# THE INFLUENCE OF DISRUPTIVE TECHNOLOGIES ADOPTION READINESS MODEL (ARM) IN ROAD INFRASTRUCTURE OPERATION AND MAINTENANCE

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# THE INFLUENCE OF DISRUPTIVE TECHNOLOGIES ADOPTION READINESS MODEL (ARM) IN ROAD INFRASTRUCTURE OPERATION AND MAINTENANCE

**by**

**HENG YONG MING**

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**TABLE OF CONTENTS**

# LIST OF TABLES

**Page**

## LIST OF FIGURES

**Page**

# LIST OF EQUATIONS

## LIST OF SYMBOLS

| | |
|---|---|
| $\alpha$ | Alpha |
| $\beta$ | Beta |
| $\chi^2$ | Chi-Square |
| $R^2$ | Coefficient of Determination |
| $f^2$ | Effect size of $f^2$ |
| $q^2$ | Effect size of $q^2$ |
| $\mu$ | Population Mean |
| $\sigma$ | Population Standard Deviation |
| $\sigma^2$ | Population Variance |
| $Q^2$ | Prediction Relevance |
| X | Sample Mean |
| S | Standard Deviation |
| $S^2$ | Variation in Sample |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| 10MP | Tenth Malaysia Plan |
| ADS | Automated Driving Systems |
| AI | Artificial Intelligent |
| ANPR | Automatic Number Plate Recognition |
| APTS | Advanced Public Transportation System |
| AR | Augmented Reality |
| ARM | Adoption Readiness Model |
| ATIS | Advanced Traveler Information System |
| ATMS | Advanced Traffic Management System |
| AVE | Average Variance Extracted |
| AVs | Autonomous Vehicles |
| BIM | Building Information Modelling |
| C&S | Civil and Structural |
| CAVs | Connected and Autonomous Vehicles |
| CIDB | Construction Industry Development Board |
| C-ITS | Cooperative ITS |
| CVC | Cross-Validated Communality |
| CVI | Content Validity Index |
| CVO | Commercial Vehicle Operation |
| CVR | Cross-Validated Redundancy |
| DPM | Durability Performance Measures |
| DSRC | Dedicated Short-Range Communication |
| E&C | Engineering and Construction |
| EM | Expected Maximisation |
| EMS | Emergency Management System |
| ETCS | Electronic Toll Collection System |
| GPS | Global Positioning Systems |
| HAR | Highway Advisory Radio |
| HDV | Human-driven Vehicles |
| HSR | High-Speed Rail |
| HTMT | Heterotrait-Monotrait ratio of correlations |

| | |
|---|---|
| I-CVI | Item-level Content Validity Index |
| IoT | Internet of Things |
| IR 4.0 | Fourth Industrial Revolution |
| ITS | Intelligent Transport Systems |
| LiDAR | Light Detection and Ranging |
| LLM | Lembaga Lebuhraya Malaysia |
| M&E | Mechanical and Electrical |
| MHA | Malaysian Highway Authority |
| MLFF | Multi-lane Free Flow |
| MPM | Management Performance Measures |
| NHAI | National Highways Authority of India |
| O&M | Operations and Maintenance |
| OPM | Operational Performance Measures |
| PIS | Participant Information Sheets |
| PLS-SEM | Partial Least Squares-Structural Equation Modelling |
| PLUS | Projek Lebuhraya Usahasama Berhad |
| PWD | Public Work Department |
| RADAR | Radio Detection and Ranging |
| RDA | Road Development Authority |
| RFID | Radio Frequency Identification |
| RPV | Resources, Processes and Values |
| S-CVI | Scale-level Content Validity Index |
| SDC | Sabah Development Corridor |
| SEM | Structural Equation Modelling |
| SPSS | Statistical Package of Social Science |
| TAM | Technology Acceptance Model |
| TR | Technology Readiness |
| TRA | Theory of Reasoned Action |
| TRAM | Technology Readiness and Acceptance Model |
| TRI | Technology Readiness Index |
| TTMS | Tunnel Traffic Management System |
| UAV | Unmanned Aerial Vehicle |
| VIDES | Video Incident Detection and Enforcement System |
| VIDS | Video Incident Detection System |

| | |
|---|---|
| VIF | Variance Inflator Factor |
| VMS | Variable Message Signs |
| VR | Virtual Reality |
| VSDS | Vehicle Speed Detection System |
| WCE | West Coast Expressway |
| WHO | World Health Organisation |
| WIM | Weigh-In-Motion |
| WIS | Weather Information System |

## LIST OF APPENDICES

# PENGARUH MODEL KESEDIAAN PENERIMAAN (ARM) TEKNOLOGI DISRUPTIF DALAM OPERASI DAN PENYELENGGARAAN INFRASTRUKTUR JALAN

## ABSTRAK

Revolusi Perindustrian Keempat (IR 4.0) mewakili kemajuan penting dalam revolusi digital yang menggabungkan ruang siber, dunia fizikal, dan domain biologi. Transformasi ini sedang merubah pelbagai sektor ekonomi dan mempengaruhi aspek-aspek masyarakat yang berbeza. Di Malaysia, sektor infrastruktur sedang mengalami transformasi digital yang pesat, suatu perubahan penting untuk mencapai matlamat pembangunan masa depan dan meningkatkan kesiapsiagaan Malaysia terhadap IR 4.0. Namun, kajian terdahulu menunjukkan bahawa digitalisasi dan automasi dalam sektor pembinaan Malaysia, khususnya dalam infrastruktur, masih berada di peringkat awal. Walaupun penerapan teknologi IoT dalam industri pembinaan Malaysia semakin berkembang, ia masih ketinggalan berbanding negara-negara Asia yang lain. Teknologi disruptif adalah inovasi yang secara signifikan mengubah operasi perniagaan dan tingkah laku pengguna untuk mewujudkan pasaran baharu, rangkaian nilai atau model perniagaan, dan memainkan peranan penting dalam peralihan ini. Kajian ini memberi tumpuan kepada empat jenis teknologi disruptif: Sistem Pengurusan Trafik Termaju dengan Sistem Pengangkutan Pintar (ITS), Kenderaan Udara Tanpa Pemandu (dron), Internet Benda (IoT) dengan sensor, dan Kenderaan Terhubung dan Autonomi (CAVs). Objektif kajian ini adalah untuk merangka Model Kesiapsiagaan Penerimaan (ARM) untuk menggalakkan pelaksanaan teknologi ini di kalangan pengendali lebuh raya semasa peringkat operasi dan penyelenggaraan (O&M) infrastruktur jalan raya di Malaysia. Pendekatan kaedah campuran dengan

