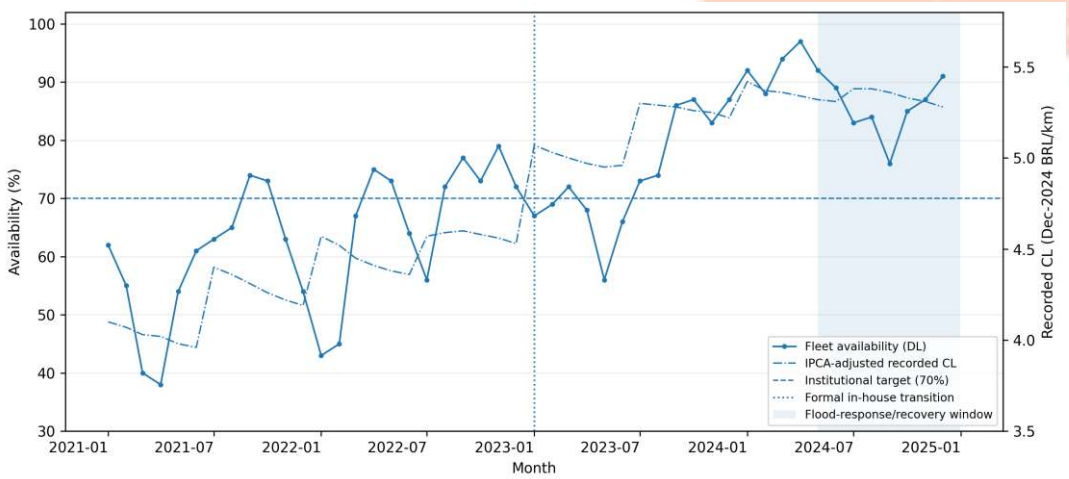
were 12.1 and 10.7 points, and both periods spanned 41 points. The later observations sit at a higher level, but their overall dispersion is only modestly smaller.

The annual means rose steadily: 58.5% in 2021, 66.3% in 2022, 74.0% in 2023 and 88.2% in 2024. The target was met in 2, 7, 7 and 12 months, respectively. Target attainment was unchanged at 7 of 12 months in 2022 and 2023, then rose to 12 of 12 months in 2024. The two-period contrast therefore includes substantial improvement well after the formal transition.

Across the full periods, target attainment increased from 9/24 months (37.5%) to 19/24 (79.2%). Mean monthly shortfall below 70% fell from 9.17 to 1.00 percentage points; in cumulative terms, it fell from 220 to 24 percentage-point-months (89.1%). DL then averaged 86.0% from July 2023 through December 2024, with all 18 months meeting the target. That later run is a post hoc description after the first six post-transition months, not evidence of a documented six-month implementation process.

The two supplied daily summaries report 274/730 records at or above target (37.53%) and 578/730 (79.18%). Rounded to one decimal place, these percentages match the monthly attainment rates. Their derivation cannot be audited. If the unrepresented post-period day is assigned either possible status, the rate is 79.07–79.21%, leaving the descriptive contrast essentially unchanged.

Figure 2. Recorded fleet availability and IPCA-adjusted unit-cost indicator across governance periods, 2021–2024.



The shaded window covers May–December 2024, overlapping flood response and recovery. The figure is descriptive and does not identify a causal effect.
Source: Author's calculations based on the authorised SILOMS monthly series and authorised operating-organisation cost records; IPCA adjustment uses official IBGE data.

Table 4. Descriptive comparison of maintenance-governance periods

Indicator	Contracted 2021–2022	In-house 2023–2024	Difference / qualification
Availability, mean (%)	62.4	81.1	+18.7 percentage points
Availability, median (%)	63.5	84.5	+21.0 percentage points
Availability, SD (points)	12.1	10.7	−1.4 points
Availability, range (%)	38–79	56–97	Same 41-point span; higher level
Months at/above 70%	9/24 (37.5%)	19/24 (79.2%)	+41.7 percentage points
Mean monthly target shortfall	9.17 points	1.00 point	−89.1% in cumulative shortfall
Supplied daily summary at/above target	274/730 (37.53%)	578/730 (79.18%)	+304 records; unaudited summary
Nominal recorded CL, mean	BRL 3.73/km	BRL 5.03/km	+34.7%; unweighted
IPCA-adjusted recorded CL, mean	BRL 4.33/km	BRL 5.24/km	+20.9%; unweighted

Target shortfall = max(0, 70 − DL). IPCA-adjusted CL uses the month-end index and December 2024 purchasing power. CL values are unweighted institutional ratios, not pooled cost per kilometre.
Source: Author's calculations based on the authorised SILOMS monthly series and authorised cost records; IPCA adjustment uses official IBGE data.

