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Assessment of Digital Solutions for Conformity Assessment of Legally Controlled Measuring Instruments in Tanzania

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ABSTRACT

The advent of state-of-the-art digital technologies since 2011 has led to the digital transformation of legal metrology practices to ensure the trustworthiness of software-controlled measuring instruments globally. Despite the digital transformation in legal metrological practices, the conformity assessment of legally controlled measuring instruments is manually done (i.e., paper-based) in Tanzania. The paper-based conformity assessment of legally controlled measuring instruments is prone to error and lacks efficiency and effectiveness. This study aimed to assess digital solutions for improving conformity assessment through a comprehensive survey conducted across various regions in Tanzania, targeting a stratified sample of 51 respondents from organizations involved in legal metrology. Data was collected using structured questionnaires. SPSS® 23.0 analyzed the collected data. The reliability testing through the Cronbach's alpha value was 0.887, implying high internal consistency of the data collected. The findings revealed that the awareness level spans from neither aware to fully aware. The overall readiness level was as follows: digital solutions (level 2), instrument (level 3), infrastructure (level 3), skilled personnel (level 2), financial arrangement (level 2) and government policy (level 4). The overall readiness level approximated to level 4. Thus, the findings indicate that there is an intermediate level of readiness to adapt state-of-the-art technologies to enhance conformity assessment of legally controlled measuring instruments. Approximately 75% of respondents are aware of various digital solutions for conformity assessment of legally controlled measuring instruments, including digital conformity assessment certificates, digital twins for products and instruments, and smart sensors.

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INTRODUCTION

Conformity assessment encompasses the procedures used to evaluate products, services and processes to ensure they meet established standards (ISO, 2022). The evaluation and assurance of conformity are crucial aspects that hold equal or greater importance than the standards (Pendrill, 2014). This process involves testing, inspection, audits, certification, and approval (Badnjevic et al., 2023). When

consumers seek a recognized certificate of approval on a product, it signifies that the product has been independently tested and verified against relevant standards, providing an additional layer of assurance (Nzumile & Taifa, 2021).

Products that have undergone conformity assessment often display a certification mark, typically managed by reputable organizations like the Tanzania Bureau of Standards. This non-profit third-party institution plays a crucial role in developing safety standards, testing products, and issuing certifications. The primary objective of conformity assessment activities is to instill confidence in relevant parties, including purchasers and regulatory agencies. This confidence empowers purchasers to make well-informed buying decisions, while regulators rely on it to determine the approval or disapproval of products for use (Kaul, 2024). A study conducted by Yadav et al. (2024) sheds light on the significance and implications of accreditation and conformity assessment processes in the global exchange of goods and services. It underscores the pivotal role of accreditation in showcasing an organization's competency and impartiality to deliver diverse services in both domestic and international trade by strictly adhering to international standards and ensuring conformity with them.

According to the International Organization of Legal Metrology (OIML), the conformity assessment of legally controlled instruments involves several key procedures (OIML, 2019). Traditionally, this assessment includes type evaluation, type approval, and verification. Type evaluation entails subjecting instruments to various tests like temperature and electromagnetic compatibility assessments, typically conducted in specialized laboratories. A type evaluation report is then issued, which influences the decision on type approval and the issuance of a certificate (OIML, 2019). This process aims to ensure that verified instruments comply with all applicable technical and metrological legal requirements to prevent non-compliant products from entering the market, thus safeguarding against unfair competition and potential risks to countries and economies (OIML, 2019).

Certification is done by the certification bodies in charge and accredited by each state or regional bodies. In Tanzania, the Weights and Measures Agency (WMA) under the Ministry of Industry, Investment and Trade has developed various regulations for checking compliance of metrological controlled measuring instruments. The regulations are made under section 54 of the Weights and Measures ACT (Cap.340) R.E 2002. The regulations are made to meet the requirements for legally controlled instruments, and before making measuring instruments available on the market, they should undergo a conformity assessment according to the Measurement Instruments requirements of regulations and standards.

Modern measuring instruments are electronic, meaning they are software-controlled and replace mechanical ones. The digital transformation of processes in legal metrology for measuring instruments has recently been a significant focus as it provides a foundation for the trustworthiness of conformity assessment of software-controlled measuring instruments in each OIML member state (Oppermann et al., 2022). In Tanzania, the conformity assessment processes of legally controlled instruments performed by WMA are paper-based. An authorized staff physically signs these paper-based documents, typically printed on special paper. These papers must conform to the Acts, regulations and international standards of the International Organization of Legal Metrology (OIML recommendations). This manual transcription of the conformity assessment data lacks accuracy, efficiency and effectiveness. It is also noted by (Peters et

al., 2015) that most electronic measuring instruments suffer from security issues, especially those connected to the Internet of Things, i.e., software-controlled instruments.

Moreover, un-notified bodies do the major tasks of IT services in legally controlled instruments in Tanzania and there is not enough information for officials of regulatory bodies concerning the rapid development and custom–tailored IT infrastructure and services. This hinders the transparency of metrological processes to all stakeholders. The general conformity assessment processes, market surveillance/verification, and inspections should lead to significant cost savings in national quality infrastructure (Oppermann et al., 2018). Therefore, employing digital solutions in the conformity assessment of software-controlled measuring instruments is highly demanding because electronic measuring instruments are replacing mechanical ones. Hence, a study must be conducted to assess the digital solutions for conformity assessment of legally controlled measuring instruments. This will unveil feasibility of various digital solutions, the level of awareness regarding digital technologies, and the readiness to implement digital solutions in conformity assessment of legally controlled measuring instruments. Assessing the digital solutions in the conformity assessment of legally controlled measuring instruments in Tanzania involved answering the following research questions.

a) What digital solutions are employed in the conformity assessment of legally controlled measuring instruments in Tanzania?
b) What is the awareness level of conformity assessment digital solutions in Tanzania?
c) What is the readiness level to employ digital solutions in the conformity assessment of legally controlled measuring instruments?

