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Transparency and trust for bunkering custody transfer in Singapore's high-value maritime supply chain

NMC ensures quantity measurement assurance through a real-time, tamper-evident, fully digital bunkering system using mass flow meters

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The Challenge

This case study addresses a sector-wide need for transparent, trusted, and efficient determination of bunker fuel quantity, as well as for protecting custody-transfer records in a high-value maritime supply chain. Through reliable measurements and an innovative digital trading infrastructure, this work supports fair, accountable economic transactions for a major commodity and resource for Singapore. It is significant for Singapore because bunkering is a major economic activity, and Singapore's position as a global maritime hub depends on confidence in measurement outcomes and transaction integrity. Before the metrological intervention, quantity determination relied heavily on manual tank gauging and paper-based records, which were labor-intensive and prone to human error and disputes. As the sector transitioned to mass flow metering (MFM) and digital records, additional risks associated with real operating conditions have emerged. For example, two-phase flow, high-viscosity fuels, start/stop transients, and shipboard dynamics can affect meter accuracy, and concerns over digital data integrity, metrological traceability, and potential tampering across interconnected systems.

The measurement gap was that bunker quantity determination could be inaccurate or disputed when it depended on manual dip-stick or tank-sounding practices, which were labor-intensive and susceptible to human influence or manipulation, with errors of about 5 % under legacy manual methods. In Singapore, the world's largest bunkering port, such an error could translate into substantial financial discrepancies, creating recurring disputes and weakening trust in custody-transfer outcomes. Although mass flow meters provide direct mass measurement and could potentially reduce custody-transfer uncertainty to below 0.5 %, their performance in bunkering had yet to be proven under real shipboard conditions. Two-phase flow, high fuel viscosity, transient flow, and shipboard dynamics can all bias meter performance if not properly managed and evaluated. At the same time, digital bunkering relies on electronic signals and data exchange across multiple devices, creating a second gap: without independent quality assurance, stakeholders may not be confident that the custody-transfer data transmitted is complete, authentic, and tamper-evident. Because bunker deliveries are high-value, small discrepancies can create material financial exposure and erode trust in transactions and regulatory oversight.

The Solution

Working with the Maritime and Port Authority of Singapore (MPA), suppliers, ship operators, and meter manufacturers, A*STAR National Metrology Centre (NMC) developed the scientific

and operational framework needed to implement mass flow metering (MFM) for bunkering with confidence. This included standardized bunkering procedures to manage operational influences, such as flow stabilization, start-up and shut-down effects, air entrainment, and fuel-handling practices, which help reduce variability caused by two-phase and transient flows.

NMC also developed an on-board (in-situ) evaluation methodology to assess and certify MFM performance during actual deliveries, so that meter behavior and uncertainty are characterized under normal operational conditions that cannot be fully replicated in a laboratory calibration, while maintaining metrological traceability to the SI unit of mass. Building on this physical measurement assurance, NMC pioneered data metrology for digital bunkering by creating independent verification tools (i.e., an independent reference datalogger and a “listener” device) to authenticate key data streams and detect inconsistencies, data loss, or unauthorized modifications without disrupting normal operations. These developments were documented and institutionalized through Singapore Standards SS 648,¹ and SS 709,² and later internationally standardized as ISO 22192,³ embedding both measurement accuracy and digital data assurance into regulatory, licensing, accreditation, and audit frameworks.

A Quantifiable Impact

Since the mandatory implementation of the MFM bunkering metrology solution for bunkering custody transfer in 2017, Singapore now operates a real-time, tamper-evident, fully digital bunkering system that improves transparency and trust in a sector valued at about USD 33 billion. As a result, operational efficiency improved through savings of approximately 40 000 man-days annually⁴ and a reduction in bunkering time of up to 25 %.^{5,6} Disputes were minimized through custody-transfer accuracy within 0.5 %, ⁷ supported by traceability and independent verification of digital records, and safety was improved by reducing reliance on manual tank gauging and lowering onboard manpower requirements. The assurance of digital records is supported by metrological traceability to the SI unit of mass and independent verification of digitally transmitted data using the reference datalogger and a listener device, with documentary references in SS 648, SS 709, and ISO 22192.

¹ Singapore Standards Council, 2024. SS 648:2024 Code of practice for bunker mass flow metering. Singapore: Enterprise Singapore.

² Singapore Standards Council, 2024. SS 709:2024 Specification for digital bunkering supply chain documentation: Enterprise Singapore.

³ International Organization for Standardization, 2021. ISO 22192:2021 Bunkering of marine fuel using the Coriolis mass flow meter.

⁴ Maritime and Port Authority of Singapore (MPA). Digital Bunkering. <https://www.mpa.gov.sg/port-marine-ops/marine-services/bunkering/digital-bunkering> (accessed 2026-06-25)

⁵ Maritime and Port Authority of Singapore: Economic Benefits of Technical Reference (TR) 48: 2015.

https://scic.sg/sdosic/images/Public_TR_48_Case_Study_Presentation.pdf

⁶ Chem Digest. A Quarterly Publication by the Singapore Chemical Industry Council Limited. Issue No. 1 Jan-Mar 2016.

<https://scic.sg/images/publications/chemDigest/2016/2016-Chem-Digest-Q1.pdf>

⁷ National Archive of Singapore. Bunkers Factsheet.

[https://www.nas.gov.sg/archivesonline/data/pdfdoc/20140415004/factsheet_\(bunkering-final\).pdf](https://www.nas.gov.sg/archivesonline/data/pdfdoc/20140415004/factsheet_(bunkering-final).pdf)

From a policy and institutional perspective, the initiative strengthened governance by embedding physical measurement accuracy and digital data assurance into regulatory, licensing, accreditation, and audit frameworks, improving system-wide auditability and trust. By underpinning SS 648 and SS 709 and contributing to ISO 22192, the framework supports international harmonization, interoperability, and confidence in cross-border trade.

The success and impact of this metrological intervention on Singapore's maritime activities were led by Mr Wu Jian, NMC's Principal Metrologist,

"The metrological assurance gives confidence in bunkering custody transfer by ensuring that both the fuel quantity and the digital records are accurate and trustworthy. This has significantly reduced disputes and strengthened Singapore's reputation as a trusted bunkering hub."

The case study also illustrates how metrologically traceable measurements and independent data verification can reduce 70 %, ⁸ of disputes and enable transparent digital trading workflows, directly supporting maritime and fuel transportation infrastructure. The same foundations can be extended to next-generation fuels such as liquefied natural gas (LNG), methanol, ammonia, and hydrogen, where trusted measurement of quantities and secure digital records will be even more critical.

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⁸ Maritime and Port Authority of Singapore: Economic Benefits of Technical Reference (TR) 48: 2015.
https://scic.sg/sdocscic/images/Public_TR_48_Case_Study_Presentation.pdf