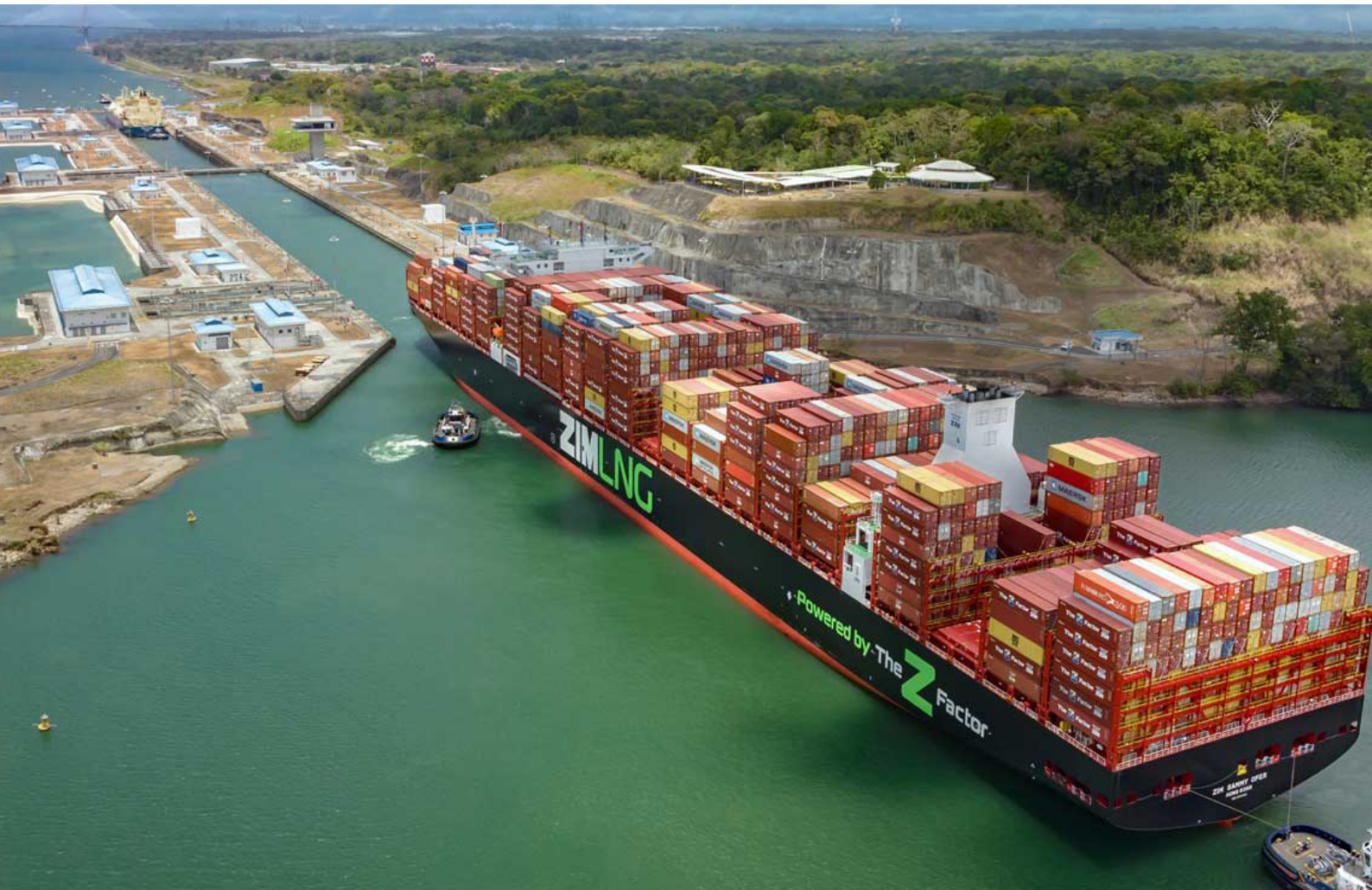




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Optimization of Multimodal Transport and Preservation of Road Infrastructure in Panamá through Metrological Traceability in Weighbridges