LITERATURE REVIEW

Conformity assessment process

The world is currently in the middle of a disruptive digital revolution that impacts nearly all business, manufacturing, and economic sectors worldwide (Eichstädt, 2020). The advent of the latest digital solutions since 2011 has impacted numerous aspects of metrology, including industrial, legal, and scientific ones. Several digital solutions have been integrated into metrological operations, such as calibration, which entails the digitalization of the calibration process (Andonov and Cundeva-Blajer, 2018), the conformity assessment digital certificate, to mention a few (Oppermann et al., 2022). To enable the digitalization of metrological operations, which include conformity assessment, numerous digital solutions have been discussed by several authors.

The automatic validation of conformity assessment is enabled by the employment of an Extensible Markup Language (XML) schema in which an online conformity assessment is enabled. The process involves several functionalities such as a web of service also known as the declaration of conformity (DoC) service, an XML validation scheme where the user provides information about the device or product required in the conformity assessment process, as well as REST interfaces for transmission of metrological information from one entity to another as depicted in Figure 1 (Oppermann et al., 2022).

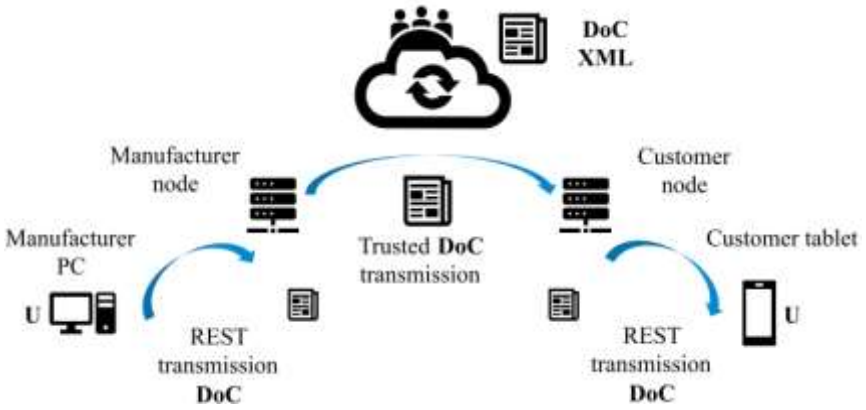

Figure 1: On-line conformity assessment process

Source: Oppermann et al. (2022)

Moreover, a study conducted in Newszeland regarding the digitalization of conformity assessment found that digital technologies such as artificial intelligence, big data, and digital twins are already integrated in the process, though not at a large scale (Koch et al., 2022). The report also stressed that cloud computing, mobile technologies, and embedded information technology systems are widely used in conformity assessment processes. This indicates that the potential of state-of-the-art digital technologies is yet to be utilized in the digitalization of metrological operations, and conformity assessment is one of them.

The calibration of measuring instruments is one of the conformity assessment activities that can be digitized through the employment of the latest digital technologies. A study conducted by Cunha & Santos (2020) proposed using the Internet of Things (IoT), cloud computing, and big data technology to digitalize the calibration process. The study stressed that the new system would no longer need the unit under test (UUT) to be transferred to calibration laboratory, saving time, cost and error minimization compared to the conventional calibration procedure. A concept of the touchless calibration was also presented by Andonov and Cundeva-Blajer (2018) by synchronizing the communication between clients and calibration laboratories in real time. The calibration data from calibration laboratories is sent to the client laboratory through digital network without transporting a unit under test (UUT) to the reference lab enabled by the IoT, cloud computing, and big data technologies. However, some challenges still require due attention during the implementation such as data security, professionals, advanced sensors, among others.

It is also noted that the success of the employment of advanced digital technologies in metrological operations depends on multiple readiness factors. These factors are crucial to ensure the effective integration of the technologies, which will eventually output the expected results when attention is paid to them. The study by Koch et al. (2022) highlighted numeral factors that the organization should consider when needing to digitalize the conformity assessment process. The factors include the availability of qualified personnel in advanced digital technologies application, compatibility of existing measuring equipment with the latest technologies, organization culture, i.e. openness, transparency etc., the government policies, financial set up, infrastructure i.e. electricity, speed of the internet to mention a few. Moreover, a global study conducted on the digitalization in conformity assessment identified factors

that required due attention to enable effective digitalization, which include the availability of data security infrastructure, qualified personnel, availability of provision professional training as well as financial resources to cater for investment cost among (Castka, 2022). Therefore, these factors should be assessed within organizations to check for the capability to digitalize the conformity assessment process for cost reduction and error-free measuring instruments, eventually leading to fair trade and customer satisfaction.

Metrology as an Important Component of Quality Infrastructure

Digital Conformity assessment of measuring instruments requires a holistic approach by all concerned stakeholders of international organizations related to quality infrastructure. The organizations which have common declarations on quality are the International Bureau of Weights and Measures (BIPM), International Organization of Legal Metrology (OIML), International Organization for Standardization (ISO), International Laboratory Accreditation (ILAC), and International Accreditation (IAF). The two International Metrology Organizations (BIPM) and (OIML) work together to achieve digital transformation of scientific, industrial and legal metrology and conformity assessment-related activities: calibration, testing, certification, verification, inspection market surveillance, accreditation and standardization. Figure 2 depicts the international quality organizations for quality infrastructure bodies and metrological processes.

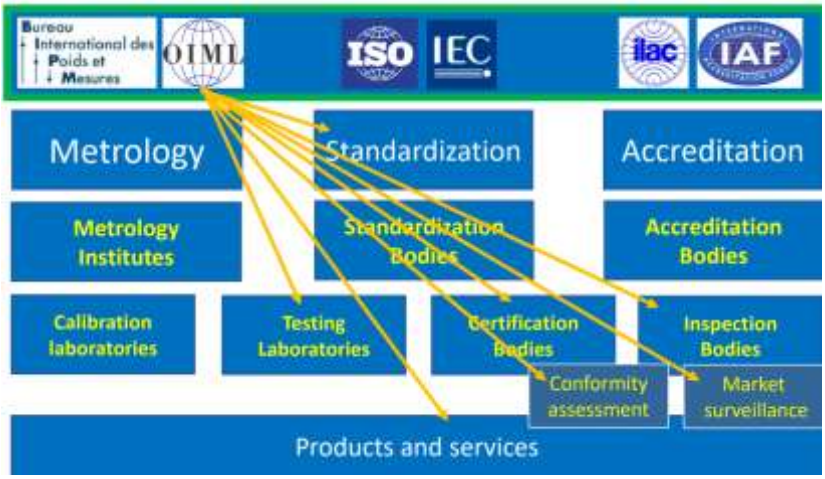

Figure 2. The international quality organizations for quality infrastructure bodies and metrological processes