strategi segitiga serentak digunakan, di mana kajian kualitatif dan kuantitatif dijalankan secara serentak. Data kuantitatif dikumpul melalui kaedah tinjauan soal selidik, manakala temuduga separa berstruktur digunakan untuk pengumpulan data kualitatif. Data kualitatif dianalisis secara kod dan tema, kemudian dibandingkan dengan hasil kuantitatif. Responden terdiri daripada konsesi lebuh raya dalam sektor swasta dan pegawai-pegawai dari Lembaga Lebuhraya Malaysia (LLM), dengan tumpuan khusus pada pengurusan atasan, pembuat keputusan dan pengurus yang terlibat dalam operasi dan penyelenggaraan di Semenanjung Malaysia. Hasil kajian menunjukkan bahawa lebih daripada 85% responden menyedari teknologi dron, dengan lebih daripada separuh berada di peringkat 5 dan 6 penerimaan. Sebaliknya, hanya sekitar 40% yang menyedari teknologi CAVs, dengan kebanyakan berada pada peringkat kesedaran (peringkat 1). Sembilan pembolehubah dimasukkan dalam analisis PLS-SEM untuk menentukan hubungan, dengan tujuh pembolehubah dikenal pasti sebagai penting bagi rangka kerja ARM: Inovasi, Ketidakselesaan, Ketidakamanan, Persepsi Kemudahan Penggunaan, Persepsi Kegunaan, Sikap Terhadap Penggunaan, dan Niat Tingkah Laku. Kesimpulannya, walaupun kesedaran mengenai manfaat teknologi disruptif seperti CAVs dan IoT agak tinggi, penerimaan sebenar dalam operasi dan penyelenggaraan infrastruktur lebuh raya Malaysia masih terhad. Rangka kerja ARM menyediakan pendekatan praktikal untuk membimbing pengendali lebuh raya dalam mengadaptasi teknologi ini, yang berpotensi mempercepatkan transformasi digital dan mempromosikan model pengurusan infrastruktur yang lebih cekap dan bersepadu secara teknologi selaras dengan matlamat IR 4.0.

# THE INFLUENCE OF DISRUPTIVE TECHNOLOGIES ADOPTION READINESS MODEL (ARM) IN ROAD INFRASTRUCTURE OPERATION AND MAINTENANCE

## ABSTRACT

The Fourth Industrial Revolution (IR 4.0) represents a significant progression in the digital revolution, merging cyberspace, the physical world and biological domains. This transformation is reshaping numerous economic sectors and influencing various aspects of society. In Malaysia, the infrastructure sector is currently undergoing a rapid digital transformation, a vital shift to meet future development goals and enhance Malaysia's readiness for I R 4.0. However, previous studies reveal that digitalisation and automation within Malaysia's construction sector, particularly in infrastructure, are still in their early stages. Although IoT technology adoption in Malaysia's construction industry is advancing, but still trails behind other Asian countries. Disruptive technologies, are the innovations that significantly alter business operations and consumer behaviour to create new markets, value networks or business models and play a key role in this transition. This study focuses on four types of disruptive technologies: Advanced Traffic Management System with Intelligent Transport Systems (ITS), Unmanned Aerial Vehicles (drones), Internet of Things (IoT) with sensors and Connected and Autonomous Vehicles (CAVs). The objective is to formulate an Adoption Readiness Model (ARM) framework to promote the implementation of these technologies among highway operators during the operations and maintenance (O&M) of Malaysian road infrastructure. A mixed-method approach with a concurrent triangular strategy is used, where qualitative and quantitative studies are conducted simultaneously. Quantitative data is gathered through a questionnaire survey, while semi-structured interviews provide qualitative data. The qualitative data is coded and thematically analysed, then compared with quantitative results. Respondents include highway concessionaires from the private sector and officials from the Malaysian Highway Authority (MHA), with a focus on top management, decision-makers and managers involved in operations and maintenance in Peninsular Malaysia. Results indicate that over 85% of respondents are aware of drone technology, with more than half in stages 5 and 6 of adoption. In contrast, only about 40% are aware of CAVs, with most in the awareness stage (stage 1). Nine variables are included in the PLS-SEM analysis to determine relationships, with seven identified as essential for the ARM framework: Innovativeness, Discomfort, Insecurity, Perceived Ease of Use, Perceived Usefulness, Attitude Towards Using, and Behaviour Intention. In conclusion, while awareness of the benefits of disruptive technologies like CAVs and IoT is relatively high, actual adoption in Malaysian highway infrastructure O&M remains limited. The ARM framework provides a practical approach for guiding highway operators in adopting these technologies, potentially accelerating digital transformation and promoting a more efficient, technology-integrated infrastructure management model aligned with IR 4.0 goals.

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Development of infrastructure brings substantial impacts on the economics of a country, especially in developing countries like Malaysia. Infrastructure as the physical assets of the country, unravelling connectivity within and between cities and countries, providing facilities to link living systems of residents for example transportation, education, communication, sewage, water, and electric systems and etcetera.

Although some infrastructure facilities might be expensively to construct and preserve, but various economic advantages and benefits could be provided by those high-quality infrastructures in long term. Technical structures such as roads, water supply system, bridges, tunnels and communications system are essential for urbanisation and always getting attentions from government for development and maintenance. The country relies heavily on its roads and highways infrastructure, which plays an important role in the nation's social and economic development.