How the development of national regulations, metrology capacity building, and legal control has established a global, sustainable port and container transport infrastructure for Panama

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The Challenge

Panama stands as one of Latin America's top three logistics hubs thanks to the convergence of the Panama Canal, strategically positioned Atlantic and Pacific ports, the Colón Free Zone (second-largest free trade zone in the world), and Tocumen International Airport, which set a historic record of 20.9 million passengers in 2025.¹ Panama ranks 57th worldwide in the World Bank's 2023 Logistics Performance Index (score: 3.1), driven by outstanding port infrastructure efficiency.² The logistics and transport sector also contributes a significant portion (11.5 %) to the national Gross Domestic Product (GDP).³ In 2025, Panamanian ports handled 9.9 million Twenty-foot Equivalent Units (TEUs), a 3.6 % increase from the previous year (2024),⁴ while the Panama Canal generated revenues above USD 5 702 million, representing 6.3 % of Panama's GDP.⁵

Panama's economic dynamism depends critically on reliable and interconnected road, port, and logistics infrastructure. Continuous heavy freight movement generates mechanical impact on road networks beyond what original designs anticipated, imposing unplanned maintenance costs on the State and creating accident risks for workers and road users. At sea, weight misdeclaration has historically caused serious casualties: the International Maritime Organization (IMO) estimates that before the Safety of Life at Sea (SOLAS) amendment on *Verification of the Gross Mass of a Packed Container* entered into force in 2016, approximately 20 % of containers carried globally presented incorrect tonnage declarations, leading to cargo losses, container stack collapses, and loss of human life.⁶ Before the Centro Nacional de Metrología de Panamá AIP (CENAMEP AIP) intervention, Panama lacked a standardized, internationally recognized calibration method for truck weighbridges, leaving measurement results without technical validity before regulators or international commercial partners.⁷

¹ La Estrella de Panamá, "Aeropuerto de Tocumen alcanza récord histórico de pasajeros en 2025," 2026. [Online]. Available: <https://www.laestrella.com.pa/panama/nacional/aeropuerto-de-tocumen-alcanza-record-historico-de-pasajeros-en-2025-y-lidera-la-puntualidad-aerea-mundial-ML19127193>

² World Bank, "Logistics Performance Index 2023," 2023. [Online]. Available: <https://www.analdex.org/wp-content/uploads/2023/04/Informe-del-Indice-de-Desempeno-Logistico-2023-LPI-Banco-Mundial-1.pdf>

³ Instituto Nacional de Estadística y Censo (INEC), Panama — GDP by sector statistics, 2023.

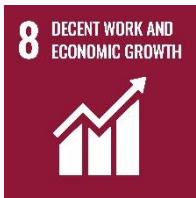
⁴ Autoridad Marítima de Panamá (AMP), "Movimiento portuario de contenedores crece 3.6% en 2025," Jan. 2026. [Online]. Available: <https://www.amp.gob.pa/noticias/notas-de-prensa/movimiento-portuario-de-contenedores-crece-3-6-en-2025/>

⁵ Panama Canal Authority (ACP), Annual Report 2025. [Online]. Available: <https://pancanal.com/wp-content/uploads/2026/01/Informe-2025Esp.pdf>

⁶ IMO, "Verification of the Gross Mass of a Packed Container — SOLAS Chapter VI, Reg. 2," 2016. [Online]. Available: <https://www.imo.org/en/ourwork/safety/pages/verification-of-the-gross-mass.aspx>

⁷ IMO, International Convention for the Safety of Life at Sea (SOLAS), Chapter VI, Regulation 2, Amendment Resolution MSC.380(94), 2014.

Table 1. Alignment of case study elements with individual UN SDGs.

