Current Stages of Disruptive Technologies Adoption among Malaysian Highway Infrastructure Operators

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ABSTRACT

Highway infrastructure is the key element in road transport system in developing country like Malaysia. However, the challenges of inadequate maintenance and outdated approaches persist, leading to increased costs and inefficiencies. This study addresses the issue by exploring the awareness and adoption stages of disruptive technologies, namely Advanced Traffic Management System (ATMS), unmanned aerial vehicle (UAV)/Drone, internet of things (IoT) and connected and autonomous vehicle (CAV) among highway operators in the Malaysian highway infrastructure operation and maintenance (O&M) stage. The research aims to identify the current adoption stages of these technologies and examine the relationship between awareness and demographic variables such as age, education level, working experience and job position. A quantitative research method was employed, utilizing a questionnaire survey to collect data from highway concessionaires responsible for operations and maintenance. The study targeted 31 operational highways and 5 under construction, and through judgment sampling, 27 valid responses were collected between January and November 2023. Data analysis was conducted using SPSS Statistics 28, applying both descriptive and inferential statistical methods. The findings reveal that while awareness of ATMS, UAV/Drone, and IoT is relatively high, awareness of CAV is significantly lower. Most technologies are still in the early adoption stages, with UAV/Drone technology showing the most advanced implementation. Significant relationships were observed between awareness and certain demographic factors, such as job position and working experience. This study contributes by identifying barriers to adoption and highlighting the need for innovative strategies, policies, and future research to advance the integration of disruptive technologies in highway infrastructure management.

Keywords: Stage of adoption, Disruptive technologies, Road infrastructure, Operation and Maintenance

INTRODUCTION

Malaysia boasts some of the most impressive physical infrastructure in the Southeast Asia region. Nevertheless, the nation confronts challenges in maintaining its assets and facilities, exerting pressure on the government. Malaysia grapples with maintenance issues, and prior studies, such as the one by Sani, Mohammed, Misnan, and Awang (2012) [1], reveal that numerous public assets and government-owned facilities are inadequately maintained and in poor condition. The absence of a robust culture of asset and facilities maintenance in Malaysia has contributed to the escalating costs associated with real estate management and maintenance.

The total amount of maintenance cost of state road in the year 2000 was RM841,900,000.00 and this has periodically increased every year in line with the increment of road length to the amount of RM4,328,342,800.04

in the year 2017 with more than 500% increment [2]. These huge amounts of maintenance cost will not only burden the government but also causes a nuisance to the public whenever refurbishment work is carried out.

Poor maintenance of public infrastructure in Malaysia has drawn substantial criticism directed at local authorities. Regularly, various parties in the press comment and argue about the inadequate performance and incompetence of these facilities. Notably, the Ministry of Housing and Local Government, over the last five years, has received between 2,400 and 4,500 maintenance complaints annually [3]. The lack of attention to maintenance has led to public facilities suffering damage and deterioration in terms of their physical structure, as evidenced by Karim (2007) and Annies (2007) [4] & [5].

Bock (2015) made a compelling argument that traditional construction methods have reached their limitations, and the potential for innovative technologies, such as automation and robotics, to address the industry’s productivity challenges is significant [6]. However, the construction sector has exhibited reluctance in adopting new technologies and has not undergone a major disruptive transformation and revolution [7]. Regrettably, the construction industry remains predominantly low-tech and heavily relies on craft-based methods, resulting in subpar performance and quality [8]&[9]. Despite being aware of the benefits offered by disruptive innovations in the construction industry, industry players have been hesitant to adopt them.

LITERATURE REVIEW

Schober and Hoff (2018) conducted a study on the digitization in construction industry [10]. The authors found that 93% of construction industry players agreed that digitization will affect every construction process but less than 6% of the construction companies fully utilize the digital planning tools. At the same time, almost all of the building materials firms thought that they have not yet exhausted their digital potential.

Define Disruptive Technologies

In prior literature, Christensen (1997) defined disruptive technology as “an innovation that results in worse product performance in mainstream markets” [11]. IT is also categorized as “an often more affordable, streamlined, compact, and frequently more user-friendly’ iteration of an already existing product [11] & [12].

