UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Institute of Technology Management and Entrepreneurship

ENHANCING STANDARDISATION OF FORENSIC LABORATORY PERFORMANCE THROUGH LIMS TECHNOLOGY IN THE UAE

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DECLARATION

I declare that this thesis entitled “Enhancing Standardisation of Forensic Laboratory Performance Through LIMS Technology in the UAE” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

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APPROVAL

I hereby declare that I have checked this thesis, and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Technology Management and Entrepreneurship

Signature : .....

Supervisor Name : Prof Ts Dr Massila Kamalrudin

Date : 13/08/2022

DEDICATION

This work is dedicated to the inspiring persons towards my life, my dear father and my dear mother who always want me to have the best, for their love and the prayers that they made for me.

…To my wife…

My wife is a wonderful wife, a great companion and so much more in my life. She is always a source of love, courage and strength at every tough instant throughout these years.

…To my family and colleagues at work…

They pushed to my objectives, complement my happiness.

…To my great guide…

My dear supervisor, Prof Ts Dr Massila Kamalrudin.

ABSTRACT

Technology has gained a reputation as a suitable and efficient tool for the analysis, tracking and profiling of forensic evidence. However, the quest to improve efficiency and quality, whilst reducing cost and minimising response time in forensic laboratory activity through the application of technology, lacks the adoption of standardised metrics. In other words, even though standards have been introduced to guide forensic work, errors persist, and cross-laboratory compatibility remains a major issue. Severe cost overruns and performance deviations continue to be experienced, and these have emphasised the need for technology-aided standardisation in diverse scopes of forensics activity. The present research aimed to assess the role of technology in the standardisation of forensic laboratory performance within the various scopes of forensic laboratory information management systems (LIMS) applications such as case management, sample management, staff competency and process automation. Following a critical review of literature, the research focuses on the population of all forensic specialists, technicians and experts in government-owned forensic laboratories across the UAE. The research adopts a quantitative methodological approach in a survey research strategy; the findings are further validated in a quantitative observational research strategy to validate the degree to which the findings may be further revealed within its natural context. Given a population of 2,000 forensic experts and support workers across the UAE, a minimum sample of 323 is estimated, and an actual sample of 646 is employed to allow a 50% non-response rate. A total of 325 actual responses were received and used for the analysis. The structural equation modelling analytical technique is implemented with the help of IBM SPSS Statistics 24 and IBM SPSS AMOS 23. As part of the survey results, Bayesian Markov Chain Monte Carlo (BSEM MCMC) is used to validate the inter-relationships in the primary model to authenticate valid findings. A case of a forensic laboratory in Abu Dhabi was as well observed to further validate the research model. BSEM MCMC validated results indicate that staff competency (Regression weight Estimate $\beta = .814$, p-value < 0.001) and automation (Regression weight Estimate $\beta = .252$, p-value < 0.001) play a significant role in laboratory performance (Multiple correlations $R^2 = .81$, Chi Square (Sig) $x^2 = 335.201$, Degree of Freedom df = 179). A strong association exists between staff competency and automation (Covariance R = .426), even though this does not generally correspond with the other association between case management and sample management (Covariance R = .374). The quantitative observation revealed that technology-aided standardisation of lab performance significantly improves staff competency, automation, case management, and sample management. It is concluded that standardisation, with the help of technology, is critical for forensic laboratory performance, and this is true for staff competency and automation areas. However, the orchestration of staff competency and automation must be implemented separately from the contribution of case and sample management to forensic laboratory performance. It is recommended that forensic experts and technology developers pay extra attention to laboratory performance standardisation in the areas of case and sample management, using laboratory information management systems (LIMS) in forensic work. The uniqueness of these scopes of forensic activity does not make it easily correspond with staff competency and automation. Ultimately, the areas of sample and case management prove most challenging to laboratory performance standardisation. Future research may adopt an even versatile methodology to help develop and validate measurement scales for forensic case management, sample management, staff competency, and automation.