To perform digital metrology processes such as conformity assessment and market surveillance for products and services, it is recommended that certificates, standards, and regulations be provided in a machine-readable way. Machine-readable interfaces connect manufacturers, users and conformity assessment bodies through reliable IT infrastructure. Secure and validated information to notified bodies enables the automation of digital quality infrastructure processes through the use of digital platforms. All data on digital platforms is legally important. Therefore, we need to standardize data in digital platforms, measurement instruments, reference materials and other technical objects in legal metrology. This requires cooperation with all concerned stakeholders. Figure 3 depicts a digital representation of the legal measuring instrument's conformity certificate.

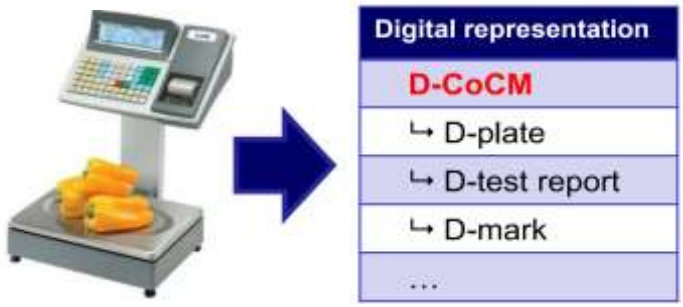

Figure 3. Digital representation of certificate of conformity of legal measuring instrument

Types of legal metrological control

The International Organization for Legal Metrology (OIML) publishes standards known as OIML Recommendations for each type of measuring instrument under legal metrology control (instruments used in trade, health, safety, and environment). The legal control also includes the application of laws and regulations on measurements and measuring instruments during the implementation of conformity assessment procedures such as type evaluation, type approval, Initial verification, subsequent verification and field surveillance of measuring instruments. These laws and regulations in legal metrology are referenced from OIML Recommendations, regional standards and national standards. According to UNIDO (2019), the OIML Certification System (OIML-CS) is a framework for the issuance, registration, and utilization of OIML certificates and their corresponding OIML-type evaluation and test reports for various types of measuring instruments, including families of instruments, modules, or families of modules, in accordance with the stipulations of OIML Recommendations. These Certificate Systems verify that a design or type of measuring instrument adheres to the stipulations of pertinent OIML Recommendations through the assessment and testing of instrument samples or modules provided by manufacturers or their representatives.

OIML-CS (2021) suggests the four distinct types of OIML Certification Systems/schemes that any member state of OIML may decide to adopt. These certification systems are voluntary for the OIML member states who are signatories to the OIML Certification System to accept and utilize OIML type evaluation and test reports issued by an OIML Issuing Authority for the type approval process of metrological controls of measuring instruments. Signatories of OIML have a joint declaration that one test report and one Certificate of Conformity to Type. This always helps to avoid repeated tests and evaluations during type approval. The system indicates acceptable certificates of type evaluation that are issued by Issuing Authorities having accredited test laboratories to ISO/EIC 17025, which may be considered during type approval by Legal Metrology authorities. Test reports and Type Evaluation Reports accompany the certificate.

Monitoring throughout the manufacturing phase in System C is conducted as an integral component of the certification process (type assessment and type approval), where non-compliance could result in the revocation of the type approval certificate (OIML-CS, 2021).

Types modules of conformity assessment in legal measuring instruments

One important guideline for digital certification of conformity in legal metrology is a publication by the European Coordination Group for Notified Bodies in Legal Metrology (NoBoMeT) produced by

the Working Group of Notified Bodies of the European Commission. The guidance proposes three kinds of modules of conformity assessment in legal measuring instruments, all of which have common information to complement European Directives for Non-Automatic weighing instruments and European Directive for Measuring Instruments (NAWID 2014/31/EU and MID 2014/32/EU). These modules are module B for type examination, module D for quality assurance during production and module F for product verification (Velychko, 2014).

Principles of the data structure of digital certificates of conformity

The principle of data structure is a graphical representation of prefixes for the digital certificate of conformity (dcoc) and modularisation of root elements and sub-elements depending on the module of conformity assessment under consideration. The main elements in the data structure for any kind of module (B, D and F) of the digital certificate of conformity assessment are the administrative data of the certificate (certification data), the details of the certification result and the comment section (Figure 5).

Regarding the administrative data (certification data) of the digital certificate of conformity, there are a number of basic sub-elements referred to as building blocks (Figures 6 and 7).

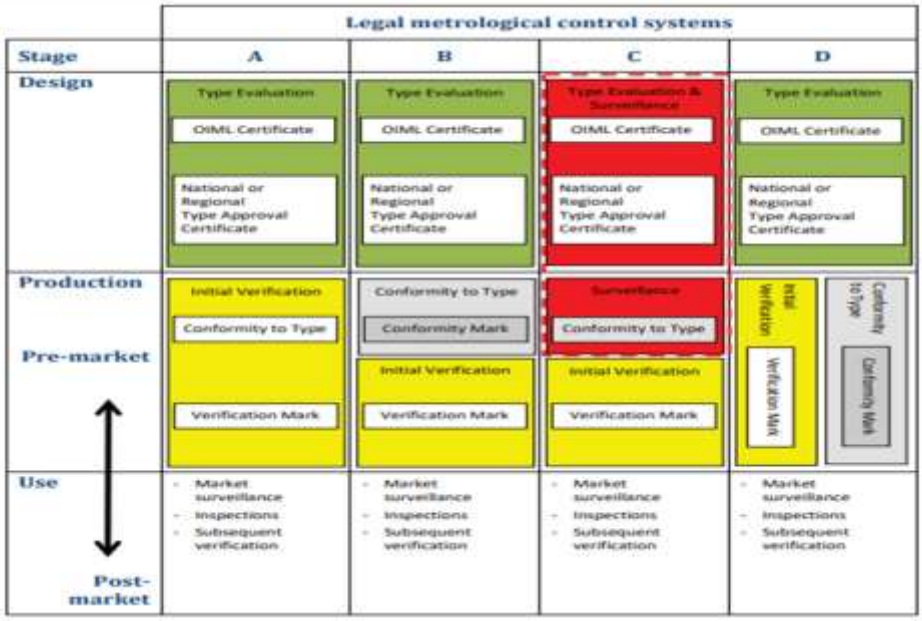

Figure 4. Distinct types of legal metrological control systems

Figure 5. The root elements of any conformity assessment module

Source: www nobomet.org

Figure 6. Overview of the basic sub-elements within the root element of administrative data (dcoc:certification Data)