In a later version of the concept, Christensen, Clayton and Raynor (2003) distinguished between “low-end disruptions” and “high-end disruption (new market)” [13]. Low-end disruptions encompass products or services that deliver diminished performance at a more affordable cost, without introducing any additional enhancements to their performance, Conversely, high-end disruptions provide products and services that present better performance in attributes that deviate from those highly esteemed by the broader mainstream customer base.

In short, “disruptive technology” is innovation that significantly change business operations and consumer behavior to create new markets, value networks or business models. One such technology i.e., blockchain has disrupted the logistics sector by enhancing transparency and traceability [14]. Technological innovation forms the cornerstone of an economy driven by innovation. Values can be created from new products, services, and knowledge at the same time, the quality of life can be improved by solving the problems with the new innovations. New technologies are rapidly supplanted in the relentless pursuit of innovation [15].

Types of Disruptive Technologies in Highway Operation and Maintenance (O&M)

Suitable data digitalization, rapid problem-solving responses, and a collaborative working environment within project scheme design, construction, operation, resource utilization, and quality and safety improvement are all key factors. This approach will not only revolutionize the design, construction, and maintenance of physical structures but also transform their subsequent use [16].

Four (4) types of disruptive technologies are covered for highway and expressways operations and maintenance in this research, which are Advanced Traffic Management System (ATMS) in Intelligent Transport System, unmanned aerial vehicle (UAV/Drone), internet of things (IoT) with sensors and connected and autonomous vehicle (CAV).

Advanced Traffic Management System (ATMS)

Intelligent Transport Systems (ITS) encompass a suite of transport infrastructure and operational systems. These leverage advanced information technologies to optimize safety, efficiency, and accessibility within the road network while concurrently minimizing the need for extensive and expensive road construction [17]. Advanced Traffic Management System (ATMS) is one of the major ITS sectors, which provides real-time traffic monitoring and control, Highway Advisory Radio (HAR), incident detection and monitoring, Tunnel Traffic Management System (TTMS) and provide road surface status information.

Unmanned Aerial Vehicle (UAV)/Drone

Unmanned aerial vehicle (UAV), commonly known as drone, is employed for inspecting bridges and tunnels and monitoring traffic remotely. Drones have revolutionized the approach to asset management, maintenance, and inspections, especially in the contexts of bridges, tunnels, and construction sites [18].

The main roles of drone in road operation and maintenance are bridge inspection, pavement conditions and road distress monitoring. Drones play a crucial role in streamlining the laborious process of road assessment and repair. Through monitoring, surveying, and mapping operations, drones efficiently gather valuable data for comprehensive mapping. Briefly, drone inspections offer substantial time and cost savings for bridge inspectors, simultaneously delivering customers more comprehensive data for efficient resource allocation [18].

Internet of Things (IoT)

IoT stands out as one of the most dynamic domains in disruptive technologies [19]. Leveraging sensor technology for data gathering, collection, and storage enables the acquisition of real-time information. The utilization of sensors in data collection gives rise to data nodes, offering valuable insights for situational analysis [20]. The IoT infrastructure facilitates integrated management of information systems, particularly in the context of machine-to-machine interactions. Furthermore, IoT also facilitates the connection of devices with local counterparts, global internet, and mobile network infrastructures, enabling communication with remote devices in both wired and wireless modes [21].

Connected and Autonomous Vehicle (CAV)

Connected and Autonomous vehicles (CAV), also known as self-driving vehicles, utilize a fully automated driving system to execute all driving tasks without human intervention [22]. CAVs represent a pivotal innovation in the automotive sector, reshaping societal perspectives on vehicular advancements. They contribute to enhanced mobility, reduced resource consumption, lower carbon emissions, decreased demand for parking spaces, and improved traffic safety [23] & [24]. The increasing attention from scholars, governments, and professionals underscores the significant role of AVs as a crucial development in the automobile industry [25].

METHODOLOGY

The objectives of this research are to assess the awareness and current adoption of highway operators to embrace disruptive technologies in the operational and maintenance stages of Malaysian road infrastructure. A quantitative research approach has been employed in this study, utilizing questionnaire survey as the primary instrument for data collection.

Research Questions

The research questions for the research are as below:

a) Is the highway operator aware of disruptive technologies in the road infrastructure's operations and maintenance stages?

b) What are the current stages of adoption of different types of disruptive technologies among clients in the Malaysian road infrastructure operations and maintenance stage?

c) Is there any relationships between awareness of disruptive technologies and demographic variables, such as age group, level of education, working experience in years and current job positions?