MENINGKATKAN STANDARDISASI PRESTASI MAKMAL FORENSIK MELALUI TEKNOLOGI LIMS DI UAE

ABSTRAK

Adaptasi teknologi telah dikenalpasti sebagai alat yang mempunyai reputasi serta sesuai dan efisien untuk analisis, pengesanan dan pemprofilan bukti forensik. Namun bagitu, dalam usaha untuk memperkasakan kecekapan dan kualiti, yang mana dalam masa yang sama menuntut pengurangan kos dan meminimumkan waktu maklumbalas terhadap kegiatan makmal forensik penggunaan melalui penerapan teknologi dan penerapan metrik piawai masih lagi kurang. Dengan erti kata lain, walaupun ada piawaian yang diperkenalkan untuk memberi panduan kepada kerja-kerja forensik, massih lagi, terdapat ralat yang berterusan serta masalah utama dalam keserasian rentas makmal. Lebihan kos yang parah dan penurunan prestasi terus dialami, yang mana perkara ini menyebabkan perlunya penekanan diberikan kepada perlunya bantuan teknologi diseragamkan dalam pelbagai skop aktiviti forensik. Kajian ini bertujuan untuk menilai peranan teknologi dalam standardisasi prestasi makmal forensik dalam pelbagai skop aplikasi sistem pengurusan maklumat makmal forensik (LIMS) seperti pengurusan kes, pengurusan sampel, kecekapan kakitangan dan automasi proses. Bepandukan kritikan dalam kajian literatur, kajian ini memfokuskan pada populasi pakar forensik, juruteknik dan pakar dalam makmal forensik milik kerajaan di seluruh UAE. Kajian ini menerapkan pendekatan metodologi kuantitatif dalam strategi kajian tinjauan; yang mana penemuan selanjutnya disahkan dalam strategi penyelidikan pemerhatian kuantitatif untuk mengesahkan sejauh mana penemuan boleh didedahkan lagi dalam konteks semula jadinya. Memandangkan populasi 2000 pakar forensik dan pekerja sokongan di seluruh UAE, sampel minimum 323 dianggarkan dan sampel sebenar 646 digunakan untuk membolehkan kadar tidak respons 50%. Sebanyak 325 respons sebenar diterima dan digunakan untuk analisis. Teknik permodelan analisis persamaan struktur dilaksanakan dengan bantuan IBM SPSS Statistics 24 dan IBM SPSS AMOS 23. Bayesian Markov Chain Monte Carlo (BSEM MCMC) telah digunakan untuk mengesahkan antara hubungan dalam model. Justeru, penemuan kes makmal forensik di Abu Dhabi juga diperhatikan untuk mengesahkan lagi model penyelidikan. Keputusan disahkan oleh SKMM BSEM yang mana menunjukkan kecekapan kakitangan (Regression weight Estimate $\beta = .814$, p-value < 0.001) dan automasi (Regression weight Estimate $\beta = .252$, p-value < 0.001) memainkan peranan penting dalam prestasi makmal (Multiple correlations $R^2 = .81$, Chi Square (Sig) $x^2 = 335.201$, Degree of Freedom df = 179). Perkaitan yang kukuh wujud antara kecekapan kakitangan dan automasi (Covariance R = .426) walaupun pada umumnya perkaitan hubungan lain diantara pengurusan kes dan pengurusan sampel (Covariance R = .374). Pemerhatian kuantitatif mendedahkan bahawa penyeragaman prestasi makmal berbantukan teknologi meningkatkan kecekapan kakitangan, automasi, pengurusan kes dan pengurusan sampel dengan ketara dalam pembentangan bukti forensik. Walau bagaimanapun, prestasi terhadap kecekapan dan automasi kakitangan mesti dilaksanakan secara berasingan daripada sumbangan pengurusan kes dan sampel kepada prestasi makmal forensik teknologi memberi perhatian tambahan kepada penyeragaman prestasi makmal dalam bidang pengurusan kes dan sampel, menggunakan sistem pengurusan maklumat makmal (LIMS) dalam kerja forensik. Keunikan skop aktiviti forensik ini tidak menjadikannya mudah sesuai dengan kecekapan dan. Akhirnya, bidang pengurusan sampel dan kes terbukti paling mencabar kepada penyeragaman prestasi makmal. Penyelidikan masa depan mungkin menggunakan metodologi yang serba boleh untuk membantu membangunkan dan mengesahkan skala pengukuran untuk pengurusan kes forensik, pengurusan sampel, kecekapan kakitangan dan automasi.

