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Implementation of Internet of Things in Road Infrastructure Monitoring and Preservation

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ABSTRACT: In the digital transformation era, Internet of Things (IoT) technology has greatly influenced various sectors, including road infrastructure. Businesses increasingly integrate technology to stay competitive and drive growth among various technological advances. The research findings reveal that Internet of Things (IoT) technology significantly improves the efficiency and effectiveness of road monitoring and maintenance practices. The results of this study reveal several factors that influence the application of the Internet of Things (IoT) in monitoring and preserving road infrastructure, namely: fault location and reasons, camera systems, vibration sensors, piezoelectric sensors, non-intrusive sensors, road network resilience, multi-criteria models for road classification or maintenance evaluation, solving unexpected blackouts, intelligent road networks, smart traffic signals. This study also found several factors that influence the application of the Internet of Things (IoT) in monitoring and preserving road infrastructure in the role of stakeholders, namely: changes in development regulations such as taxes, protracted project permits, shortage of workers, access to mobilisation of materials to the location, access to mobilisation and demobilisation of workers at the location.

KEYWORDS: Internet of Things (IoT), Monitoring, Preservation, Infrastructure, Influential Factors, SEM-PLS

INTRODUCTION

Internet of Things (Iot) technology, with its potential to revolutionise various sectors, including road infrastructure, is a source of inspiration. The real-time data acquisition and analysis it provides can significantly increase the efficiency and effectiveness of monitoring systems (Ye et al., 2024). Integrating IoT into road infrastructure monitoring can transform the implementation of maintenance and preservation strategies. This technology enables early detection of damage and helps optimise maintenance strategies, ensuring the longevity and safety of roads. Infrastructure development is an important component of national progress, representing a deliberate effort to address the essential facilities and infrastructure the Indonesian people need.

In the digital transformation era, businesses increasingly integrate technology to stay competitive and drive growth. Iot is characterised by a complex network of interconnected devices equipped with sensors, software, and connectivity capabilities, enabling seamless data exchange and communication across multiple domains (Raschendorfer & Frühwirth, 2023). Integrating these Iot technologies enables businesses to collect and analyse large amounts of data, improving operational efficiency, customer experience, and increased competitive advantage (Harish et al., 2023).

Teguh Prasetya, the founder of the Indonesian IoT forum, said that the IoT market is expected to grow to IDR 444 trillion in 2022, with the need for sensor devices reaching 400 million units. The composition of content and applications will be IDR 192.1 trillion, followed by platforms of IDR 156.8 trillion, Iot devices of IDR 56 trillion, and networks and gateways of IDR 39.1 trillion.

The impact of IoT implementation on decision-making effectiveness among technology companies in Jakarta, Indonesia, is a knowledge gap that requires rigorous examination (Dash et al., 2023). Implementing Iot in the Indonesian business sector, including the technology industry in Jakarta, still faces challenges such as inadequate infrastructure, data security issues, and limited access to technology (Dewi & Avianto, 2023). However, the use of IoT in the Indonesian defence industry is needed to increase the level of local content, strengthen defence and security equipment, and reduce the burden of production activities (Metarini & Rusilowati, 2023). This underscores the crucial role of strategic leadership in the success of digital businesses and the potential for businesses to gain a competitive advantage by leveraging digital technology and strategic leadership to direct their operations (Sirait et al., 2023).

This system demonstrates the potential of Iot to provide accurate and timely data on road conditions, which is essential for effective road maintenance and preservation—stated that roads are land transportation infrastructure that have a vital role in the land transportation sector, which can support the continuity of the distribution of goods and services, driving economic growth in an area. Damage to the road will cause many losses that can be felt directly by users, because it will undoubtedly hinder the speed of vehicles and make it less comfortable for drivers to pass. Besides, road damage can also cause victims if not immediately handled by the authorities (Kurrahman, 2021).

According to Ye et al. (2024), who designed a system to monitor pavement vibrations that captures traffic data instantly, thereby improving road safety and operational efficiency. This particular system illustrates the capacity of Iot in providing accurate and fast information about road conditions, a critical element for efficient road maintenance and conservation. The deployment of Iot technology in road infrastructure goes beyond urban settings, as previous research by Ai et al. (2023) advocates the integration of Iot devices equipped with various sensors in remote areas such as rural highways.