Statistics from Public Work Department (PWD) stated that total road length in Year 2010 was 137,219.5KM and increased to 250,023.4KM in Year 2018, and the recent record of 289,996.6KM in Year 2022 (JKR, 2019; JKR, 2023). In 2022, there are 32 inter-urban and intra-urban highways or expressways in operation, with another 2 more under construction in Peninsular Malaysia. Economic growth of the country is greatly affected by the highway network system occasionally. Table 1.1 shows the road lengths of federal road, states road and agencies owned road in 2022.

**Table 1.1** Malaysia Road Length in Year 2022 (JKR, 2023)

| Category | Total Length (KM) | Percentage (%) |
|---|---|---|
| Federal Road | 20,133.152 | 6.9 |
| States Road | 259,729.713 | 89.6 |
| Agencies Owned Road | 10,133.790 | 3.5 |
| **Total** | **289,996.655** | **100.0** |

The government has faced increasing maintenance costs, which rose from RM841,900,000.00 in Year 2000 to RM4,328,342,800.04 in Year 2017, in line with the expanded road length, which was more than 500% increment (PWD Malaysia, 2018). These significant costs not only burden the government but also inconvenience the public whenever refurbishment work takes place. At the same time, the government also assigned maintenance responsibilities to concession companies and contractors in order to ensure road performance (PWD Malaysia, 2015).

In most countries, significant annual expenditures on highway, expressway as well as roadway maintenance, while road agencies at all levels of government incur the costs of roadway rehabilitation and reconstruction. It is commonly recognised that these funds from government are usually insufficient to address all road works and repair needs instantaneously. Therefore, it becomes imperative to select the most deserving projects and schedule them in a timely manner.

Highway agencies in developing countries, where large-scale greenfield highway projects are common, and in developed countries, where investments primarily focus on preservation over expansion, act as protectors of public infrastructure. They strive to transparently account for their maintenance efforts on public highway infrastructure (Callaghan, 2016). This evolving situation increasingly pushes them to adopt advancements in operations research and integrate new technologies in data collection and analysis to support informed decision-making aligned with the agency's broader goals and mission. The highway maintenance process is undertaken by highway operators, specifically the highway maintenance department. These departments often face limitations in terms of available resources, which in turn can lead to ineffective maintenance management, posing safety hazards and endangering human lives (Sinha, 2015).

Inadequately maintained highways and poorly designed roads contribute to a significant number of annual accidents, as reported by The World Bank in 2013. The Levin Firm (2014) further highlighted that various common conditions leading to accidents result from negligence in road maintenance or design. These conditions encompass issues such as potholes, insufficient signage, ineffective road drainage systems, non-functional traffic signals, uneven and bumpy pavement, faded or missing lane's markers, malfunctioning streetlamps, debris of road, badly maintained bridges and insufficiency hazard warnings.

Besides that, poor management remains one of the persistent challenges in highway maintenance. Malaysia has made strides in modernizing its highway maintenance by implementing computerised systems and enhancing reporting and communication with electronic tools (PLUS, 2014; Lingkaran Trans Kota Sdn Bhd,2014), regrettably, decision-making in highway maintenance continues to be a deeply rooted issue that has not seen any significant change (The Chartered Institution of Highways and Transportation (CIHT), 2012).

Disruptive technologies can be either a new combination of present technologies or entirely new technologies that apply to the problematic parts or new commercialisation challenges, for example in systems or operations, which can cause major and significant paradigm shifts or create new ones (Walsh & Linton, 2000)

Consequently, disruptive technologies can be considered as scientific discoveries that step forward the abilities of typical product or technology and therefore deliver a basis for a totally new competitive paradigm (Kostoff, Boylan & Simons, 2004). Artificial intelligent (AI), blockchain, machine learning, augmented reality (AR), virtual reality (VR), drone, robots and etcetera are the examples of potential disruptive technologies which might possibly impacted and transformed the construction industry. Immense challenges, characterised by the adoption of digital and innovative technologies such as sensor systems, intelligent machines and smart materials, are being faced by the construction industry in recent times. (Craveiro, Duarte, Bartolo, & Bartolo, 2019).

## 1.2 Problem Statement

Although the Malaysian government has spent billions of ringgits in developing the infrastructure and facilities for our country, but it is disappointing that lack of maintenance and commitment to safety and the maintenance culture is not strong among the nation (Lee, 2018). Weak maintenance in infrastructure, principally in highway infrastructure, is a significant issue in many countries including Malaysia. Previous studies found that maintenance management is complex and required the balancing of reliability, cost as well network-wide interdependencies, and that traditional approaches often fail to address these challenges effectively (Shi et al., 2021; Sánchez-Silva et al., 2016). Moreover, poor road maintenance, inadequate drainage and substandard road surfaces are closely connected to road traffic accidents, with factors such as potholes, poor workmanship, water pooling and insufficient signage being particularly influential (Zahidy, Sutanto & Sorooshian, 2024; Ismail et al., 2021; Musa, Hassan & Mashros, 2020). Moreover, The Star (2025, February 26) reported that almost RM2 billion was spent on road maintenance in Peninsular

Malaysia over the past three years. The funds were primarily allocated to federal roads, with a noteworthy portion used for repairing potholes, resurfacing as well as upgrading highway infrastructure.

The primary strain on highway infrastructure is typically due to increased traffic flow. Studies found that the rapid growth in vehicle numbers, overloading, and climatic effects further exacerbate pavement damage, leading to faster-than-expected failures and negative socioeconomic impacts (Ismail et al., 2021). In 2015, the global motor vehicle amount has reached 923.6 million, 1.68 times compared to Year 2000 and 6.61 times increment since Year 1965 (Davis, Diegel & Boundy, 2015; Williams, Davis & Boundy, 2017). Globally, the average annual number of vehicles per capita was 1.27 between Year 1965 and 2000, rising to 2.71 from Year 2000 to 2015, and further to 4.25 between Year 2010 and 2015 (Williams, Davis & Boundy, 2017). Additionally, global urbanisation has reached 55%, while Malaysia's urban density has surged to 76% and is projected to reach 82% within the next decade (United Nations, 2018). According to Asia IoT Business Platform (2019), Malaysia also ranks as the third-highest nation globally for car ownership, with 93% of households owning at least one vehicle. This high rate of ownership is mainly attributed to the preference among urban Malaysians for purchasing cars using available cash (Abdelfatah, Shah & Puan, 2015). Currently, 88% of the Malaysian population (28.2 million) is represented by registered automobiles, in contrast to the total population of 32.4 million (Malaysian Automotive Association, 2017). Over-reliance on personal vehicles has introduced several challenges, including worsening traffic congestion, environmental degradation, road safety issues, and accelerated infrastructure wear and tear (Abdelfatah et al., 2015).