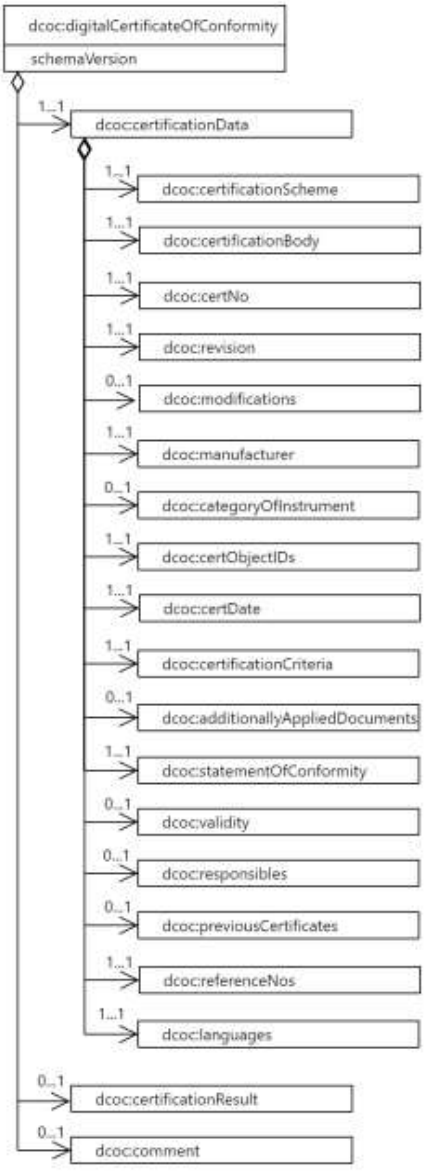

Figure 7. Graphical representation of sub-elements of individual elements of the administrative data structure of digital certificate of conformity

Research Gap

The advent of state-of-the-art digital technologies is disruptive and has already impacted numerous fields of science and others since 2011 (Eichstädt, 2020). The integration of digital technologies in several sectors continues to be implemented due to their promising output while increasing the competitive advantage in the dynamic world market. Technologies such as IoT, cloud computing, cyber security, big data, and augmented and virtual reality, to mention a few have already been integrated into several industrial operations such as quality control, process controls, supply chain, customer services, measurement etc., (Javaid et al., 2021; Wieczorowski and Trojanowska, 2023). However, the digitalization of conformity assessment of legally controlled measuring instruments has not been adequately addressed in the literature, taking into account that it plays a critical role in fostering customer satisfaction and free and fair trade between different parties. In light of this research gap, the assessment of digital solutions for conformity assessment set a foundation for the feasibility of integrating various digital solutions or technologies in the conformity assessment of legally controlled measuring instruments.

Conceptual Framework

The conceptual framework encompasses dependent and independent variables. In

the digitalization of the conformity assessment process, digital technologies such as IoT, artificial intelligence (AI), big data, and cyber security are critical to enable digitalization. For example, technology such as IoT is critical to ensure the devices, stakeholders, and other entities are connected in a real-time to ensure seamless information flow between them. The conformity assessment entails large amount of data to be handled and processed without being lost; the employment of big data and cyber security technologies enables this. On the other hand, utilizing these technologies, which enable digital conformity assessment requires infrastructure, skilled personnel, financial resources, supportive government policy, organization culture i.e. openness, willingness to change etc. Therefore, having all these factors in hand, such as the digital technologies and their prerequisites, would enable effective digitalization of the conformity assessment process, as shown in Figure 8. In Figure 8, the independent variables are the digital technologies and readiness factors for digital solution implementation, while the dependent variable is the digitalization of conformity assessment of legally controlled measuring instruments.

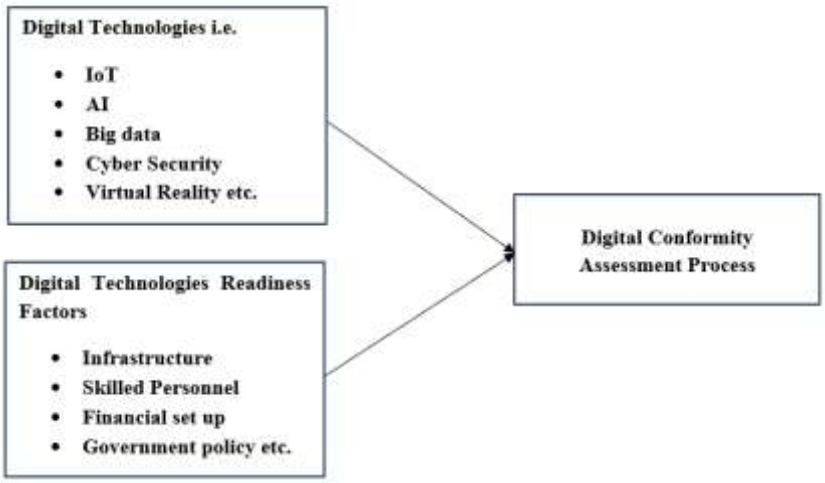

Figure 8. Conceptual Framework for Digital Conformity Assessment Process

METHODOLOGY

Research Design

The research employed a survey method to collect quantitative data. The identified digital solutions in the conformity assessment process and digital conformity assessment readiness factors were used to develop a closed-ended questionnaire for quantitative data. The questionnaire assessed the awareness level regarding digital technologies, the readiness factors for digital conformity assessment, and the available digital solutions employed in the conformity assessment process from four organizations involved in legal metrology.