The Internet of Things (Iot) significantly impacts the strategies used to maintain roads. In a study conducted by Kumar et al. (2019), an intelligent system for public transportation was designed that utilises IoT to monitor traffic conditions and critical transportation facilities. Despite the many benefits of its implementation, integrating Internet of Things (IoT) technology in road infrastructure encounters various obstacles. These obstacles include concerns about security, such as data privacy and cyber threats, the need for a reliable monitoring system, and the high initial investment required for IoT-based solutions. Organisations in IoT-based security monitoring tools invest significantly to protect their infrastructure from cyber threats (Lu, 2023).

LITERATURE REVIEW

A. INTERNET OF THINGS

Construction management involves the effective allocation of resources by project managers in a construction project. These resources typically include labour, materials, machinery, money, and methods (Ervianto, 2019). Construction management, as defined by Abrar (2021), relates to the collective responsible for overseeing managerial tasks in the construction process, especially during the implementation phase, a role inherent in all construction efforts. The Internet of Things, known as IoT, presents the concept of interconnected objects around the world (Ηυανικων et al., 2009), enabling communication in an integrated system facilitated by the Internet. An Iot device consists of several sensors for data collection, an Internet connection for communication, and a server to collect and analyse the information obtained by the sensors (Rane et al., 2023).

Kevin Ashton initiated the Internet of Things (Iot) in 1999. This technology, which utilises radio frequency identification (RFID) as its foundation, involves unique electronic product codes that have evolved into new technological advancements (Song & Liang, 2022). Various entities in our environment were enabled to communicate through a network facilitated by the Internet, initially established by the Auto-ID Centre.

B. INTERNET OF THINGS IN ROAD INFRASTRUCTURE

The Internet of Things (IoT) has penetrated various aspects of society, especially the transportation sector. Iot presents advanced solutions in this domain that improve operational efficiency, user safety, and comfort. As technology advances, innovations in the transportation sector are becoming more diverse. The Internet of Things (Iot) has triggered a significant transformation in the transportation sector, encompassing many applications that are reshaping our engagement with the transportation system. Transportation efficiency and road safety on the road network, both critical factors in driving economic growth, are significantly affected by the presence of damage and deficiencies in the road surface (Ye et al., 2024). The goal is that this IoT (Internet of Things) technology can provide qualitative and quantitative insights into the condition of the road surface, allowing for rapid maintenance actions to improve transportation efficiency and road safety.

C. PUBLIC TRANSPROTATION MANAGEMENT SYSTEM

In 2003, Seoul, the capital of South Korea, initiated the Seoul Smart Mobility Reform program. This program aimed to improve transportation management by utilising information and communication technologies to facilitate Seoul’s transition into a smart city (Kumar et al., 2019). One of the key components of this program is the Bus Management System (BMS), a comprehensive scheme designed to support efficient bus transportation administration.

Through implementing BMS, authorities can monitor all data related to bus transportation, including details such as fleet size and real-time vehicle position. This data is disseminated to passengers through information panels at each bus stop and a dedicated mobile application. As a result, passengers experience reduced waiting times, increasing satisfaction with public transportation services, and potentially reducing traffic congestion by promoting greater reliance on public transportation. Studies show a massive surge in public transportation use in the South Korean capital, increasing from 30% to 70% between 2000 and 2003 (World Bank).

Smart Transportation, facilitated by integrating Iot (Internet of Things), has triggered a significant transformation in traffic management and transportation logistics. The results include reduced congestion, time efficiency, and stress levels for drivers. The data obtained is also used to design more effective transportation routes and schedules, reduce passenger waiting times, and maximise the utilisation of transportation resources. Furthermore, integrating Iot can potentially reduce greenhouse gas emissions from vehicles by using more effective routes and schedules, strengthening environmental conservation efforts through more sustainable transportation. This marks a progressive step towards a more intelligent and environmentally conscious transportation network.

RESEARCH METHODS

This study combines quantitative and qualitative descriptive research approaches that utilise numerical data and are subjected to statistical analysis. According to Darmawan (2013), quantitative research is a methodology that aims to systematically, factually, and precisely describe the characteristics and aspects of a particular population or provide a detailed explanation of a phenomenon. Descriptive methods, as explained by Sugiyono (2012), involve formulating questions related to the existence of independent variables, whether they relate to a single variable or multiple variables (where the independent variable is a stand-alone variable, different from the dependent variable and the intervening variable as a variable that affects both). In line with the research methodology mentioned above, this study aims to explain the findings derived from the processed data, evaluated in line with the theory explored, which ultimately leads to reasonable conclusions.

This descriptive exploratory study focuses on a specific target population to examine the manifestation of a concept or phenomenon by detailing many variables related to the problem. Furthermore, additional data regarding the study variables will be derived from various sources that are considered relevant or significant. The research variables are divided into three, namely independent variables, dependent variables, and intervening variables.