Furthermore, existing assets such as buildings and infrastructures are often ignored by numerous governments in both developed and developing countries, and up-to-date O&M practices are frequently seriously unsatisfactory. (World Economic Forum, 2014). The assets failed to be utilised and meet reasonable quality standards because the ignorance of O&M in operation of those assets. Many highways were constructed without robust strategies for long-term O&M practices, leading to inefficiencies and higher lifecycle costs (Islam et al., 2021; Masi & Abidin, 2022). Moreover, the complexity of maintaining various highway components like bridges, electrical devices and traffic systems have caused the operational burden to the highway operators (Masi & Abidin, 2022). Besides that, the maintenance of buildings and infrastructure has been neglected due to political bias toward funding new assets. Over time, existing assets deteriorate much faster than necessary because of maintenance accumulations and a lack of resilience actions, ultimately shortening their useful life (World Economic Forum, 2014).

In addition, management and maintenance expenses increased from year-to-year due to the repairing works and processes for the damaged assets and facilities (Sani, Mohammed, Misnan, & Awang, 2012). According to the British Standards Institute (1974), maintenance work combines technical and administrative actions to conserve or protect a structure, system or equipment so that it can function appropriately. In brief, maintenance is known as a work process or work activity planned by an individual or group to be undertaken to protect, preserve and preserve the function of a facility. Statistics from PWD indicated that RM4.3 billion has been spent by the government in maintaining the state and federal roads for the Year 2017 (PWD Malaysia, 2018). Furthermore, the article by Malay Mail. (2025, April 9) discussed the persistent issues behind the poor condition of Malaysian roads were because of the insufficient budget allocations for consistent road repairs across federal and state levels and potholes and uneven surfaces remain widespread due to reactive rather than preventive maintenance practices.

Shahid (2019) argued that timely involvement and proper maintenance are often hindered by budget restraints, inadequate planning and insufficient adoption of advanced technologies. At the same time, previous study claimed that new technologies have been slow to be adopted by the construction industry, and a major disruptive transformation and revolution has never been undergone by it (Gerbert et al., 2016). In short, the construction industry is predominantly not involving advanced technology such as the use of UAV photogrammetry and AI-driven crack detection (Ashraf et al., 2024; Zainal Abidin & Ariff, 2023) and extensively rely on the craft-based approaches and this results in poor performances and quality images (Al-Qutaif, Nazari & Bagheri, 2018; Farmer, 2016). Even though the construction players know the benefits of the disruptive innovations in the construction industry, but they are not adopted it.

Despite the promise of digital technologies, digitisation in highway operation and maintenance remains low and fragmented, with recent surveys showing that most agencies still struggle to integrate and utilize digital tools effectively (Yin et al., 2025). A survey by Berger (2016) revealed that while 93% of construction stakeholders believed digitisation will influence all of the process and operation in the industry, and only less than 6% of construction firms are wholly employing digital planning applications. Ansaruddin Agus, Hamzah and Khoiry (2019) found that while the implementation of Internet of Things (IoT) technologies in the Malaysian construction industry is progressing, it remains slower compared to other Asian countries like

Singapore, China, Japan, South Korea and Hong Kong. In addition, the construction sector in Malaysia is exploring IoT applications integrated with technologies, like Building Information Modelling (BIM), augmented reality, cloud computing and big data analytics. Nevertheless, these employments are still in its initial stages and require substantial improvement and higher expertise to effectively manage the IoT integration (Alaloul et al., 2018; Urie, 2019; Ibrahim et al., 2019). In overall, previous studies (Talaghat et al., 2024; Pavard, Dony & Bordin, 2023; Huang et al., 2025) suggests that despite the advantages of digitalisation, most highway infrastructure maintenance processes remain only partially digitalised, and there are significant rooms for growth in the adoption of integrated and real-time digital solutions.

Additionally, the underpinning theories for this study are the Technology Acceptance Model (TAM) and the Technology Readiness Index (TRI), Batarseh and Kamardeen (2017) claimed that the intention of TAM is to understand individuals' acceptance of new technologies and their related behaviours, while Blut and Wang (2020) acknowledged TRI as a vital concept that links people's behaviour to technology adoption. However, Kim and Wang (2021) pointed out that the original TAM does not sufficiently account for intrinsic and extrinsic factors, particularly with newer technologies like the IoT. This limitation is particularly relevant in the context of Malaysian highway infrastructure, where studies on how external variables influence technology adoption are lacking. Furthermore, Lin, Shih, Sher and Wang (2005) linked TRI with TAM to predict technology readiness, which affects technology acceptance and subsequently, behavioural intention, leading to actual usage. Despite these advancements, the application of TAM and TRI in the Malaysian highway infrastructure sector remains underexplored, particularly in light of the growing role of Industry 4.0 technologies, and this gap underscores the need for further research to explore these frameworks in this sector.

In short, there are some research gaps that need to be bridged by this study. Four (4) gaps of the research are demonstrated as Figure 1.1.