4.2 RECORDED UNIT-COST INDICATOR

The unweighted mean nominal CL was BRL 3.73/km in 2021–2022 and BRL 5.03/km in 2023–2024, a 34.7% difference. In December 2024 reais, using the month-end IPCA index, the means were BRL 4.33/km and BRL 5.24/km, a difference of 20.9%. Beginning- or mid-month timing gives 20.6–20.7%, so the comparison is insensitive to that convention.

The 20.9% estimate applies only to the supplied, equally weighted indicator after adjustment with a general consumer-price index. Monthly expenditures and kilometres are unavailable, and contractor payments cannot be reconciled with internal labour, facilities, inventories and overhead. Lower kilometres could also raise BRL/km while reducing wear and coinciding with higher availability. The **recorded, IPCA-adjusted unit-cost indicator was higher** in the later period, but the data do not identify total maintenance cost, cost-effectiveness or lifecycle value.

4.3 SEGMENTED TIME-SERIES ANALYSIS

Before the formal transition, the estimated trend was already positive at 0.97 percentage points per month (95% HAC CI 0.48 to 1.46; $p < 0.001$). That trend predicted a January 2023 level of 74.50%. The estimated immediate change at the transition was −5.54

points (95% CI −15.47 to 4.39; p = 0.274), while the change in slope was 0.087 points per month (95% CI −0.695 to 0.868; p = 0.827). Neither term was statistically detectable. The fitted post-transition slope was 1.05 points per month (95% CI 0.44 to 1.67; p < 0.001).

Table 5. Segmented regression diagnostic for monthly availability

Term	Estimate	HAC SE	95% CI	p
Pre-trend-predicted level at Jan 2023	74.50	2.99	68.64 to 80.37	<0.001
Pre-transition trend (points/month)	0.967	0.251	0.475 to 1.459	<0.001
Immediate level change at Jan 2023	−5.540	5.066	−15.469 to 4.389	0.274
Slope change after Jan 2023	0.087	0.399	−0.695 to 0.868	0.827
Post-transition trend (linear contrast)	1.054	0.312	0.443 to 1.665	<0.001

n = 48. Newey–West HAC standard errors use three lags and normal-approximation intervals. January 2023 is coded PostTime = 0, following the corrected segmented-regression parameterisation. Lag-1 residual r = 0.599; Durbin–Watson = 0.789. HAC lags 1–6, Prais–Winsten AR(1), month indicators and logit-transformed DL yielded no detectable level or slope change.
Source: Author's calculations based on the 48 authorised monthly SILOMS availability observations.

Residual dependence was material (lag-1 residual r = 0.599; Durbin–Watson = 0.789), supporting the use of autocorrelation-robust inference. Both discontinuity terms remained nonsignificant with HAC lags from one to six. Prais–Winsten AR(1) estimates were also imprecise (level change −4.95, SE 6.95; slope change 0.22, SE 0.68). Calendar-month indicators and logit-transformed availability led to the same conclusion.

The fitted series largely continues the improvement already visible before January 2023. This is not evidence that the same path would have continued without the sourcing change. The pattern is compatible with no governance effect, an effect that began in anticipation of the formal date or one that emerged gradually; the available data cannot distinguish among those possibilities. No later breakpoint is presented as confirmatory evidence because choosing one after inspecting the series would be post hoc.

4.4 AVAILABILITY DURING THE FLOOD-RESPONSE WINDOW

From May to December 2024, monthly availability was 92%, 89%, 83%, 84%, 76%, 85%, 87% and 91%. The mean was 85.9%, the median 86.0% and the standard deviation 5.1 points; all eight observations, ranging from 76% to 92%, exceeded the institutional target. The mean was 6.9 points lower than in January–April 2024 (92.8%). With no utilisation or work-order data, the reason for that difference is unknown.

This window overlaps Operation Taquari II and subsequent recovery activity. By 16 May, the wider campaign had reported 3,600 tonnes of donations moved by military personnel and civilian partners, using 26 aircraft, 38 trucks and five ships (Agência Gov, 2024). A later CTLA communication recorded the mobilisation of 15 tractor-trailers and trucks from the centre for the relief flow (Força Aérea Brasileira, 2024b). These sources establish CTLA's participation but do not measure use or performance within the 35-vehicle analytical fleet. The empirical result for this window is limited to the recorded availability series, which remained above target.