SDG	Link to metrological intervention	Impact mechanism
 8 DECENT WORK AND ECONOMIC GROWTH	Fair trade in logistics depends on reliable weight measurements that ensure equal conditions for all freight operators.	Calibrated weighbridges eliminate information asymmetries, reduce illegal overloading, and strengthen Panama's competitiveness as a logistics hub (11.5 % of GDP).
 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Preservation of road and port infrastructure is essential to the sustainability of Panama's multimodal economic model.	Vehicle weight metrological control, backed by DGNTI-COPANIT 37-2002 and ATTT enforcement, prevents premature pavement deterioration from overloaded vehicles.
 11 SUSTAINABLE CITIES AND COMMUNITIES	Vehicular weight control directly affects road safety, urban and peri-urban mobility, and emissions from unnecessary overloads.	Vehicles within legal weight limits present a lower accident risk. SOLAS compliance additionally protects port workers and maritime crews.

Reliable measurement of the gross mass of large-capacity freight vehicles is indispensable for three simultaneous purposes: road freight enforcement, road infrastructure access control, and container mass verification prior to maritime loading. The core challenge was to accurately and reliably measure these freight vehicles in a metrologically traceable and legally recognized manner.

Panama's truck weighbridges also lacked an established metrology traceability chain to the International System of Units (SI), leading to a lack of confidence in the indication accuracy and preventing results from being compared across instruments with any measurement assurance. The global standard for non-automatic weighing instruments, OIML Recommendation R 76,⁸ requires that instruments used for legal cargo control be verified under controlled conditions. Any non-compliance invalidates any result they produce, which can undermine enforcement, commercialization, and regulatory compliance. The consequences of the lack of metrological control were direct: overloaded vehicles circulated without effective detection or sanction, accelerating the deterioration of road surfaces. The absence of calibrated equipment also prevented fulfillment of SOLAS Verified Gross Mass

⁸ OIML, R 76-1:2006 *Non-automatic weighing instruments — Metrological and technical requirements*, Paris, 2006. [Online]. Available: https://www.oiml.org/en/files/pdf_r/r076-1-e06.pdf

(VGM) requirements.⁹ Further, the lack of SI-traceable measurements fostered distrust and unfair competition across the freight sector, limiting the Autoridad de Tránsito y Transporte Terrestre (ATTT) capacity for evidence-based enforcement.

The Solution

CENAMEP AIP, Panama's National Metrology Institute (NMI), was established under Law No. 52 of 2007 and has participated in the CIPM Mutual Recognition Arrangement (CIPM MRA) since September 2003.¹⁰

The binding international instrument is the SOLAS Convention (1974, as amended), Chapter VI "Carriage of Cargoes and Oil Fuels", Part A "General Provisions", Regulation 2 "Cargo information", as amended by IMO Resolution MSC.380(94) and adopted 21 November 2014, and put into enforcement on 1 July 2016. The amended Regulation VI/2.2 states: *"The master or his representative and the terminal representative shall not load a packed container onto a ship unless they have obtained the verified gross mass of that container."* CENAMEP AIP, as Panama's National Metrology Institute under Law No. 52 of 2007, provides SI-traceable mass standards on which the Consejo Nacional de Acreditación (CNA) laboratory accreditation depends, thereby serving as the technical backbone of the weighing certification framework established by this resolution.

The national implementing instrument is AMP Resolution ADM. No. 125-2016, published in Gaceta Oficial No. 28060-A (24 June 2016). Article CUARTO of the resolution requires that any shipper, port terminal, or third party providing container weighing services must present calibration certificates issued by laboratories accredited by the CNA of MICI. The resolution further designates the Dirección General de Puertos e Industrias Marítimas Auxiliares to conduct periodic and random inspections to verify compliance (Article TERCERO), establishes a weighing tolerance of 5 % in the first year, reduced to 2 % thereafter, and entered into enforcement on 1 July 2016.