Quantitative Research Method

The rationale for employing a quantitative strategy in this study is grounded in the ability to gather a relatively large volume of data efficiently, as compared to a qualitative approach [26]. Additionally, the quantitative approach facilitates the observation, measurement, and application of statistical procedures to the gathered information. Questionnaire survey is appointed in this research with the closed-ended questions in the questionnaire, which were designed in accordance with the guidelines provided by Sekaran (2005) to align with the purpose of this study [27].

Participants and Data Collection

The study focuses on clients from both the public and private sectors engaged in road infrastructure, particularly highway and expressway projects across Malaysia. As per the Malaysian Highway Authority, there are currently 31 operational interurban and intraurban highways or expressways, with an additional 5 under construction. Accordingly, the research involves a total of 36 participants. Judgement sampling (also known as purposive sampling) is appointed in this study [28]. This sampling design is used when the population for this study is quite small and the researchers require the individuals with insightful opinions and knowledge to provide valuable data. So, this sampling design is useful for answering specific research questions.

The target participants for this study comprise top management personnel and decision-makers of highway operations and maintenance operators. These individuals are chosen to answer the questionnaire due to their roles in formulating policies, guidelines and strategic objectives, while also providing leadership and direction for effective management across the companies. Therefore, these personnel are the one who will affect the adoption and diffusion of disruptive technologies in the companies.

The questionnaires were distributed from January 2023 to November 2023. Total 29 highway concessionaire companies from 36 highways were approached either through email, phone or physical presence at the office. The researchers expected to get 2 respondents from each highway concessionaire companies, thus the total questionnaire population for this study is 58. After multiple follow-up emails and phone calls to the target respondents, the researchers successfully received questionnaire data from 30 sets. Unfortunately, 3 sets were excluded due to incomplete information and thus 27 sets data were accessed and analysed. The results for the data analysis are demonstrated in the next section.

It took almost a year for data collection period was primarily due to the focus on top management personnel and decision-makers, who are often occupied with demanding schedules and responsibilities. Securing their participation required persistent follow-ups to accommodate their availability. Furthermore, reaching out to 29 highway concessionaire companies across 36 highways involved significant logistical efforts, including emails, phone calls, and physical visits, which further extended the timeline. While 27 valid responses may appear limited, the focus on highly relevant participants ensures that the insights derived are reliable and reflect the perspectives of individuals with the authority to influence technology adoption.

RESULTS OF ANALYSIS

The demographic information for the respondents, awareness of the disruptive technologies and stages of disruptive technologies adoption in highway O&M are reported in this sub-section.

The respondents were first asked about their awareness of disruptive technologies through a simple yes or no question. Those who indicated awareness were further asked about their adoption stage, which was categorized into six levels:

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Stage 1: Awareness only.

Stage 2: Learning the process.

Stage 3: Understanding and application of the process.

Stage 4: Familiarity and confidence.

Stage 5: Adaptation to other contexts.

Stage 6: Creative application to new contexts.

The data was then analysed using SPSS Statistics 28, with descriptive statistics to summarise awareness and adoption stages. Inferential statistical method (correlation analysis) was used to examine the relationships between awareness and demographic variables. This analysis aimed to determine whether demographic factors influenced respondents' awareness of disruptive technologies.

Respondents' Demographic

The demographic data of the respondents are classified into 4 categories according to their personal characteristics, for instances, age group, level of education, years of working experience and current position held in the company.

According to the 27 sets of data received, 37.04% of the respondents were from the age group of 21-30 years, 29.63% were from 41-50 years, 22.22% of the respondents from 31-40 years and only 11.11% of the respondents were from 51-60 years age group. For the level of education of the respondents, more than half of them (55.56%) are the bachelor degree holders, 29.63 of the respondents hold a postgraduate certification and only 14.81% of them are diploma holders. In the working experience categories, 37.04% of them have less than 5 years working experience, 22.22% of them already work for 5 to 10 years, 7.41% of the respondents have 11-15 years of working experience, 14.81% have 16-20 years of working experience, while 18.52% of the respondents work more than 20 years in their professional fields. Furthermore, for the current job position of the respondents, 29.63% of them are senior managers, 18.52% of them are project manager, professionals in the firm and other positions respectively, lastly, only 14.81% of the respondents are supervisors. The details of the demographic information are depicted in Table I.