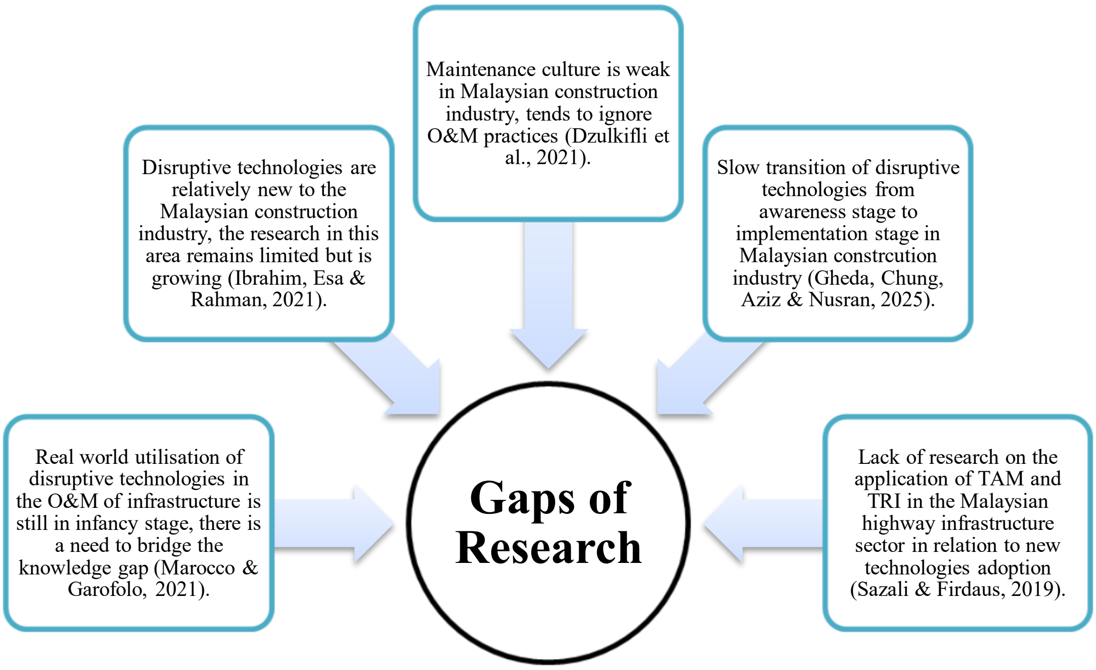


**Figure 1.1** The Research Gaps for the Study

The first gap is the knowledge gap, where the adoption of disruptive technologies in the O&M of infrastructure remains at an early stage (Marocco & Garofolo, 2021). Although the awareness of disruptive technologies is growing, specifically in highway and energy infrastructure, but the actual integration into daily O&M practices is limited and often hindered by barriers (Marocco & Garofolo, 2021; Rathore et al., 2022). The second gap is the literature gap, disruptive technologies, such as the Internet of Things (IoT), Building Information Modelling (BIM) and advanced automation, are comparatively new to the Malaysian construction industry, the research studies in this area remains limited but is growing (Ibrahim, Esa &

Rahman, 2021; Jaafar et al., 2024). Studies (Mansour, Aminudin & Mansour, 2021; Jaafar et al., 2024) also claimed that much works are need to integrate the disruptive technologies into the Malaysian construction industry although these technologies hold significant promise for improving productivity and sustainability.

The industrial gap is the third gap, where the maintenance culture is weak in the Malaysian construction industry, particularly the tendency to ignore O&M practices (Dzulkifli et al., 2021). Khalid et al. (2019) found that maintenance practices in Malaysian buildings, especially public buildings were still relied heavily on reactive methods, with many stakeholders misunderstanding or lacking sufficient awareness of proactive maintenance concepts. In short, strengthening maintenance culture is seen as essential for improving building quality, safety and sustainability in Malaysia (Dzulkifli et al., 2021).

Practical gap is the fourth gap for the study, as the adoption of disruptive technology within the Malaysian highway infrastructure and construction industry is the slow progression from high awareness to actual implementation (Gheda, Chung, Aziz & Nusran, 2025). Most of the disruptive technologies remain in early adoption stages as hinder by significant barriers (Ye et al., 2024; Marocco & Garofolo, 2021).

Lastly, theoretical gap is the last gap where limited studies in applying the Technology Acceptance Model (TAM) and Technology Readiness Index (TRI) to the adoption of disruptive technologies within the Malaysian highway infrastructure field (Sazali & Firdaus, 2019). Current academic studies emphasized the need for focused investigations to identify adoption challenges and formulate tailored implementation approaches for technological integration in this field (Sazali & Firdaus, 2019; Khudzari, Haron, Ayer & Rahman, 2025).

## 1.3 Research Questions

This research aims to address five (5) key questions based on the problem statement, which are essential for providing comprehensive answers. The questions are:

i. What are the awareness and current stages of adoption of various disruptive technologies among highway operators in the Malaysian highway infrastructure operations and maintenance?

ii. What are the factors affecting the adoption of disruptive technologies among highway operators in the Malaysian highway infrastructure operation and maintenance?

iii. How do the dimensions of the Technology Readiness Index (TRI) influence the Perceived Ease of Use and Perceived Usefulness of disruptive technologies in the Malaysian highway infrastructure operations and maintenance stage?

iv. How do the variables within the Technology Acceptance Model (TAM) impact the adoption of disruptive technologies in the Malaysian highway infrastructure operation and maintenance?

v. What framework can be proposed for the Adoption Readiness Model (ARM) to promote the adoption of disruptive technologies in the Malaysian highway infrastructure operation and maintenance?

## 1.4 Research Aim

The principal aim of this research is to formulate a framework for Adoption Readiness Model (ARM) to promote the implementation of disruptive technologies among highway operators in the operations and maintenance (O&M) stage of Malaysian highway infrastructure.

## 1.5 Objectives of the Research

The following objectives are formulated in order to accomplish the aim of this study:

i. To assess the awareness and current stages of adoption of several types of disruptive technologies among highway operators in the Malaysian highway infrastructure operation and maintenance.

ii. To analyse the factors affecting the adoption of disruptive technologies among highway operators in the Malaysian highway infrastructure operation and maintenance.

iii. To investigate the influence of dimensions of Technology Readiness Index (TRI) on the Perceived Ease of Use and Perceived Usefulness of disruptive technologies in the Malaysian highway infrastructure operation and maintenance.

iv. To explore the relationship between Technology Acceptance Model (TAM) towards disruptive technologies adoption in the Malaysian highway infrastructure operation and maintenance.

v. To propose a framework for Adoption Readiness Model (ARM) that promote the adoption of disruptive technologies in the Malaysian highway infrastructure operation and maintenance.