In direct response to these requirements, CENAMEP AIP developed the highest-capacity weighbridge calibration service in the country (70,000 kg), which was built on two metrological pillars: (1) OIML R 76,¹¹ which defines the accuracy classes, maximum permissible errors (MPEs) and verification procedures for non-automatic weighing instruments; and (2) Guide SIM MWG7/cg-01,¹² which is a methodology developed within the Inter-American Metrology System (SIM) that is used to determine calibration uncertainty from an instrument's intrinsic characteristics without being confined to a fixed set of MPEs.

⁹ IMO, International Convention for the Safety of Life at Sea (SOLAS), Chapter VI, Regulation 2, Amendment Resolution MSC.380(94), 2014.

¹⁰ BIPM, "Panama — CENAMEP AIP," bipm.org. [Online]. Available: <https://www.bipm.org/en/countries/pa>

¹¹ OIML, R 76-1:2006 *Non-automatic weighing instruments — Metrological and technical requirements*, Paris, 2006. [Online]. Available: https://www.oiml.org/en/files/pdf_r/r076-1-e06.pdf

¹² SIM, "Guide SIM MWG7/cg-01: Calibration of High-Capacity Weighing Instruments." [Online]. Available: <https://www.sim-metrologia.org.br>

Metrological traceability was established through 500 kg reference weights traceable to CENAMEP AIP's national 1 kg mass standards, which are linked to the SI through international CIPM MRA comparisons.^{13,14} To deliver this traceability to the field, the institution invested in a high-capacity calibration truck and specialized staff training. This capacity allows CENAMEP AIP to assume responsibility as the technically competent body for SOLAS VGM verification, in accordance with its CIPM MRA Appendix C CMCs.¹⁵ In parallel, the technical regulation DGNTI-COPANIT 37-2002¹⁶ was enacted, providing the legal foundation for the ATTT's cargo weight enforcement.

Weighbridge measurement data quality is ensured through a management system compliant with ISO/IEC 17025:2017,¹⁷ which requires measurement uncertainty to be evaluated in accordance with the GUM (JCGM 100:2008).¹⁸ Each calibration certificate documents the observed indications, indication errors, expanded uncertainty ($U_{95\%}$), and conformity with OIML R 76 maximum permissible errors (MPEs)¹⁹ and DGNTI-COPANIT 37-2002.²⁰ CENAMEP AIP's mass CMCs have been peer-reviewed under the CIPM MRA and published in the BIPM KCDB,²¹ providing internationally verified proof of technical competence. Active participation in SIM interlaboratory comparisons²² provides continuous evidence of laboratory accuracy and serves as an early-warning mechanism for systematic deviations — a mandatory requirement of the CIPM MRA.

¹³ CENAMEP AIP, "Centro Nacional de Metrología de Panamá AIP," cenamep.org.pa. [Online]. Available:

<https://cenamep.org.pa/cenamep-aip/>

¹⁴ BIPM, "Panama — CENAMEP AIP," [bipm.org](https://www.bipm.org). [Online]. Available: <https://www.bipm.org/en/countries/pa>

¹⁵ H. Laiz, "The impact of the CIPM MRA in the Americas," CGPM26 Presentation, BIPM, 2022. [Online]. Available:

<https://www.bipm.org/documents/20126/43975114/Presentation-CGPM26-Laiz-Americas.pdf/2bfc010a-95f4-0343-114d-6f272845c26b>

¹⁶ MICI/DGNTI Panama, "Technical Regulation DGNTI-COPANIT 37-2002: Weights and Dimensions — Cargo Vehicles on Public Roads," Panama, 2002.