The selection of sample units is considered a simple random sampling technique. The method was selected because it is less cost-effective and ensures the inclusion of pertinent units in the sample. Moreover, the unit of observation consisted of practitioners of conformity assessment procedures from four organizations involved in legal metrology. Those organizations were divided into four categories: importers, users, repair or installation, and metrological control.

Several equations can be employed in the computation of sample size depending on the nature of the population. Since the population is unknown, the formula proposed by Taherdoost (2017) for calculating sample size is going to be employed as indicated in equation (1).

$$n = \frac{p(1-p)Z^2}{e^2} \quad (1)$$

Where n = sample size, e = maximum error

required; p = proportion of state recurrence, Z = confidence level value.

With a recurrence proportion of 5%, a maximum error of 5%, and a confidence level of 95%, whereby Z =1.96, the sample size using equation (1). Therefore, the targeted sample size for the study was 51 practitioners from the selected organizations.

$$n = \frac{0.05\times(1-0.05)\times 1.645^2}{0.05^2} = 51 \qquad (2)$$

Since four different categories of organizations were involved in the study, a total of 51 sample sizes was distributed, as indicated in Table 1.

Table 1. Sample size distribution

S/N	Category	Subtotal Sample size
1	Importers	11
2	User	9
3	Repair/ Installation	14
4	Metrological Control	17
	Total sample size	**51**

Data Collection Methods

The study employed a primary data collection method using a closed-ended questionnaire. This method was employed to gather primary data from practitioners of the conformity assessment process. The questionnaire was used to collect various information regarding the respondents, including their demographic characteristics, their awareness regarding digital solutions in the conformity assessment of legally controlled measuring instruments, as well as the readiness of organizations to employ digital solutions in the conformity assessment of legally controlled measuring instrument process. The questionnaire used structured questions with a 5-point Likert scale in which the response was supposed to be based on the five-point scale with 1 indicating "not important" or "not implemented" while 5 indicating "very important" or "fully implemented".

Data Analysis

A descriptive analysis was performed regarding the demographic information and practitioners' awareness of digital solutions in the conformity assessment of legally controlled measuring instruments. Statistical Package for Social Science (SPSS) version 23.0 was used for the analysis. The study employed descriptive analysis to evaluate the awareness level questions and derive the mean scores, which were subsequently analyzed using the awareness model established by Paguigan and Jacinto (2018). This model ranked the five-point Likert scale in accordance with the awareness level scale, as illustrated in Table 2.

Table 2. Awareness Level Scale

Scale	Range	Descriptive ratings	Qualitative description
1	1.00 – 1.79	Fully Not Aware	Struggles to comprehend the topic despite expert help. Do not monitor or execute the policy.
2	1.80 – 2.59	Not Aware	Comprehension of the topic is contingent upon expert help.
3	2.60 – 3.39	Neither Aware or Not Aware	Can comprehend certain facets of the situation
4	3.40 – 4.19	Aware	Can sufficiently comprehend the issue
5	4.20 – 5.00	Fully Aware	Exhibits expertise and understanding of the matter

Source: Paguigan and Jacinto (2018)

Other analyses included establishing the readiness level assessment. The readiness level was determined by adapting the studies by Schumacher et al. (2016) and Mohammad *et al.* (2021). Schumacher et al. (2016) and Mohammad *et al.* (2021) deployed a closed-ended questionnaire to garner relevant data that calculated the readiness level. Likewise, this study collected data suing a closed-ended questionnaire. The following procedures were deployed to determine the readiness level of to employ digital solutions in the conformity assessment of legally controlled measuring instruments.

a) Defining suitable criteria for evaluating the preparedness level for the implementation of Industry 4.0 in legally controlled measuring instruments. These were obtained from Schumacher et al. (2016) and Mohammad *et al.* (2021), and a panel of seven experts possessing a minimum of five years of experience in legally controlled measuring instruments.
b) b) A consortium of specialists executed the procedure of allocating weights for each dimension.
c) Formulating a questionnaire that included dimensions of preparedness levels and their respective sub-dimensions.
d) Determine each readiness level by evaluating the weights and ranking each sub-dimension based on responses from 51 respondents who works in importation, user, repair or installation and metrological control organizations. The readiness level for each dimension was determined using equation (3), which involved weighing the average of each sub-dimension inside the respective dimension.

$$RL = \frac{\sum_{i=0}^{n} RLIixgDIi}{\sum_{i=0}^{n} gDIi} \quad (3)$$

R stands for the readiness level, D for dimension, I for the item, G for weighting, and n for the number of maturity items applied to establish the readiness level.

e) The results were displayed in a tabular format and a radar chart., as shown in Table 4.2 and Figure 4.1. All ranges for deciding the readiness levels are in Table 3 as modified from Rajbhandari *et al.* (2022)

RESULTS AND DISCUSSION

Demographic attributes

This section delineates the demographic attributes of the respondents included in this study and the details on the organizations from which data was gathered. Table 4 presents the demographic findings and details regarding the four organizations involved in legal metrology.

Table 3. Range for deciding the readiness levels

Degree of Readiness (DR)-%	Status	Level
0 < DR < 10%	Embryonic	1
10 < DR < 25%	Initial	2
25 < DR < 50	Primary	3
50 < DR < 75%	Intermediate	4
75 < DR < 90%	Advance	5
90 < DR < 100%	Ready	6

Source: Modified from Rajbhandari *et al.* (2022)