## 1.6 Scope and Limitations of the Research

The scope of study generally focuses on the adoption of disruptive technologies in the highway infrastructure operations and maintenance (O&M) stage. Nevertheless, not all disruptive technologies are covered in this study. For example, the technologies that been used in other construction stages such as preliminary stage, pre-construction and post-construction stages are not considered as this study is interested on technologies in O&M stage. While the research population is focused on highway concessionaires in the Malaysian highway infrastructure industry specifically in O&M stage, relevant officials from the Malaysian Highway Authority (MHA), a public regulatory body are also involved in this study. In short, the participants of the research consist of private sector highway operator as well as public regulatory authority in the highway infrastructure.

Moreover, this study is limited to the highway infrastructure projects, with a specific focus on tolled highways and expressways in Peninsular Malaysia. These highways and expressways play a crucial role in enhancing mobility and driving socio-economic development across states and countries.

Hamizan (2017) broadly classified the Malaysian road network into federal roads and state roads. Federal roads in Malaysia are primary roads managed and maintained by the federal government, serving as the backbone of the national road network and facilitating the movement of goods and people across the country. These roads are crucial for economic activities, as about 96% of all transported goods and passengers in Malaysia rely on the road network, with federal roads playing a central role in connecting major cities, towns and regions (Zulkefli et al., 2024). Federal roads encompass toll expressways, national highways, regional road schemes and other minor roads (Zulkefli et al., 2024). In contrast, primary routes that facilitate intra-state travel between district administrative centres, urban collector roads under municipalities as well as smaller roads within villages and rural areas are included within state roads. This study focuses exclusively on federal roads, particularly toll expressways and national highways, given their importance in inter-state connectivity and their impact on Malaysia's economic growth and infrastructure development.

Specifically, the scope of this research is limited to Peninsular Malaysia. Malaysia is a federation consisting of thirteen (13) states and three (3) federal territories, but this study focuses solely on the highway infrastructure projects within Peninsular Malaysia. This is due to the concentration of major highway and expressway projects in this region, which are critical for enhancing connectivity and economic development.

Some key highways in Peninsular Malaysia include the North-South Expressway, which is a 823KM road running from Bukit Kayu Hitam near the Thailand border in the North, to Johor Bahru in the South, the Johor-Singapore Causeway and "Second Link" bridge, and the West Coast Expressway (WCE) which is a 316 KM highway linking Banting in Selangor to Taiping in Perak. These major highways and expressways are central to this study as they represent the primary routes supporting inter-state travel and economic activity within Peninsular Malaysia.

## 1.7 Significance of the Research

This research is vital to attain operational efficiency, sustainability and social performance during the operation and maintenance (O&M) stage of the highway infrastructure lifecycle. This study allows the highway operators to have deeper understanding of how disruptive technologies such as Advanced Traffic Management

System (ATMS) in Intelligent Transport System, unmanned aerial vehicle (UAV/Drone), internet of things (IoT) with sensors and connected and autonomous vehicles (CAVs) can be applied in highway O&M. It is beneficial to the highway operators when they know what are the factors that affecting the readiness and adoption of disruptive technologies in highway infrastructure operation and maintenance processes. They also can understand how to cope with the challenges when adopting disruptive technologies and this will allow them to take merits from the disruptions like first mover or early adopter advantages.

By producing the framework of Adoption Readiness Model (ARM), the adoption stage of different kind of disruptive technologies in the O&M can be understand and allow the highway players as well as the concessionaires to understand the recent trends of advanced technologies in highway infrastructure O&M stage. Additionally, the ARM can also be the vital model when consider the criteria and prerequisites during disruptive technologies adoption in the infrastructure O&M stage.

Furthermore, this study also aims to promote the disruptive technologies application in the Malaysian construction industry especially in the highway infrastructure O&M stage. The researcher also hopes that the construction industry able to be reshaped from conventional way of methods to a more contemporary Approach at the same time achieved sustainability in the coming future. Not only the highway operators can be beneficial from the disruption of new technologies in maintaining the infrastructure, but the well-maintained infrastructure such as highway infrastructure can be utilised by the public and users in a better and reliable condition with the assistance of disruptive technologies.

Lastly, this research makes a significant contribution to the academic body of knowledge by providing valuable findings on the adoption of disruptive technologies in the highway infrastructure industry, specifically in the O&M stage. It also helps to establish a foundation for future studies and research on the adoption of these technologies in infrastructure management.

## 1.8 Research Methodology

Mixed method research design is appointed in this study. Mixed method research is used with the justification that more comprehensive findings can be acquired and increased conclusion validity (Johnson & Christensen, 2004). Besides that, mixed methods also allow researchers to capitalise on the strengths and minimize the weaknesses of each method, leading to richer, more nuanced insights and increased conclusion validity through triangulation and methodological pluralism (Turner, Cardinal & Burton, 2017; Schoonenboom & Johnson, 2017). The integration of different methods in mixed method research can lead to more robust theory development and testing, as well as improved practical application of findings (Turner, Cardinal & Burton, 2017; Timans, Wouters & Heilbron, 2019)

Concurrent mixed methods design is applied in this research where both quantitative and qualitative data collections are conducted simultaneously (Creswell & Creswell, 2018) Both types of data are analysed and later combined during the interpretation phase to deliver a more comprehensive understanding of the overall results. The concurrent triangulation approach is adopted for this study, both quantitative and qualitative data are collected in the same phase with equal weight. The data is then integrated during interpretation phase, either by merging or comparing results side by side (Creswell & Creswell, 2018). Figure 1.2 demonstrates the concurrent triangulation design that been appointed in this research study.