¹⁷ ISO/IEC 17025:2017, "General Requirements for the Competence of Testing and Calibration Laboratories," ISO/IEC, Geneva, 2017. Available: <https://www.iso.org/standard/66912.html>

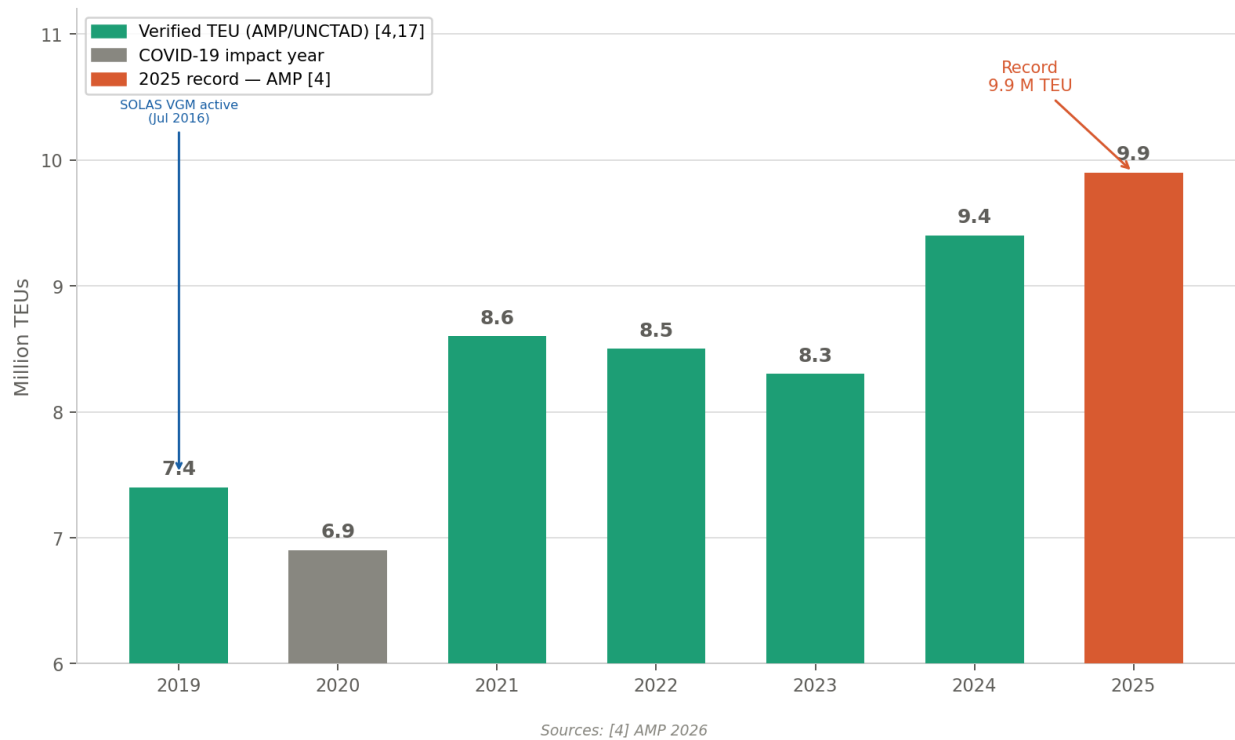
¹⁸ JCGM 100:2008, "Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)." Available: https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf

¹⁹ OIML, R 76-1: *Non-automatic weighing instruments — Metrological and technical requirements*, Paris, 2006. [Online]. Available: https://www.oiml.org/en/files/pdf_r/r076-1-e06.pdf