Table 4. Demographic and general information

Item	Category	Frequency	Percent
Age	>56 years	1	1.3
	18 – 24 years	31	39.7
	25 - 35 years	10	12.8
	36 - 45 years	3	3.8
	46 – 55 years	6	7.7
	Total	51	100
Gender	Female	6	7.7
	Male	45	57.7
	Total	51	100
Organisation	CBE	5	10
	Cotton soccer	7	14
	Kanali Plascon limited	7	14
	Measuring technology	2	4
	Muhimbili National Hospital	2	4
	Ogproh	4	8
	Shalom Calibrators International Limited	2	4
	Singida Water Quality Laboratories	4	8
	Spring safaries company	3	6
	WMA	11	22
	Zainab Bottlers Company Limited	4	8
	Total	51	100
Category of organization	Metrological controller of measuring instrument	39	50.0
	Repairer/ installer of measuring instruments	3	3.8
	User of measuring instruments	9	11.5
	Total	51	100
Position in the organization	Distributor	3	3.8
	Executive director	1	1.3
	Inspector	31	39.7
	Manager	7	9.0
	Quality control	9	11.5
	Total	51	100.0
Experience	<2 years	27	34.6
	>20 years	3	3.8
	11-20 years	6	7.7
	2 years	1	1.3
	3-10 years	14	17.9
	Total	51	100
Education level	Bachelor degree	37	47.4
	High school/Diploma/ FTC	7	9.0
	masters	6	7.7
	PhD	1	1.3
	Total	51	100

Category of conformity service	Accredited Testing/ calibration laboratory	9	11.5
	Initial /subsequent Verification	15	19.2
	Inspection or market surveillance Body/Section	14	17.9
	Licensed repairer/installer	1	1.3
	Measuring instrument manufacturing company	9	11.5
	Pattern approval and Certification authority	3	3.8
	Total	51	100

Reliability Test

Reliability denotes the extent to which the study results are stable over time and appropriately reflect the population being examined (Mercader et al., 2021). Assessing the internal consistency of the gathered data prior to conducting evaluation tests is essential for ensuring validity (Leung, 2015). A reliability test was conducted in SPSS 24.0 utilizing Cronbach's alpha to assess the internal consistency of the gathered data. The total Cronbach's alpha for the data was 0.887, whereas the Cronbach's alpha values for the research variables ranged from 0.707 to 0.9471 (Table 5). All satisfy the requisite minimal threshold of Cronbach's alpha for internal consistency, set at 0.7, as elucidated by Rashid and Rasheed (2024).

Table 5. Reliability Test Results

Item measured	Cronbach's Alpha (CA)	CA based on standardized items	N of Items
Awareness level	0.879	0.861	9
Digital solution	0.772	0.707	12
Instrument	0.9501	0.9471	5
Infrastructure	0.902	0.899	5
Skilled personnel	0.781	0.778	4
Financial arrangements	0.8511	0.8481	8
Government policy	0.9107	0.9077	5
Overall	0.893	0.887	48

Awareness level assessment results

The study evaluated the comprehension of awareness level of conformity assessment digital solutions in Tanzania. The awareness level assessment indicated an overall mean of 3.92, thus being within the range of 3.40 - 4.19 (Aware level). The average score for total awareness corresponds to "Aware" on the awareness scale, signifying that the chosen organizations recognized the digital solutions. The cut-off point for the awareness is as per Table 2 (Paguigan and Jacinto, 2018). Figure 9 and Table 6 shows the computed awareness levels for the engaged organizations.

Among the technologies ranked, Artificial Intelligent (AI): Ability of system to learn from the environment or data and make decision and improve system (AMT7) achieved the highest mean score of 4.79, indicating full awareness according to Paguigan and Jacinto's (2018) awareness scale. Respondents demonstrated comprehensive awareness of Mobile technology: Enabling connectivity, flexibility and real-time data accessible across the entire organization (AMT1), with a mean score of 4.68. Conversely, the Cloudy computing: Provide a centralized conformity assessment data storage system that can be readily accessible and secured

(AMT2) had the lowest mean score of 3.23, signifying a state of neither awareness nor unawareness.

The importance of digital solutions or advanced technologies is supported by Nzumile, Mahabi, et al. (2024) and Nzumile, Pastory, et al. (2024), who highlighted the integration of Industry 4.0-related technologies to transform the metrology field. They emphasized that the technologies of Industry 4.0 are in line with the fourth industrial revolution contribution. Such technologies contribute to the adoption of metrology 4.0 (M4.0) in various organizations, including all metrology-related organizations. Certain technologies are noted to potentially facilitate M4.0 adoption, whilst the capabilities of other technologies remain unexplored. Therefore, the awareness of various technologies as per the research findings aligns with previous studies, including those by Nzumile, Mahabi, et al. (2024) and Nzumile, Pastory, et al. (2024). Other studies that support the digital solutions in legal metrology include Cunha & Santos (2020), Groot & Schmidt (2021) and Rubel et al. (2022).