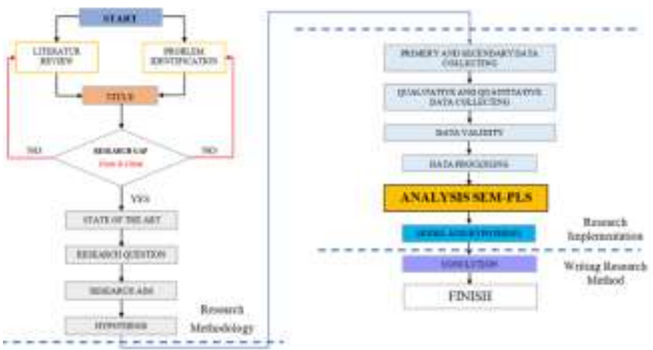

Figure 1 Research Flow Diagram

RESULT AND DISCUSSION

The results and discussion of this study start from the data collection process, data validation, data processing, statistical analysis, and hypothesis testing, along with the basis for decision making, are presented in this chapter. In making the questionnaire, we look for indicators that influence journal references and books that previous researchers have cited. The questionnaire will be distributed to stakeholders, including those directly involved in this toll road infrastructure project. Alternatively, those who are not directly involved in it are included in the provisions that have been previously determined. These stakeholders must represent the toll road infrastructure project and consist of academics, consultants, contractors, developers, and officials in government institutions (Berawi et al., 2019).

The data analysis will use a simulation tool, SEM-PLS (Structural Equation Modelling - Partial Least Squares). Through this software, the primary factors and sub-factors that apply affect the cost effectiveness, which is the focus of this study. SMART PLS stands as a tool for simulation, which is currently popularly used in several scientific studies to analyse data. The data collection that has been carried out is data from the distribution of research questionnaires, where the data will later be analysed to answer the problem formulation questions. In each dependent variable (variable Y), independent variable (variable X), and intervening variable (Variable Z), parameters are needed to be used as benchmarks in the assessment of each variable. In this study, the dependent variable (variable Y) is monitoring and preservation efficiency, while for the independent variables (Variable X) namely Internet of Things (IoT) Monitoring (X1), Internet of Things (IoT) Maintenance Preservation (X2), and Stakeholder Role (X3) as intervening variables.

A. DATA ANALYSIS

SEM-PLS involves importing data from questionnaire processing in CSV file format, followed by establishing structural paths connecting latent variables according to the theoretical framework in the internal model. Next, an external model is determined to represent the relationship between latent variables and their indicators or observable variables. The direction of the arrows indicates the two-way influence between the variables of interest.

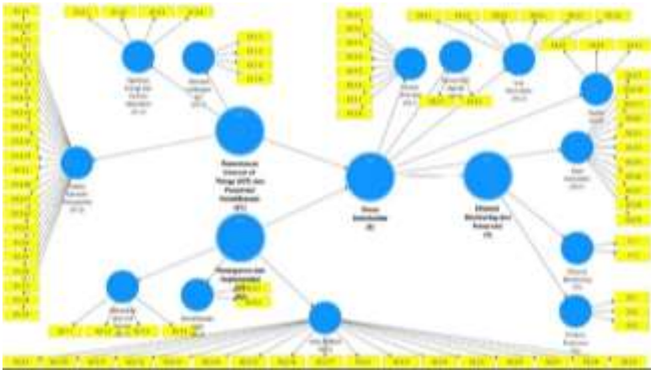

Figure 2 Main SEM Modelling

Table 1 SEM Modelling Relationships.

Variable / Indicator	Latent Variables	Main Variables
X1.1.1 – X1.1.4	IoT Backup Plan	IoT Monitoring (X1)
X1.2.1 – X1.2.4	Energy Optimisation and Fault Detection	
X1.3.1 – X1.3.22	Transportation Sensory System	
X2.1.1 – X2.1.4	The Need for Smart IoT	IoT Maintenance Preservation (X2)
X2.2.1 – X2.2.17	Application Areas	
X2.3.1 – X2.3.2	Road Maintenance	

X3.1.1 – X3.1.8	Owner (Owner)	Stakeholder Role (X3)
X3.2.1 – X3.2.11	Main Contractor	
X3.3.1 – X3.3.6	Sub Contractor	
X3.4.1 – X3.4.3	Supplier	
X3.5.1 – X3.5.2	Local government	
Y1.1 – Y1.2	Monitoring Efficiency	Monitoring and Preservation Efficiency
Y2.1 – Y2.3	Preservation Efficiency	

Table 2 SEM Modelling Path Analysis.