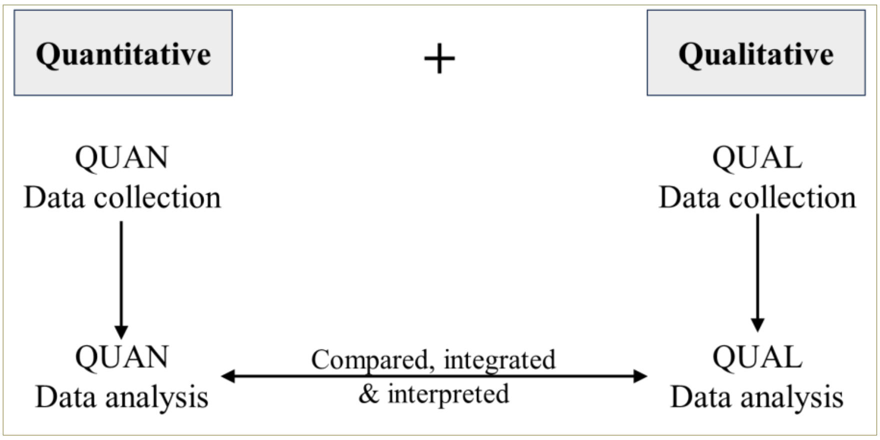


**Figure 1.2** Concurrent Triangulation Design (Creswell & Creswell, 2018)

In a nutshell, the four (4) Phases of Research Procedures are explained as below:

**Phase I – Preliminary Study**

First, the study area is evaluated and confirmed in the beginning stage, where O&M stage of highway infrastructure is focused in this research. After confirming the area and scope of the research, a comprehensive review of existing literature is carried out continuously throughout the entire research process in order to have an overall idea of the research and further identify the problem statement of the study. Next step is to formulate the aim and objectives of the research. For instance, the study aims to assess the awareness and adoption stages of disruptive technologies, identify influencing factors, and establish the framework for Adoption Readiness Model (ARM). After all, a theoretical framework is developed that will guide the research and this framework will outline the variables to be studied.

**Phase II – Quantitative and Qualitative Data Collection**

A mixed methods research design is employed in this study, with both quantitative and qualitative approaches conducted concurrently to explore the use of disruptive technologies in the highway infrastructure industry. Six (6) research objectives are established. Objectives 1, 3, 4, 5 and 6 are addressed through the quantitative approach, using a structured questionnaire survey as the data collection tool. Meanwhile, the qualitative approach explores objective 2, with researchers conducting semi-structured interviews to gain deeper insights into the adoption of disruptive technologies.

**Phase III – Analysis of Data**

The collected quantitative data is carefully analysed with the Statistical Package of Social Science (SPSS) software and SmartPLS software. Basic descriptive statistics are used to summarise the data, giving an overview of the respondents' characteristics, while advanced statistical techniques, such as structural equation modelling are used to explore relationships between variables and test the hypotheses of for the proposed model of study. Meanwhile, the qualitative data is systematically analysed using thematic analysis with the assistance of NVivo software. The results from both the quantitative and qualitative analyses are merged and interpreted to provide a extensive knowledge about the adoption stages as well as the factors influencing readiness of disruptive technologies.

**Phase IV – Conclusion**

After integration and interpretation of both data analysis outcomes, a study model is developed. The key findings and results are discussed thoroughly in this phase. Furthermore, the study concludes with a summary of the findings and how they relate to the original objectives, providing insights into the adoption of disruptive technologies in the highway infrastructure O&M stage. Further studies recommendation is the final step of the study.

In short, an overview of the flow of research process for the study is illustrated as Figure 1.3.