Table I Demographic Information of Respondents

Personal Characteristics	Frequencies (N= 27)	Percentage (%)
Age Group		
21-30 years	10	37.04
31-40 years	6	22.22
41-50 years	8	29.63
51-60 years	3	11.11
> 60 years	0	0.00
Level of Education		
High School	0	0.00
Diploma	4	14.81

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Bachelor Degree	15	55.56
Postgraduate (Master/PhD)	8	29.63
Working Experience (in Years)		
< 5 years	10	37.04
5-10 years	6	22.22
11-15 years	2	7.41
16-20 years	4	14.81
> 20 years	5	18.52
Current Job Position/Title		
Managing Director	0	0.00
General Manager	0	0.00
Senior Manager	8	29.63
Project Manager	5	18.52
Supervisor	4	14.81
Professionals in the firm	5	18.52
Other	5	18.52

Awareness of the Disruptive Technologies in Highway O&M

A simple yes or no question was used to assess awareness by distinguishing between respondents who were generally aware of disruptive technologies and those who were not. This study focuses on four distinct types: Advanced Traffic Management System (ATMS), unmanned aerial vehicle (UAV)/Drone, internet of things (IoT), and connected and autonomous vehicle (CAV). The awareness levels vary, with the highest for UAV/Drone (85.2%) and the lowest for CAV (37%). Based on the participants' understanding and knowledge of these technologies, total 77.80% of the respondent aware of the ATMS technology, 85.20% of the respondents acknowledge the benefits of the drone. While for the IoT technology, 81.50% of them are aware of it and only 18.50% of the respondents not aware of IoT. Lastly, only 37.00% of the respondent aware of CAV and more than half of them (63.00%) not acknowledge this technology.

Table II Awareness of Disruptive Technologies

Disruptive Technologies Awareness	Frequencies (N= 27)	Percentage (%)
Advanced Traffic Management System (ATMS)		
Yes	21	77.80
No	6	22.20
Unmanned Aerial Vehicle (UAV)/Drone		
Yes	23	85.20

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No	4	14.80
Internet of Things (IoT)		
Yes	22	81.50
No	5	18.50
Connected and Autonomous Vehicle (CAV)		
Yes	10	37.00
No	17	63.00

First basic awareness of technologies among respondents is established in this part to ensure clarity and ease of response. While for next section, detailed stages for technologies adoption are asked to capture the respondents' levels of familiarity, learning and application of disruptive technologies.

Stage of Adoption of Disruptive Technologies

This section discusses the stage of adoption of 4 types of disruptive technologies in highway operation and maintenance. With refer to Christensen (1997), stage of adoption can be classified into 6 stages, which are, Stage 1 - awareness; Stage 2 - learning the process; Stage 3 - understanding and application of the process; Stage 4 - familiarity and confidence; Stage 5 - adaptation to other contexts; and Stage 6 - creative application to new contexts. The results are depicted as below.

Advanced Traffic Management System (ATMS) Adoption

According to Fig. 1, it is evident that among the total of 21 respondents who possess awareness of the Advanced Traffic Management System (ATMS), they were subsequently prompted to define the current stage of ATMS adoption within their respective companies. The obtained results show a nuanced distribution, depicting that 6 respondents are situated in both Stage 2 and Stage 3 of ATMS adoption. Furthermore, 3 respondents find themselves in both Stage 1 and Stage 6, while a minority of participants, 2 in number, occupy Stage 4, and only 1 respondent stands in Stage 5 concerning ATMS adoption. This detailed breakdown provides a comprehensive understanding of the varied stages of adoption among the surveyed participants.