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Journal:

1. Almessabi, A., & Kamalrudin, M. (2018). The contribution of technology standardization in forensic process automation to forensic test accuracy: A systematic literature review. *The Turkish Online Journal of Design, Art and Communication*, pp. 2605-2612.

Proceedings:

1. Almessabi, A., & Kamalrudin, M. (2018). The contribution of technology standardization in forensic process automation to forensic test accuracy: A systematic literature review. ISoRIS 2018.
2. Almessabi, A. (2018). Laboratory Information Management System (LIMS) used in Abu Dhabi Police. 4th International Conference of Forensic Science in Saudi Arabia (27th-29th of November 2018).
3. Almessabi, A (2019). Strenthining preparedness and response capacity for biological events. UAE fourth Biosecurity Conference in Dubai (28th-29th of October 2019).

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter starts with the research background, a brief introduction of the role of technology in the standardisation of forensic laboratory performance. The problem statement regarding the topic de-scribed is presented, followed by research questions and research objectives. The significance of the study, scope, and limitation are also mentioned. The chapter ends with the structure of the research.

1.2 Background of the research

Forensic and laboratory practices are going through various levels of automation and efficiencies with new applications of technology (Prilusky et al., 2005). The use of traditional laboratory notebooks has increasingly become inefficient in documenting time, processes, outcomes, data classifications that make multiple samples indexing impossible. In the production of forensic engineering gadgets, the emphasis has been placed on the simplification of work performance (Hendrickson et al., 2005). In these developments, laboratory information management systems (LIMS) and the application of artificial intelligence have increasingly gained the reputation as a suitable and efficient gadget for the analysis, tracking and profiling of forensic evidence (Gall, 2015; Hoelz et al., 2009).

The primary challenge, however, is that it is nearly impossible to obtain a LIMS that can completely satisfy all aspects of forensic laboratory activity. Several technology systems that aspire to offer more than just database and sample integration, tracking and profiling have been proposed, principally given the need to ensure reliability, effectiveness and more seamless laboratory activity (Haas, 2015; Elijah, 2014). The need to ensure efficiency,

quality, minimum cost and minimum response time in forensic laboratory activity is a critical driver of the adoption of technology in forensic sciences (Steinlechner & Parson 2001), and the institution of key standards based on which forensic laboratory performance may be evaluated (Lentini, 2009; Butler, 2015).

The need for standardisation in forensic science activities is not new. According to Lentini (2009), the standards that govern forensic work ranges from aspirational documents such as ethical codes of conduct to procedural instructions on how to maintain quality assurance in forensic work. Standards have proven instrumental to the consistency of practice within and across laboratories at both national and regional levels (Butler, 2015; Wallace et al., 2014). It helps in the facilitation of international certification schemes, ensuring that a country's interest in the development of international standards is clearly communicated (Wallace et al., 2014). Despite the introduction of the standards, significant lapses remain on human errors, reporting, interpretation, among others (Kloosterman et al., 2014). The TC272 under the ISO has published a number of standards, and the UAE remains a key observer of the activities of this committee (Wilson-Wilde, 2018; Butler, 2015).

The United Arab Emirates (UAE) is no exception to the global developments of the role of standardisation in forensic performance. On the subject of LIMS, discussions have ensued in the UAE, with a focus on forensic development (Ali, 2016). To deliver for forensic project management, LIMS must be able to analyse data related to specific evidence, submit it to relevant parties for scrutinization based on pre-defined standards, and attribute a unique identification number in connection to the health and physical makeup of the "suspect" or "victim" (Butler, 2015). The lack of a clear standardisation platform for LIMS, however, inhibits malleability of data transfers across forensic stations, operational efficiency of forensic tests and ultimate correctness of results. The complexity and costly nature of

forensic investigations may, however, play a very important role in these developments (Casey, 2005).

Casey (2005) accentuates that effective case and evidence handling, collaboration across system administrators, incident handlers and forensic examiners, and methodical reconstruction are critical to creating a clear picture of the crime. More often than not, a high amount of resources is invested into the reliability of forensic engineered systems (Love et al., 2008). However, in the case of Casey (2005), actors in the early stages of forensic preparation are trained to prepare evidence and monitor capabilities of a threat to arrive at sufficient evidence, but collaboration with network system administrators and forensic examiners was breached due to overlapping roles and lack of common technological standardisation.