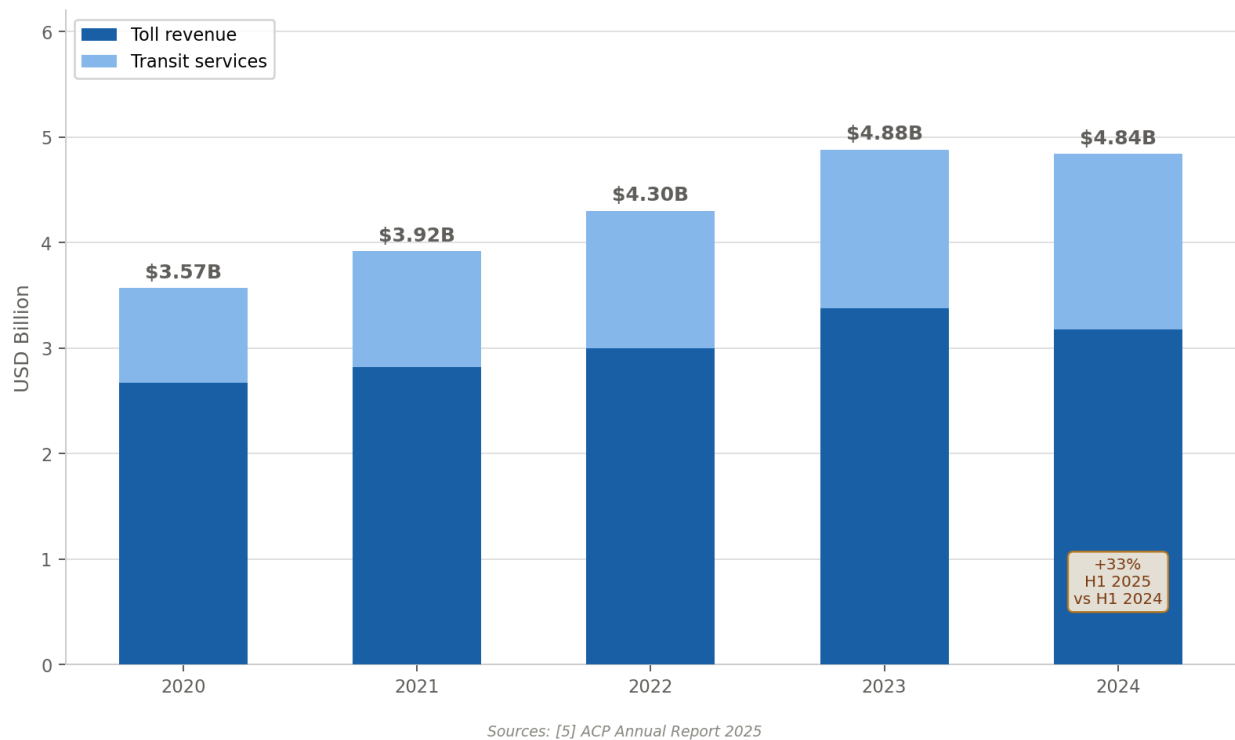
²⁰ MICI/DGNTI Panama, "Technical Regulation DGNTI-COPANIT 37-2002: Weights and Dimensions — Cargo Vehicles on Public Roads," Panama, 2002.

²¹ BIPM, "Panama — CENAMEP AIP," [bipm.org](https://www.bipm.org). [Online]. Available: <https://www.bipm.org/en/countries/pa>

²² SIM, "Guide SIM MWG7/cg-01: Calibration of High-Capacity Weighing Instruments." [Online]. Available: <https://www.sim-metrologia.org.br>



(a)



(b)

Figure 1. (a) Panama port container throughput (M TEU, 2019–2025) and (b) Panama Canal annual revenue (USD Billion, 2020–2024).

A Quantifiable Impact

The metrological intervention produced measurable results across four interconnected national sector areas. **Table 2** summarizes the baseline shift that occurred following the intervention.

This case study illustrates an institutional value chain: first, developing metrological capacity, which then promotes deliberate and thus effective technical regulation that can lead to effective enforcement. CENAMEP AIP's calibration service was a precondition for the Ministry of Commerce and Industries to enact specific technical regulations and for the ATTT to follow with technically sound enforcement. Importantly, this framework would not have been defensible without metrologically traceable measurements. Panama's recognition as the SOLAS-competent body²³ directly supports its international position as a reliable logistics hub. As a result, the Canal contributed USD 5 702 million to the national economy in 2025.²⁴ While Canal Tolls are assessed per vessel capacity and cannot be directly attributed to weighbridge calibration, the integrity of that value chain depends on metrologically verified cargo weights. CENAMEP AIP's calibration service is the legal precondition for SOLAS VGM compliance at Panama's ports, without which no packed container can be loaded onto a vessel.