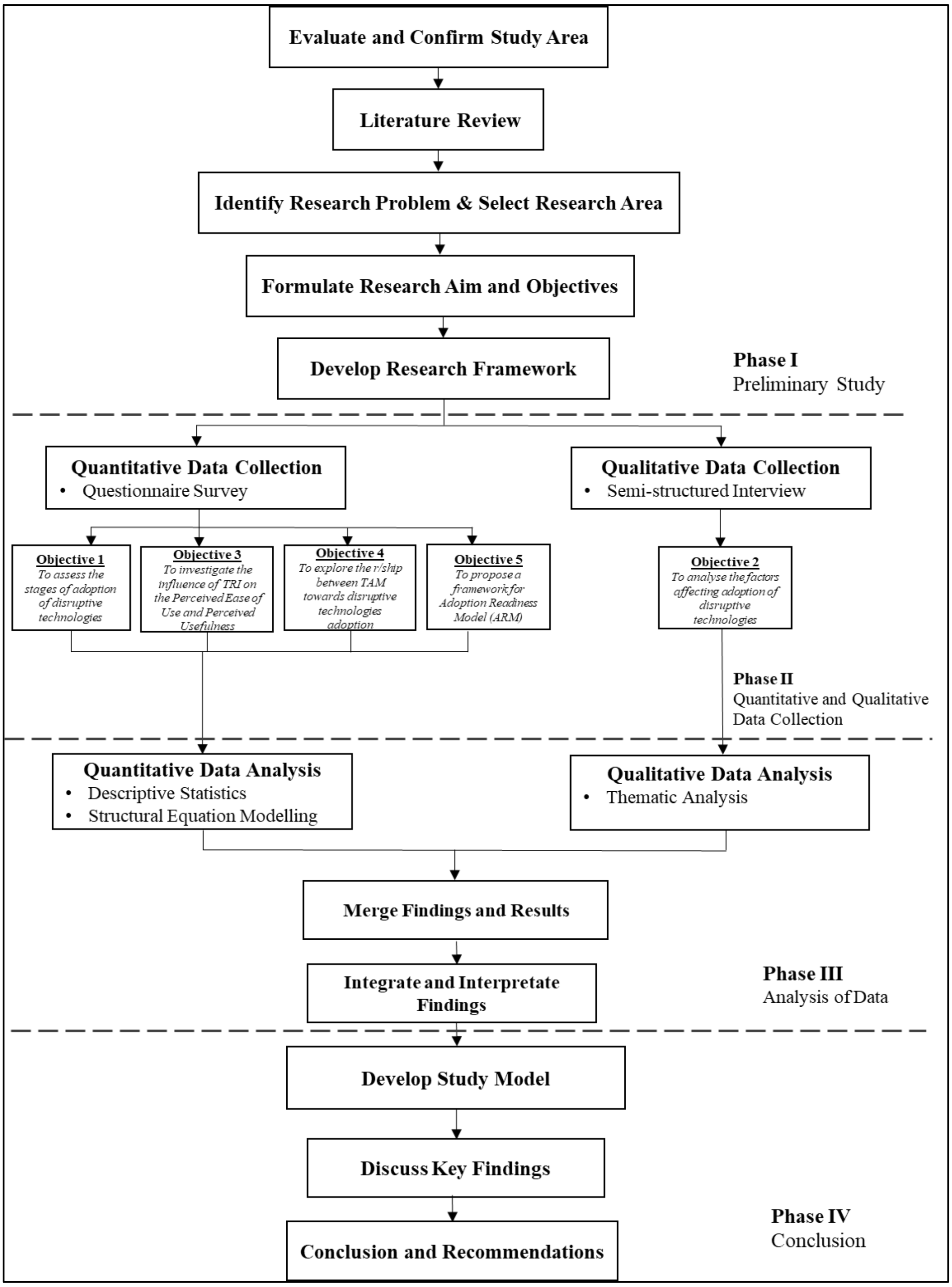


**Figure 1.3** The Flow of Research Study

## 1.9 Outline of the Thesis

This thesis is built up with seven (7) chapters. An overview of each chapter is presented below.

Chapter 1 is the introduction chapter. It begins with the research background part and explains the recent operation and maintenance problems in the highway infrastructure projects. The aim of study, research questions and objectives are also presented in this chapter. Besides that, this chapter also comprises the scope and limitations of the study and points out the significance of this study. Methodology of the research and thesis outline are also revealed in this chapter.

Chapter 2 clarifies and discusses the literature, previous studies, related journals and articles on various areas that relevant to this research. It is vital to establish theoretical framework of the study by reviewing the previous related literature. In this chapter, the maintenance issues of infrastructure are exposed especially in O&M stage, types of disruptive technologies that are useful in O&M stage are also debated together with some examples, challenges and issues of infrastructure O&M stage will also be discussed in this chapter.

Chapter 3 discusses the research methodologies of the research, including the research design, data collections and analysis methods that are applied in this study. Mixed method research design is employed with semi-structured interview and questionnaire survey technique. Concurrently, the research variables are determined, instruments of questionnaire are developed and the research population are identified in this chapter. Data analysis technique, justification of analysis methods selection, validity and reliability of data are depicted in this chapter.

Chapter 4 is the quantitative data analysis. Statistical assessment and analysis are conducted and debated in this chapter. This chapter begins with data preparation and follows by missing data determination, assumption testing, non-response bias test and common method variance. After the reliability and validity tests, descriptive analysis is carried out for understand the response patterns and respondents' details. Furthermore, the adoption stages of studied disruptive technologies as well as the structural equation modelling results are debated in this chapter.

Qualitative data analysis is discussed in Chapter 5. Deductive thematic analysis is appointed as the qualitative data analysis method in this study. This chapter begins with the interviewee's details and continues with the six-phase thematic analytical process. After all, the themes for the qualitative study and the word clouds for the objectives are produced and further discussed in this chapter.

Chapter 6 is the results discussion chapter. The chapter discusses about the collected data and results from both quantitative and qualitative data analysis. The quantitative and qualitative results are integrated and further discussed in this chapter. This chapter contains the results of analysis for the stages of adoption of disruptive technologies, drivers and barriers that affecting the readiness of disruptive technologies adoption. Moreover, the possible factors that influencing the disruptive technologies adoption as well as the relationships between adoption and readiness of disruptive technologies will also be debated in this chapter.

The last chapter named Chapter 7, which is the conclusion and recommendations chapter. This chapter summaries the results of study objectives and highlights the significant outcomes for the study before a conclusion is made. Last but not the least, some recommendations for further explorations are also suggested.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Literature review chapter is one of the important chapters which required an extensive review of previous research works that are associated with the research area, such as journal papers, articles, magazine articles, textbooks, encyclopaedias, reviews and so on. The body of knowledge for this study encompasses the intersection of disruptive technologies, infrastructure management and theories for technology adoption. It is grounded in interdisciplinary domains, including civil engineering, information systems as well as innovation management, and integrates both theoretical and practical perspectives. This study also contributes to the broader discourse on the adoption of disruptive technologies, which are Advanced Traffic Management Systems (ATMS), Internet of Things (IoT), Unmanned Aerial Vehicles (UAVs) and Connected and Autonomous Vehicles (CAVs) within the highway and expressway infrastructure sector.

Furthermore, the study advances the conceptual understanding of disruptive innovation and technology by synthesizing theoretical frameworks such as the Technology Acceptance Model (TAM) and the Technology Readiness Index (TRI). By combining these models, the study proposes a more comprehensive framework of Adoption Readiness Model (ARM) that is empirically tested and refined based on both quantitative data and qualitative expert input.

In summary, the body of knowledge developed through this research provides a novel and holistic perspective on the intersection of digital innovation and infrastructure management. It contributes both to academic discourse by refining theoretical models and to industry practice by offering actionable recommendations for accelerating technology adoption in highway O&M. It also lays the groundwork for future studies to explore the scalability, adaptability, and policy implications of disruptive technologies in infrastructure sectors beyond highways.

## 2.2 Definitions of Terms

Definitions of terms are offered in this section to provide clarity and consistency throughout this dissertation. The subsequent key terms are defined and used in the context of this research:

a) **Disruptive Technology**

   Disruptive technology refers to innovations that fundamentally alter or displace existing products, services, or business models, often rendering established approaches obsolete and creating new markets or value networks (Christensen, 1997). Unlike incremental or sustaining innovations, disruptive technologies introduce products or services that are typically more affordable, accessible, or convenient, enabling new entrants to challenge industry incumbents and sometimes allowing less technologically sophisticated users to participate competitively in the market (Boylan, Kostoff & Simons, 2004).

b) **Industry Revolution 4.0 (IR 4.0)**

   Industry Revolution 4.0 (IR 4.0) also known as the Fourth Industrial Revolution, refers to the integration of advanced digital technologies such as cyber-physical systems, the Internet of Things (IoT), artificial intelligence, big data and cloud computing into manufacturing or industrial processes, in order to create highly interconnected and intelligent production environments (Xu, Xu & Li, 2018)