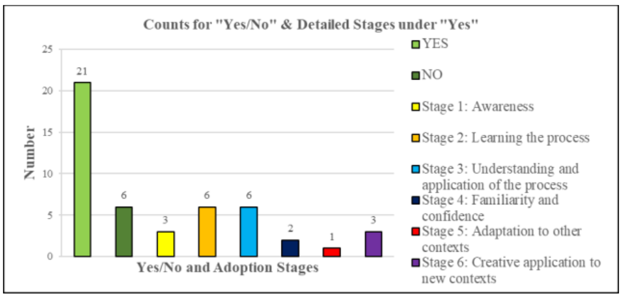

Fig. 1 Stage of adoption of ATMS

Unmanned Aerial Vehicle (UAV)/Drone Adoption

For the UAV/Drone technology adoption based on the stages from Fig. 2, total number of 23 respondents are aware of the UAV/drone and among them, Stage 5 recorded the highest number of respondents, which is 9 respondents.

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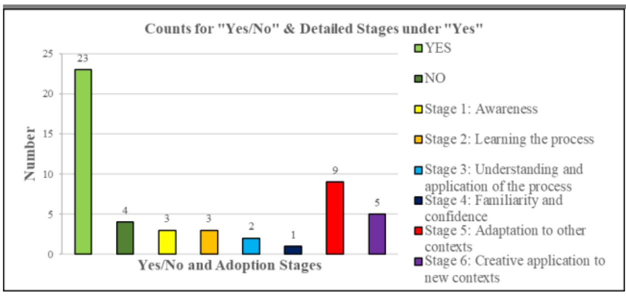

Fig. 2 Stage of adoption of UAV/drone

This indicates a strong adoption for UAV/drone where the technology is not only used but adapted creatively for various applications. At the same time, 5 respondents are situated in Stage 6. Both Stage 1 and Stage 2 have 3 respondents respectively and 2 respondents for Stage 3. Only 1 respondent claimed that their company is in Stage 4 of UAV/drone adoption.

Internet of Things (IoT) Adoption

In the realm of Internet of Things (IoT) adoption, our survey of 22 respondents reveals diverse stages of implementation. Fig. 3 depicts the result of analysis.

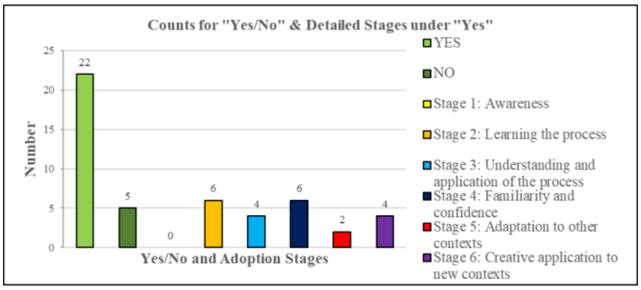

Fig. 3 Stage of adoption of IoT

Notably, 6 respondents indicate that their companies currently reside in both Stages 2 and 4 of IoT adoption. Additionally, 4 respondents report being positioned in Stages 3 and 6, respectively. A more advanced stage, Stage 5, is claimed by only 2 respondents. Interestingly, none of the respondent's report being in the initial Stage 1 of IoT adoption.

Connected and Autonomous Vehicle (CAV) Adoption

For the connected and autonomous vehicle (CAV) adoption, only 10 respondents are aware of this technology. Among the 10 respondents, 6 participants are in Stage 1, they aware of the technology but have not moved beyond the initial stage of awareness. While only 1 respondent is detected in Stage 2, Stage 3, Stage 4 and Stage 6 respectively. None of the respondents have advanced to Stage 4 to adapt the technology to different contexts, suggesting this level of application has not been achieved.

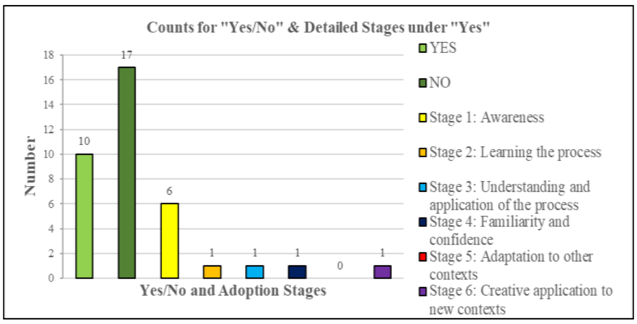

Fig. 4 Stage of adoption of CAV

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Relationships between Awareness of Disruptive Technologies and Demographic Information

Pearson correlation is useful to identify the strength of the relationship as well as the direction of the linear relationship between the two variables. Pearson correlation is conducted in this study to recognize the relationships between awareness of different disruptive technologies and age group, level of education, working experience as well as the job position of the respondents. The coefficient of correlation (r) and significance levels (Sig. (2-tailed)) to measure the strength and significance of the relationship between awareness of these technologies and the demographic variables.