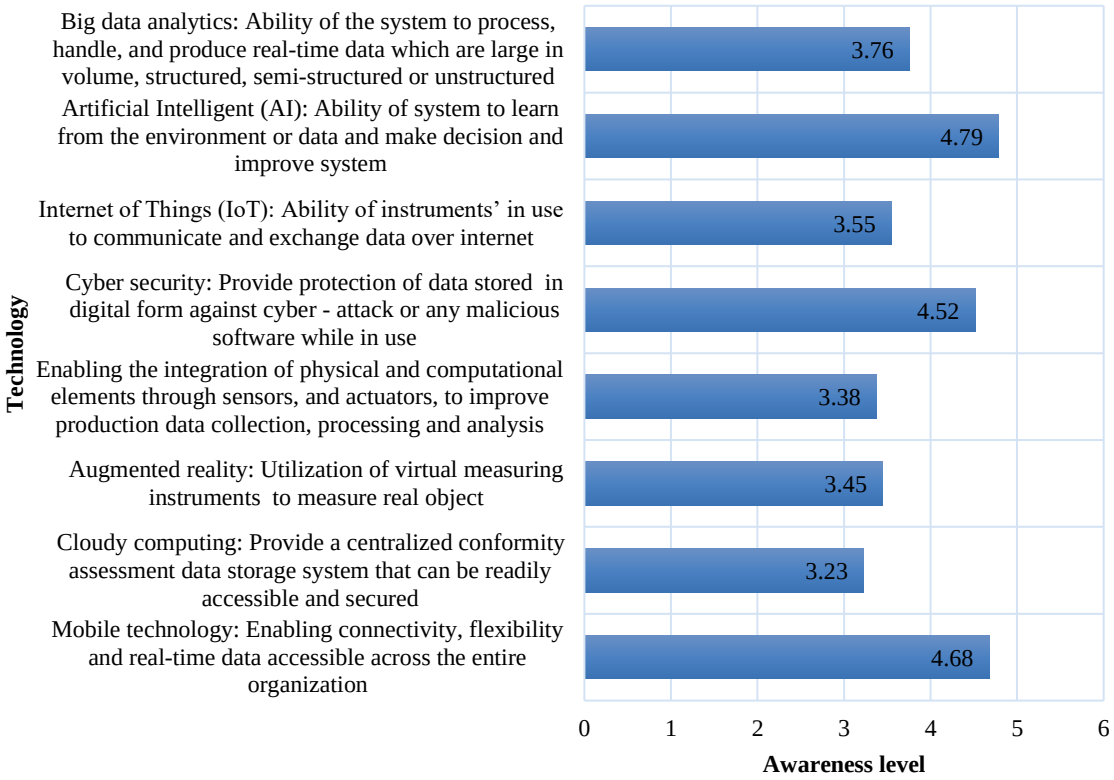

Figure 9. Awareness of digital solutions' technologies

Table 6. Awareness of digital solutions' technologies

Code	Item of technology	Std. Deviation	Mean	Range	Awareness level
AMT1	Mobile technology: Enabling connectivity, flexibility and real-time data accessible across the entire organization	.880	4.68	4.20 - 5.00	Fully aware
AMT2	Cloudy computing: Provide a centralized conformity assessment data storage system that can be readily accessible and secured	.981	3.23	2.60 - 3.39	Neither aware nor not aware
AMT3	Augmented reality: Utilization of virtual measuring instruments to measure real	.640	3.45	3.40 - 4.19	Aware

	object				
AMT4	Enabling the integration of physical and computational elements through sensors, and actuators, to improve production data collection, processing and analysis	1.002	3.38	3.40 - 4.19	Aware
AMT5	Cyber security: Provide protection of data stored in digital form against cyber - attack or any malicious software while in use	.922	4.52	4.20 - 5.00	Fully aware
AMT6	Internet of Things (IoT): Ability of instrument in use to communicate and exchange data over internet	.890	3.55	3.40 - 4.19	Aware
AMT7	Artificial Intelligent (AI): Ability of system to learn from the environment or data and make decision and improve system	.758	4.79	4.20 - 5.00	Fully aware
AMT8	Big data analytics: Ability of the system to process, handle, and produce real-time data which are large in volume, structured, semi-structured or unstructured	.800	3.76	3.40 - 4.19	Aware
Overall awareness level			**3.92**	**3.40 - 4.19**	**Aware**

Readiness Level Assessment

Table 7 depicts the readiness level to employ digital solutions in the conformity assessment of legally controlled measuring instruments. The degrees of readiness (DR) were evaluated according to the approach proposed by Rajbhandari *et al.'s* (2022) (Table 3). Equation (3) was employed to determine the readiness level. According to Table 7, the overall readiness level was 56.65%, indicating that the organizations are prepared at Level 4. digital solution (level 2), instrument (level 3), infrastructure (level 3), skilled personnel (level 2), financial arrangements (level 3), and government policy (level 4). Readiness level 1 (0 < DR < 10%) indicates that the organization had the least readiness to implement digital solutions. Level 2 (10 < DR < 25%) indicates the organizations have realized certain innovations, whilst level 3 (25 < DR < 50) reveals that all advancements are familiar to the organisations, albeit not all have been executed. Similarly, level 4 (50 < DR < 75%: Intermediate) indicates that a specific organization comprehends all innovations that have begun to be implemented, while level 5 (75 < DR < 90%: Advanced) signifies that the organisations possess a comprehensive understanding and a substantial acceptance of all technologies associated with digital solutions. Regrettably, none of the six readiness level indicators attained level 6 (90 < DR < 100%). Consequently, this suggests that organizations did not completely engage or execute technologies associated with digital solutions in the conformity assessment of legally controlled measuring instruments.

Table 7. Readiness level scores to employ digital solutions

Respondents	Digital solution	Instrument	Infrastructure	Skilled personnel	Financial arrangements	Government policy
1	14.24	6.00	10.25	6.25	13.85	22.58
2	13.05	4.78	7.60	2.14	9.43	21.23
3	12.33	5.10	8.64	4.95	12.96	21.60
4	8.64	3.84	6.71	4.78	9.52	15.68
5	7.23	3.38	6.05	4.86	9.76	16.50
6	8.86	3.71	6.32	3.78	5.98	18.32

7	1.25	0.80	1.58	1.90	1.35	19.51
8	10.90	3.87	6.04	1.18	8.36	19.77
9	10.53	4.58	7.95	5.37	13.68	24.35
10	10.79	4.72	8.20	5.61	10.51	18.86
11	15.39	6.38	10.81	6.23	11.43	23.47
12	8.36	3.60	6.22	4.08	8.36	13.61
13	15.29	6.01	9.94	4.58	13.21	21.45
14	9.99	4.41	7.69	5.39	10.69	17.53
15	12.59	5.35	9.19	5.78	6.04	17.49
16	12.56	4.19	6.29	0.01	11.30	19.46
17	3.39	1.58	2.82	2.25	5.19	24.88
18	16.02	6.40	10.65	5.28	5.91	16.49
19	11.50	4.37	7.09	2.67	10.22	24.31
20	13.87	5.54	9.23	4.59	12.64	24.98
21	10.86	4.44	7.47	4.08	11.50	19.26
22	10.85	6.15	11.75	12.65	6.73	17.58
23	6.43	3.79	7.33	8.23	10.09	16.52
24	9.96	5.67	10.86	11.76	15.39	24.35
25	6.52	3.83	7.42	8.32	10.22	16.74
26	6.76	3.97	7.66	8.56	10.59	17.36
29	5.36	3.22	6.26	7.16	8.49	13.85
30	3.65	6.57	12.55	13.45	7.92	19.56
31	7.51	4.37	8.41	9.31	11.72	19.23
32	4.45	8.06	15.35	16.25	6.12	20.56
33	5.36	3.22	6.26	7.16	8.49	13.85
34	10.21	5.80	11.11	12.01	14.22	24.43
35	7.69	4.46	8.59	9.49	11.98	19.66
36	13.04	7.32	13.94	14.84	6.01	19.06
37	8.30	4.79	9.20	10.10	12.90	21.21
39	12.91	7.24	3.81	14.71	9.81	22.71
40	4.63	8.16	5.53	16.43	5.78	20.41
41	14.70	8.20	5.88	9.50	3.89	18.59
42	8.50	4.89	9.40	10.30	13.19	21.69
43	4.21	2.61	5.11	6.01	6.77	18.84
44	6.24	3.69	7.14	8.04	9.81	22.09
45	2.39	1.64	3.29	4.19	4.04	16.34
46	3.64	2.30	4.54	5.44	5.91	19.55
47	4.10	2.55	5.00	5.90	6.60	10.70
48	5.64	3.37	6.54	7.44	8.91	14.56
49	5.06	3.06	5.96	6.86	8.04	22.91
51	4.93	2.99	5.83	6.73	7.84	21.04
53	4.86	2.95	5.76	6.66	7.74	19.86
	17.87	25.40	30.12	23.74	38.71	50.30
Level	**Level 2**	**Level 3**	**Level 3**	**Level 2**	**Level 3**	**Level 4**