In an emphasis on the need for standards, the need for the competent examiner to conduct forensic analysis necessitates that examiner-focused competent post-training is undertaken. However, these training are often paper-based, and the need for re-competency assessment has been argued as essential to evaluate competency performance. To maintain competency levels, LIMS may send a reminder for re-certification to avoid losing competence (Sepulveda & Young, 2013). Conforming to standard operating procedures, with the help of technology, has become essential forensic performance (Bacci et al., 2021), even though the ideal LIMS to achieve this may be highly debated (Sepulveda & Young, 2013).

Love et al. (2008) also add that despite the dedication to reliability, design-induced failures lead to severe cost overruns in forensic engineered systems as the resulting outcomes are not able to perform their designated duties. This has led to a high level of failures in forensic engineered systems, resulting in several challenges in the usage of such technology

systems (Love et al., 2008). There is a need for technology-aided standardisation to significantly improve the workability and effectiveness of forensic engineered systems.

Based on these issues and other factors in the larger scope of the forensic science profession, the present research investigates the perceived performance of the forensic laboratory information management system (LIMS) by building on standardisation across LIMS functionalities associated with case management, sample management, staff competency and process automation. The research builds on the use of Structural Equation Modelling with the complement of the Bayesian Markov chain Monte Carlo (BSEM MCMC) estimation to validate critical findings.

1.3 Problem statement

A wide variety of technological landscapes with varying levels of automation, standards and capabilities have been reviewed and proposed in the recent literature for forensic management (Bacci et al., 2021; Hoelz et al., 2009; Steinlechner & Parson 2001). The central research gap of the research is that no specific technology-aided standardisation model exists for the management and requirement assessments in forensic sciences (Zhai et al., 2020; Mohammed et al., 2021). This has led to persistent errors and challenges of compatibility across laboratories, even after standards are introduced (Zhai et al., 2020). The very operationalisation of laboratory information management systems (LIMS) is heavily diversified (Sepulveda & Young, 2013). Different LIMS support varied interpretation and performance levels (Steinlechner & Parson 2001; Mejia et al., 2020). The time is right that standardisation in forensic laboratory performance is discussed in conjunction with the capabilities of the employed technology or LIMS.

Literature evidence reveals that different systems have been used in an attempt to standardize one or more aspects of forensic activities. An instance is Andersen et al., (2012)

toxicological analysis of whole blood samples in forensics, using technology for sample integration. Guale et al. (2012) automated solid-phase extraction to purify a wide array of analytes also adopts the use of Liquid chromatography time-of-flight mass spectrometry (LC-TOF-MS). Other studies have built on customized LIMS to interpret forensic data; these include Deeb et al., (2014) research on drug abuse, toxicological analysis and therapeutic drug monitoring. This challenge is not new, as the very introduction of standards into forensic work has received several criticisms in the past (Wilson-Wilde et al., 2018). However, with technology brought on broad in the standardisation of laboratory performance, keen insight will be revealed on how to reduce concomitant errors that persist even after the introduction of standards and cross-laboratory challenges of standardisation faced in forensic performance.

In other assessments, standardisation in forensic evidence has made no particular reference to any LIMS technology (Raggam et al., 2008; Hoskins et al., 2010) or has reported the use of general technology such as the internet (Aghayev et al., 2008), or vacuum systems (Vickar et al., 2018). Even though each of these technology systems may be appraised in unique contexts, there is an absolute lack of benchmarking on LIMS to permit comparison and cross-evaluation across forensic contexts. The lack of standardisation creates a challenge of incompatible forensic contexts and an "everything fits all" approach to deriving forensic laboratory performance (Mejia et al., 2020). Such a situation is characterized by operational inefficiencies and complexities that inhibit the smooth undertaking of forensic activity.

1.4 Purpose of the research

The main aim of the research is to assess the role of technology in the standardisation of forensic laboratory performance within the various scopes of forensic laboratory information management systems (LIMS) application such as case management, sample