5 DISCUSSION

5.1 MAINTENANCE GOVERNANCE BEFORE DEPLOYMENT

Maintenance sourcing is decided during routine periods, but its operational relevance becomes visible when vehicles are needed. Defence acquisition treats this as a question of sustainment governance: how lifecycle decisions, incentives, monitoring, resources and technical knowledge are allocated and overseen (U.S. Government Accountability Office, 2010). Applied to humanitarian preparedness, the same lens asks whether assets listed in a response plan are serviceable and available for command tasking when demand rises.

The argument does not imply that in-house maintenance is inherently superior. A well-designed contract can maintain high availability, whereas an internal workshop may fail if it lacks parts, skills or disciplined processes. The more useful questions concern the measurability and risk allocation of contracted outcomes (Glas *et al.*, 2013; Alqahtani *et al.*, 2023), as well as fleet governance, knowledge continuity and provider capability (Goßler *et al.*, 2020; Schaumann *et al.*, 2024). None of these mechanisms is observed in the present records. The case identifies what later studies should measure; it does not test TCE or RBV directly.

Fleet availability is only the first link in the proposed pathway. DL records institutional availability days under the 30-day convention and is treated here as an indicator of serviceability. Broader readiness also depends on availability for command tasking, qualified crews, fuel, usable routes and integration with the response network. Humanitarian outcomes depend in turn on the missions selected, the deliveries completed and the value created for affected communities. Figure 1 keeps these links separate.

5.2 WHAT THE LONGITUDINAL PATTERN CAN SUPPORT

The descriptive pattern is clear. Availability was higher in 2023–2024, target shortfalls were smaller and the series later remained above target for 18 consecutive months. Its cause is much less clear. Availability had begun to improve before January 2023, the segmented model finds no break at that date and the author assumed command two months earlier. Insourcing may have formed part of a broader recovery, but these records cannot separate it from leadership, staffing, parts purchases, learning or changes already under way.

A gradual effect cannot be excluded: capability may have accumulated over time, and relevant planning may have preceded January 2023. Distinguishing that explanation from unrelated organisational change would require dated decisions, work-order throughput, workforce skills, parts fill rates and knowledge-transfer records. In their absence, the case documents a performance trajectory and helps specify a stronger comparative design.

5.3 COST, VALUE AND MEASUREMENT DISCIPLINE

The 20.9% difference in the IPCA-adjusted recorded unit-cost indicator cannot be compared directly with the 18.7-point availability difference. The recorded CL series contains only eight distinct values and rests on an accounting boundary that cannot be reconciled across periods. Without kilometres and a common treatment of contractor payments, labour, parts, facilities and overhead, neither pooled cost/km nor a readiness premium can be estimated.

For CTLA and comparable public fleets, inconsistent accounting could make one regime appear cheaper simply because costs are recorded differently. A sourcing review needs a common accounting boundary and utilisation-weighted cost, reported alongside availability, mean time to repair, backlog, critical-parts fill rate, workforce capacity and on-time completion. Recent military-maintenance research similarly treats ready-for-issue assets, workforce and maintenance completion as a portfolio rather than reducing performance to one ratio (Turan *et al.*, 2026). Together, these measures would help managers assess whether higher spending reflects capability building or inefficiency and whether low utilisation coincides with both higher unit cost and higher availability.

5.4 OPERATIONAL QUESTIONS FOR SOURCING REVIEW

Table 6 organises questions for periodic sourcing reviews; it is not a scoring model. Internal or shared control becomes more attractive when vehicle unavailability has serious mission consequences, critical knowledge is specialised and substitute capacity is scarce during a surge. Measurable work, genuine supplier contestability and tested substitute capacity strengthen the case for contracting. Hybrid arrangements may retain diagnosis, configuration control and surge capability internally while contracting standardised or scalable work.