Age Group and Awareness of Disruptive Technologies

According to the result of coefficient of correlation in Table III, none of the awareness of disruptive technologies is significant to the age group of the respondents.

Table III Coefficient of Correlation Results for Age Group

Awareness of Disruptive Technologies	Coefficient of Correlation, r	Sig. (2-tailed)
ATMS	0.009	0.963
UAV	-0.159	0.428
IoT	-0.068	0.737
CAV	-0.316	0.109

* significant at 0.10 **significant at 0.05 ***significant at 0.01

Dependent Variable: Age Group

Negative correlation values reflect a weak tendency for older respondents to have lower awareness of these technologies compared to younger respondents. However, since the correlations are weak (close to 0) and statistically insignificant, these negative values likely represent random variation in the data rather than a true trend or meaningful relationship

In other words, the observed correlation coefficient results do not significantly influence awareness of disruptive technologies in this study. The weak and statistically insignificant correlations imply that awareness is not likely influenced by the age group factor. Thus, age group of the respondents does not appear to play a significant role in influencing the awareness of disruptive technologies.

Level of Education and Awareness of Disruptive Technologies

Table IV depicts the results of the correlation analysis examining the relationship between the awareness of disruptive technologies and the level of education of the respondents. The results show that only awareness of UAV (r =-0.416) is significant to the level of Education at 0.05 significant level. However, negative relationship is noted for the awareness of UAV with the level of education.

Table IV Coefficient of Correlation Results for Level of Education

Awareness of Disruptive Technologies	Coefficient of Correlation, r	Sig. (2-tailed)
ATMS	-0.259	0.192
UAV	-0.416	0.031**

IoT	-0.255	0.199
CAV	-0.275	0.165

* significant at 0.10 **significant at 0.05 ***significant at 0.01

Dependent Variable: Level of Education

Working Experience and Awareness of Disruptive Technologies

Table V presents the results of the correlation analysis investigating the relationship between awareness of disruptive technologies and the working experience of the respondents. The correlation for awareness of CAV is statistically significant at the 0.05 significance level with a r-value of -0.466, suggesting a strong negative relationship between the awareness of CAV and the working experience of the respondents. In other words, as awareness of CAV increases, working experience tends to decrease, or vice versa.

Table V Coefficient of Correlation Results for Working Experience

Awareness of Disruptive Technologies	Coefficient of Correlation, r	Sig. (2-tailed)
ATMS	-0.101	0.617
UAV	-0.196	0.326
IoT	-0.144	0.474
CAV	-0.466	0.014**

* significant at 0.10 **significant at 0.05 ***significant at 0.01

Dependent Variable: Working Experience

Job Position and Awareness of Disruptive Technologies

The correlation results between awareness of disruptive technologies and the job positions of the respondents are outlined in Table VI below.

Table VI Coefficient of Correlation Results for Job Position

Awareness of Disruptive Technologies	Coefficient of Correlation, r	Sig. (2-tailed)
ATMS	-0.040	0.844
UAV	0.340	0.083*
IoT	0.071	0.726
CAV	0.330	0.093*

* significant at 0.10 **significant at 0.05 ***significant at 0.01

Dependent Variable: Job Position

The awareness of UAV and CAV depicts significant relationship with the job position variable and both are statistically significant at the 0.10 significance level. The r values for awareness of UAV and CAV are 0.340 and

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0.330 respectively. This suggests a moderate positive relationship between awareness of UAV and job position. The positive correlations suggest that as awareness of UAV and CAV are affected by the job positions positively.

DISCUSSIONS

According to the detailed analysis of the awareness and adoption stages of disruptive technologies in highway operation and maintenance (O&M) in this research. It highlights four key technologies: Advanced Traffic Management System (ATMS), Unmanned Aerial Vehicle (UAV)/Drone, Internet of Things (IoT), and Connected and Autonomous Vehicle (CAV). The findings reveal varying levels of awareness and adoption among respondents, with UAV/Drone technology receiving the highest awareness (85.2%) and CAV the lowest (37%). The adoption stages are classified according to Christensen's model (1997), ranging from awareness to creative application in new contexts. The data demonstrates a nuanced distribution across these stages, with significant differences among the technologies in terms of how deeply they have been integrated into companies' operations.