The results in Table 7 were further represented using a radar plot. The radar plot in Figure 10 shows that the technological readiness level score was approximately digital solution (17.87%), instrument (25.40%), infrastructure (30.12%), skilled personnel (23.74%), financial arrangements (38.71%), and government policy (50.30%).

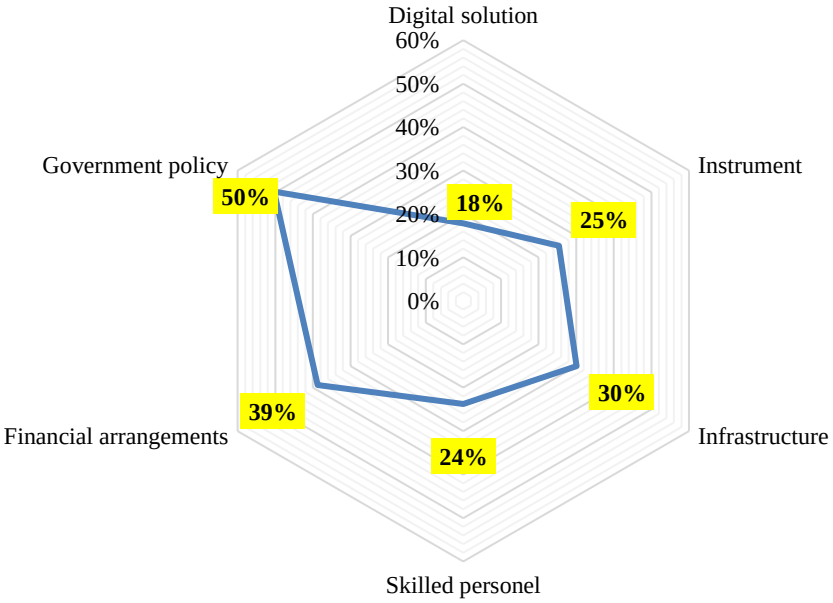

Figure 10. A radar plot for the readiness levels

CONCLUSION

Concluding remarks

Conformity assessment is the procedure for evaluating an organization's adherence to standards and laws. Conformity assessment activities may encompass testing, inspection, validation, verification, certification, and accreditation. Digital solutions encompassing advanced technologies are needed for efficient and effective conformity assessment. Digital solutions are important for conformity assessment in several organizations dealing with weights and measurements. Digital solutions can enhance compliance testing through several means, including remote evaluations.

Though a quantitative research design, this study assessed the digital solutions for improving conformity assessment through a comprehensive survey conducted across various regions in Tanzania. The target was a stratified sample of 51 respondents from organizations involved in legal metrology. Data were collected using a structured questionnaire, and SPSS® 23.0 analyzed the collected data. The reliability testing through the Cronbach's alpha value was 0.887, implying high internal consistency of the data collected. The findings revealed that the awareness level spans from neither aware to fully aware scale. The overall readiness level was as follows: digital solutions (level 2), instrument (level 3), infrastructure (level 3), skilled personnel (level 2), financial arrangement (level 2) and government policy (level 4). Likewise, the overall readiness level approximated to level 4. Thus, the findings indicate an intermediate level of readiness to adapt state-of-the-art technologies to enhance conformity assessment of legally controlled measuring instruments. Approximately 75% of respondents are aware of various digital solutions for conformity assessment of legally controlled measuring instruments, including digital conformity assessment certificates, digital twins for products and instruments, and smart sensors. Emerging technologies such as artificial intelligence,

virtual reality, big data analytics, smart sensors, augmented reality, and the Internet of Things can enhance the dynamism and rigour of distant assessments. Nevertheless, these technologies also pose vulnerabilities, including data privacy and information security concerns.

Despite the importance of digital solutions for conformity assessment in various organizations, only a limited number of conformity assessment agencies presently utilize these methods effectively. Some challenges are attributed to this. Such challenges to the digitalization of conformity assessment encompass insufficient financial resources, a shortage of competent individuals, data security concerns, difficulties in getting complete audit data, and a deficiency in human interactions.

Implication of the study

The field of legal metrology controls about 75 % of all measuring instruments globally. Legal metrology deals with all economic measurements for taxation and fair trade, health and monitoring devices, which are regulated by laws and have a high significance for the country's prosperity, industry and customer rights. The study intended to assess the digital solutions for conformity assessment of legally controlled measuring instruments in Tanzania, assess the awareness and readiness levels of the solutions to stakeholders. The research is significant to customers, manufacturers, end users, and government regulators in general. Conformity assessment offers assurance to customers and users regarding the accuracy and effectiveness of measuring instruments. With the digitalization of metrological practices on the rise, the development of legal requirements for legally controlled measuring instruments is highly demanded in different parts of the world. The research provides the foundations on how the government could develop legal requirements for digital solutions employment in the conformity assessment process of measuring instruments while referencing international standards.

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