Table 6. Questions for maintenance-sourcing review in public emergency fleets

Criterion	Evidence favouring internal/plural control	Evidence favouring contracting	Decision implication
Mission criticality	Failure materially degrades emergency response.	Postponement or substitution has low consequence.	Retain control of mission-critical layers.
Asset/knowledge specificity	Fleet-specific knowledge, tooling or authorisation.	Standard tasks and transferable knowledge.	Keep diagnosis/configuration knowledge; contract contestable work.
Surge substitutability	Suppliers, labour or parts become scarce together.	Multiple tested suppliers remain available under surge.	Secure internal, reserved or plural surge capacity.
Adaptive authority	Frequent unprogrammed decisions occur at maintenance level.	Work is specifiable, attributable and schedulable.	Place decision rights where adaptation is required.
Accounting comparability	Cost boundaries differ or hidden governance cost is material.	Lifecycle categories and utilisation are reconciled.	Do not rank regimes until cost and km are comparable.
Performance evidence	Availability, throughput, parts and skills require close control.	Contract outcomes are attributable and independently monitored.	Review the evidence profile and stress-test periodically.

These questions guide qualitative review; they are not a validated scoring instrument. Plural control retains internal capability for critical layers while using contractors for standardised or scalable work.
Source: Author's elaboration based on the theoretical framework and empirical findings developed in this study.

That boundary can move as capability matures. Internal control may support recovery and learning, while later selective contracting adds capacity or specialist innovation. Outsourcing may remain effective where outcomes are attributable and suppliers can bear the relevant risks (Glas *et al.*, 2013; Alqahtani *et al.*, 2023). Periodic stress exercises should test actual substitution during correlated demand, not merely the capacity suppliers report in routine conditions.



5.5 LIMITATIONS AND RESEARCH AGENDA

Identification is the main limitation. The analysis follows one aggregated fleet without a comparison group, and availability was already trending upwards. Organisational changes may have started before January 2023, while the author's command transition occurred two months earlier. History, maturation, anticipation and leadership therefore remain plausible explanations for part or all of the later pattern.

Measurement imposes further limits. The binary sourcing indicator says nothing about contract design, staffing, knowledge, parts, decision rights or implementation milestones. DL follows a 30-day convention and captures neither utilisation nor full readiness. The recorded unit-cost indicator contains only eight distinct steps, has no disclosed monthly numerators or denominators and rests on an unreconciled accounting boundary. Finally, neither the daily summaries nor the official operational documents can be linked independently to vehicle-level performance or relief outcomes.

The next step is comparison. Comparable fleets or staggered sourcing transitions would support controlled interrupted time-series or synthetic-control designs. Vehicle-level status, work orders, failure modes and kilometres should be linked to dated decisions, staffing, parts availability and a reconciled lifecycle-cost boundary. Preregistered transition dates and lag structures would reduce hindsight in the quantitative analysis, while process tracing could examine decision speed, knowledge retention and repair throughput. Mission tasking, delivery timeliness, volume and beneficiary outcomes would then show whether greater serviceability translates into humanitarian value.

6 CONCLUSION

Recorded performance was markedly higher across 2023–2024. Mean availability exceeded the 2021–2022 value by 18.7 percentage points, target attainment rose from 37.5% to 79.2%, and average monthly shortfall fell from 9.17 to 1.00 percentage points. The recorded, IPCA-adjusted unit-cost indicator was also 20.9% higher. From May to December 2024, during an eight-calendar-month window overlapping the Rio Grande do Sul flood response and recovery, availability averaged 85.9% and remained above target.

These comparisons do not identify an insourcing effect. Availability was already increasing before January 2023, the segmented model found no level or slope break at the

formal transition, and command changed in November 2022. With no comparison fleet, reconciled cost boundary or measured governance mechanism, the evidence remains associational.

Within those limits, the case sharpens a question for preparedness research: how does maintenance governance affect whether assets are serviceable when a response begins? Control over adaptation, fleet knowledge and critical resources offers a plausible pathway, but comparative evidence is needed to test it. In practice, sourcing reviews should record utilisation, repair throughput, workforce capability, parts access and comparable lifecycle cost alongside availability. An asset recorded as available is not, by itself, evidence of operational or humanitarian performance.

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CONFLICT OF INTEREST AND POSITIONALITY STATEMENT

The author is a serving Brazilian Air Force officer and directed the organisation operating the studied fleet from November 2022 to February 2025. This role is both a potential source of interpretive bias and a concurrent intervention in the study design. No financial conflict of interest exists.

ETHICS AND INSTITUTIONAL AUTHORISATION

Because the study used aggregate operational records and public documents and involved neither human participants nor personal data, no human-subjects ethics review was sought. The operating organisation authorised use of the records but did not issue an approval number.

AUTHOR CONTRIBUTIONS (CREDIT)

Leandro Fernandes da Silva Roman: Conceptualisation; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Validation; Visualisation; Writing—original draft; Writing—review and editing.