Firstly, Advanced Traffic Management Systems (ATMS) adoption shows a broad spectrum of engagement among respondents. It reveals that the highway concessionaire companies are spread across various stages of ATMS adoption, from initial awareness to creative application. Particularly, there's a balanced number of respondents learning and applying ATMS processes, with a few beginnings to adapt these systems innovatively to new contexts. This distribution highlights diverse levels of commitment and innovation in adopting ATMS technologies across different entities.

Besides that, IoT sensors exhibit a wide distribution across various adoption stages, showcasing active involvement with technology, from initial learning phases to innovative implementations. Interestingly, the extension of IoT sensor adaptation to other contexts appears to be less pronounced, hinting at potential barriers or hurdles in broader application. On the other hand, Connected Autonomous Vehicle (CAV) predominantly occupy the awareness stage, indicating a high level of interest, yet minimal progress in actual adoption and utilization, particularly in terms of innovative applications. This disparity between the two technologies underscores the divergent trajectories of technological assimilation within the sector. For instance, UAV/drone technology shows strong adoption and creative application for various applications, while CAV technology remains largely in the initial awareness stage among respondents. This analysis underscores the varied pace at which disruptive technologies are being embraced within the highway O&M sector, reflecting both opportunities and challenges in leveraging these innovations for enhanced efficiency and effectiveness.

Last but not the least, Pearson correlation analysis conducted in this study aimed to observe the relationships between awareness of disruptive technologies and various demographic variables including age group, level of education, working experience, and job position of the respondents. Notably, significant relationships were observed between awareness of disruptive technologies and certain demographic factors. Regarding the age group variable, the correlation coefficients for ATMS, UAV, IoT, and CAV did not reach statistical significance, indicating that age group does not significantly influence awareness of disruptive technologies. In terms of level of education variable, a significant negative relationship ($r=-0.416$) was found between awareness of UAV and level of education, suggesting that as awareness of UAV increases, level of education tends to decrease. However, no other significant correlations were observed between awareness of disruptive technologies and level of education. When examining working experience variable, a strong negative relationship ($r=-0.466$) was identified between awareness of CAV and working experience. This indicates that as awareness of CAV increases, working experience tends to decrease, or vice versa. While for the job position variable, significant positive relationships were observed between awareness of UAV and CAV, and job position with the r value of 0.340 and 0.330 respectively.

In summary, the findings highlight the importance of considering demographic factors such as level of education, working experience, and job position when examining awareness of disruptive technologies. Specifically, individuals with lower levels of education may exhibit greater awareness of UAV, while those with less working experience may have higher awareness of CAV. Additionally, individuals in higher job positions tend to demonstrate increased awareness of UAV and CAV. These insights contribute to a deeper understanding of the factors influencing awareness and adoption of disruptive technologies within organizations.

CONCLUSIONS

In conclusion, the awareness of the disruptive technologies in the operation and maintenance highway is high for ATMS, drone and IoT. Unfortunately, the awareness of CAV technology remains low, with most respondents unaware of its benefits. Overall, most of the technologies are still in the early stages of adoption, except for drone technology, which has shown greater implementation and creative applications. Further insights into the depth of understanding and application were captured in the subsequent adoption stage analysis, ranging from basic awareness to creative applications. The analysis of adoption stages discovered that most disruptive technologies, including ATMS, IoT and CAV are predominantly in the early adoption stages (awareness and learning phases). However, drone technology stands out, with respondents indicating higher levels of adoption, including application, confidence, and creative integration into other contexts. This shows a gap in the adoption progress of these technologies, and there is need for intensive efforts to speed up the adoption of underutilized technologies in highway O&M.

Moreover, the findings of this study also emphasize the necessity for additional research to explore into strategies for promote the adoption of these disruptive technologies. Future studies might investigate into specific challenges, propose targeted solutions, explore innovative business models, policies facilitating technology adoption, and address concerns related to costs and infrastructure development. Additionally, further possible disruptive technologies like big data, virtual reality and so on can be discovered in highway infrastructure operation and maintenance in future studies.

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