A quantitative impact of this service is illustrated by the magnitude of port operations via Canal tolls: Panama's container ports handled 9.9 million TEUs in 2025,²⁵ all of which required SOLAS VGM compliance. At an estimated port-handling revenue of USD 150–200 per TEU (a conservative industry benchmark), container port operations generate approximately USD 1.5–2.0 billion annually, all of which is contingent on the Panamanian metrological infrastructure supporting SOLAS VGM compliance and ensuring that container lines continue transshipment calls through the Canal. Furthermore, weighbridge calibration infrastructure is a necessary enabling condition for Panama's entire container port and logistics sector, which represents approximately 11.5 % of the GDP.

Importantly, the SOLAS VGM amendment was a direct response to casualties caused by mis-declared container weights, including the capsizing of the Deneb in Algeciras and the structural failure of the MSC Napoli off the UK coast.²⁶ The SOLAS VGM amendment has directly affected the safety of workers involved in container management and shipping

²³ H. Laiz, "The impact of the CIPM MRA in the Americas," CGPM26 Presentation, BIPM, 2022. [Online]. Available: <https://www.bipm.org/documents/20126/43975114/Presentation-CGPM26-Laiz-Americas.pdf/2bfc010a-95f4-0343-114d-6f272845c26b>

²⁴ Panama Canal Authority (ACP), Annual Report 2025. [Online]. Available: <https://pancanal.com/wp-content/uploads/2026/01/Informe-2025Esp.pdf>

²⁵ Autoridad Marítima de Panamá (AMP), "Movimiento portuario de contenedores crece 3.6% en 2025," Jan. 2026. [Online]. Available: <https://www.amp.gob.pa/noticias/notas-de-prensa/movimiento-portuario-de-contenedores-crece-3-6-en-2025/>

²⁶ IMO, "Verification of the Gross Mass of a Packed Container — SOLAS Chapter VI, Reg. 2," 2016. [Online]. Available: <https://www.imo.org/en/ourwork/safety/pages/verification-of-the-gross-mass.aspx>

Table 2. The conditions of various national-level sector areas before and after CENAMEP AIP metrological intervention.

Sector(s)	Prior to intervention (before 2006)	After intervention (2006 - present)
Metrological	No metrologically traceable calibration for high-capacity weighbridges. Results did not provide any quantified uncertainty or SI traceability.	CMCs published in BIPM KCDB since 2006. Uncertainty per GUM $U_{95\%}$. Internationally recognized in all CIPM MRA signatory countries.
Regulatory	No national standard for enforceable weight control. ATTT enforcement was technically unsupported.	DGNTI-COPANIT 37-2002 enacted. ²⁷ Seven (7) ATTT-enforced weigh stations are now operational across the national road network. ²⁸
Maritime/ SOLAS	No competent body for Verified Gross Mass (VGM) verification. Approximately 20 % of containers globally are mis-declared, with stack collapses and human losses documented. ²⁹	AMP Resolution ADM. No. 125-2016 requires VGM verification using CNA-accredited laboratory equipment. CENAMEP AIP, as Panama's NMI (Low 52-2007), ³⁰ provides the SI traceable standards underpinning that accreditation. A systemic risk now addressed by mandatory VGM verification. Panama handled 9.9 M TEUs in 2025, ³¹ all of which were subject to this requirement. ³² Internationally, documented maritime casualties attributable to weight misdeclaration have not recurred at a comparable scale since enforcement began. ³³
Economic/ Social	Premature road deterioration from undetected and unenforced overloading. Unfair competition among freight operators.	Road infrastructure protected: logistics sector = 11.5 % of GDP. ³⁴ Equitable trade conditions for all operators. Canal revenues: USD 5 702 M in 2025. ³⁵

²⁷ MICI/DGNTI Panama, "Technical Regulation DGNTI-COPANIT 37-2002: Weights and Dimensions — Cargo Vehicles on Public Roads," Panama, 2002.