GENERATIVE AI DISCLOSURE

The author used generative AI to improve English expression and manuscript organisation, cross-check reported calculations and assist with document formatting. AI was not used to generate, impute or modify any of the 48 monthly observations. Responsibility for the analysis, interpretation, citation accuracy and submitted text rests with the author.

PRIOR WORK DISCLOSURE

The authorised raw series was previously reported in the author's 2025 CAEPE monograph (Roman, 2025). The present article retains those observations but asks a different research question, develops a governance and humanitarian-preparedness framework, and adds month-specific inflation conversion and segmented time-series analysis.

DATA AVAILABILITY

Appendix A reproduces the complete monthly availability and recorded unit-cost-indicator series analysed in the paper. The underlying institutional records originated in SILOMS and

were used with organisational authorisation. Daily microdata, kilometre denominators, cost-category detail and vehicle-level operational records were not available for disclosure.

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APPENDICES

APPENDIX A. COMPLETE MONTHLY ANALYTICAL SERIES

Table A1.

Complete monthly availability and recorded unit-cost-indicator series

Month	Regime	DL (%)	Nominal CL (BRL/km)	IPCA-adjusted CL (Dec-2024 BRL/km)
Jan-2021	Contracted	62	3.22	4.10
Feb-2021	Contracted	55	3.22	4.07
Mar-2021	Contracted	40	3.22	4.03
Apr-2021	Contracted	38	3.22	4.02
May-2021	Contracted	54	3.22	3.98
Jun-2021	Contracted	61	3.22	3.96
Jul-2021	Contracted	63	3.61	4.40
Aug-2021	Contracted	65	3.61	4.36
Sep-2021	Contracted	74	3.61	4.31
Oct-2021	Contracted	73	3.61	4.26
Nov-2021	Contracted	63	3.61	4.22
Dec-2021	Contracted	54	3.61	4.19
Jan-2022	Contracted	43	3.96	4.57
Feb-2022	Contracted	45	3.96	4.52
Mar-2022	Contracted	67	3.96	4.45
Apr-2022	Contracted	75	3.96	4.41
May-2022	Contracted	73	3.96	4.38
Jun-2022	Contracted	64	3.96	4.36
Jul-2022	Contracted	56	4.13	4.57
Aug-2022	Contracted	72	4.13	4.59
Sep-2022	Contracted	77	4.13	4.60
Oct-2022	Contracted	73	4.13	4.58
Nov-2022	Contracted	79	4.13	4.56
Dec-2022	Contracted	72	4.13	4.53
Jan-2023	In-house	67	4.65	5.07
Feb-2023	In-house	69	4.65	5.03

Month	Regime	DL (%)	Nominal CL (BRL/km)	IPCA-adjusted CL (Dec-2024 BRL/km)
Mar-2023	In-house	72	4.65	5.00
Apr-2023	In-house	68	4.65	4.97
May-2023	In-house	56	4.65	4.95
Jun-2023	In-house	66	4.65	4.96
Jul-2023	In-house	73	4.98	5.30
Aug-2023	In-house	74	4.98	5.29
Sep-2023	In-house	86	4.98	5.28
Oct-2023	In-house	87	4.98	5.26
Nov-2023	In-house	83	4.98	5.25
Dec-2023	In-house	87	4.98	5.22
Jan-2024	In-house	92	5.19	5.42
Feb-2024	In-house	88	5.19	5.37
Mar-2024	In-house	94	5.19	5.36
Apr-2024	In-house	97	5.19	5.34
May-2024	In-house	92	5.19	5.32
Jun-2024	In-house	89	5.19	5.31
Jul-2024	In-house	83	5.28	5.38
Aug-2024	In-house	84	5.28	5.38
Sep-2024	In-house	76	5.28	5.36
Oct-2024	In-house	85	5.28	5.33
Nov-2024	In-house	87	5.28	5.31
Dec-2024	In-house	91	5.28	5.28

Notes: DL = institutional 30-day-normalised logistics availability. Nominal CL values are the supplied institutional records. IPCA-adjusted CL expresses each nominal observation in December 2024 reais using the month-end index. Both nominal and adjusted CL are recorded institutional unit-cost indicators, not total costs. The sourcing period changes in January 2023. Raw monthly DL and nominal CL values are unchanged from the authorised source series.

Source: SILOMS and authorised operating-organisation cost records; the adjusted calculation uses the monthly IBGE IPCA number index. Raw nominal DL and CL values are unchanged from the source manuscript.