²⁸ ATTT / Panama Logistics Portal, "Trucking Components and Operations — Weights and Dimensions," 2024. Available: <https://logistics.gatech.pa/en/logistics-platform/logistics-services/panama-trucking-industry/>

²⁹ IMO, "Verification of the Gross Mass of a Packed Container — SOLAS Chapter VI, Reg. 2," 2016. [Online]. Available: <https://www.imo.org/en/ourwork/safety/pages/verification-of-the-gross-mass.aspx>

³⁰ CENAMEP AIP, "Centro Nacional de Metrología de Panamá AIP," cenamep.org.pa. [Online]. Available: <https://cenamep.org.pa/cenamep-aip/>

³¹ Autoridad Marítima de Panamá (AMP), "Movimiento portuario de contenedores crece 3.6% en 2025," Jan. 2026. [Online]. Available: <https://www.amp.gob.pa/noticias/notas-de-prensa/movimiento-portuario-de-contenedores-crece-3-6-en-2025/>

³² IMO, International Convention for the Safety of Life at Sea (SOLAS), Chapter VI, Regulation 2, Amendment Resolution MSC.380(94), 2014.

³³ IMO, "Verification of the Gross Mass of a Packed Container — SOLAS Chapter VI, Reg. 2," 2016. [Online]. Available: <https://www.imo.org/en/ourwork/safety/pages/verification-of-the-gross-mass.aspx>

³⁴ Instituto Nacional de Estadística y Censo (INEC), Panama — GDP by sector statistics, 2023.

³⁵ Panama Canal Authority (ACP), Annual Report 2025. [Online]. Available: <https://pancanal.com/wp-content/uploads/2026/01/Informe-2025Esp.pdf>

activities at the international level. Since the 2016 enforcement of SOLAS VGM, the IMO and industry observers have consistently reported a significant deterrent effect on misdeclaration incidents globally.^{36,37} No comparable large-scale container stack collapse attributable solely to weight misdeclaration has been documented on a scale comparable to the pre-2016 incidents. This has a positive impact on Panama as a SOLAS Contracting Government and as part of this global transportation network.

Panama's metrological arc, which included its founding from INTI cooperation (1976), and through its participation in the CIPM MRA (2003), followed by its first KCDB-recognized CMCs (2006), Law No. 52 (2007), and the National Metrology Strategic Plan (2021), has demonstrated that metrological capacity and a subsequent trust in measurements can be effectively built up through sustained, long-term institutional commitment. For countries with logistics-intensive economies, the World Bank identifies national quality infrastructure, including metrology, as a key determinant of competitiveness and market access.³⁸ The Panamanian model, which coordinates CENAMEP AIP (technical capacity), Ministerio de Comercio e Industrias Panamá (MICI; regulation), ATTT (enforcement), and Autoridad Marítima de Panamá (AMP; maritime compliance), offers a transferable governance template for the region.

Acknowledgments. The authors acknowledge the technical and institutional contributions of the Inter-American Metrology System (SIM), the Autoridad de Tránsito y Transporte Terrestre (ATTT), the Autoridad Marítima de Panamá (AMP), the Dirección General de Normas y Tecnología Industrial (DGNTI/MICI), the Bureau International des Poids et Mesures (BIPM), and the International Organization of Legal Metrology (OIML).

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³⁶ IMO, "Verification of the Gross Mass of a Packed Container — SOLAS Chapter VI, Reg. 2," 2016. [Online]. Available: <https://www.imo.org/en/ourwork/safety/pages/verification-of-the-gross-mass.aspx>

³⁷ IMO, International Convention for the Safety of Life at Sea (SOLAS), Chapter VI, Regulation 2, Amendment Resolution MSC.380(94), 2014.

³⁸ World Bank, "Quality Infrastructure," [worldbank.org](https://www.worldbank.org/en/topic/competitiveness/brief/qi). Available: <https://www.worldbank.org/en/topic/competitiveness/brief/qi>