No	Path Analysis
1	V. Indicator → V. Latent
2	V. Indicator → V. Latent V. Median
3	V. Median Internet of Things (IoT) Monitoring → V. Latent Median Stakeholder Roles
4	V. Median Preservation Maintenance of Internet of Things (IoT) → V. Latent Median Role of Stakeholders
5	V. Median Role of Stakeholders → V. Median Efficiency of Monitoring and Preservation

Table 3 Results of Construct Reliability Examination based on Convergent Validity

Dimensions	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Application Area_(X2.2)	0.958	0.960	0.962	0.600
Monitoring and Preservation Efficiency (Y)	0.934	0.937	0.950	0.794
Monitoring Efficiency_(Y1)	0.733	0.734	0.882	0.789
Preservation Efficiency_(Y2)	0.949	0.951	0.967	0.908
The Need for Intelligent IoT_(X2.1)	0.849	0.856	0.898	0.689
Main Contractor_(X3.2)	0.966	0.968	0.970	0.747
Energy Optimisation and Fault Detection_(X1.2)	0.928	0.933	0.949	0.823
Owner (Owner)_(X3.1	0.935	0.939	0.947	0.693
Internet Of Things (IOT) Monitoring (X1)	0.975	0.977	0.976	0.584
Road Maintenance_(X2.3)	0.933	0.934	0.968	0.938
Local Government_(X3.5)	0.928	0.930	0.965	0.932
Role of Stakeholder (X3)	0.984	0.985	0.985	0.687
Maintenance, Preservation, and IOT (X2)	0.970	0.972	0.973	0.608
IoT Backup Plan_(X1.1)	0.769	0.800	0.853	0.596
Transportation Sensory System_(X1.3)	0.970	0.973	0.973	0.625
Sub Contractor_(X3.3)	0.934	0.944	0.949	0.759
Supplier (X3.4)	0.898	0.902	0.936	0.831

From the data presented above, it is evident that each construct shows a Cronbach's alpha value greater than or equal to 0.7, indicating that the established criteria have been met, thus establishing the realism of each construct. In cases where latent variables such as Iot Preservation and Maintenance (X2) show a Cronbach's Alpha, for example, 0.970, exceeding the threshold of ≥ 0.7, it is considered reliable.

Table 4 Reliability Test Results.

Dimensions	Limitation	Cronbach's Alpha	Information
Application Area_(X2.2)	0.600	0.958	Reliable
Monitoring and Preservation Efficiency (Y)		0.934	Reliable
Monitoring Efficiency_(Y1)		0.733	Reliable
Preservation Efficiency_(Y2)		0.949	Reliable
The Need for Intelligent Iot_(X2.1)		0.849	Reliable

Main Contractor_(X3.2)		0.966	Reliable
Energy Optimisation and Fault Detection_(X1.2)		0.928	Reliable
Owner (Owner)_(X3.1)		0.935	Reliable
Internet Of Things (IOT) Monitoring (X1)		0.975	Reliable
Road Maintenance_(X2.3)		0.933	Reliable
Local Government_(X3.5)		0.928	Reliable
Role of Stakeholder (X3)		0.984	Reliable
Maintenance, Preservation, and IOT (X2)		0.970	Reliable
IoT Backup Plan_(X1.1)		0.769	Reliable

Convergent validity can be evaluated using outer loadings or loading factors alongside Average Variance Extracted (AVE). In typical research practices, a threshold of 0.60 for loading factors is commonly applied. An indicator is considered to achieve convergent validity and possess a robust level of validity when its outer loading exceeds 0.60, while the Average Variance Extracted (AVE) value is greater than 0.50 (Chin & Todd, 1995). For instance, when every indicator within a research variable shows an outer loading greater than 0.60, it can be inferred that all indicators satisfy the criteria for convergent validity and exhibit high values. Similarly, the Average Variance Extracted (AVE) value is above 0.50 for each variable under investigation.

Table 5 Composite Reliability Values.

Dimensions	**Limitation**	**Composite Reliability**	**Information**
Application Area_(X2.2)		0.962	Valid
Monitoring and Preservation Efficiency (Y)		0.95	Valid
Monitoring Efficiency_(Y1)		0.882	Valid
Preservation Efficiency_(Y2)		0.967	Valid
The Need for Intelligent IoT_(X2.1)		0.898	Valid
Main Contractor_(X3.2)		0.97	Valid
Energy Optimisation and Fault Detection_(X1.2)	0.7	0.949	Valid
Owner (Owner)_(X3.1		0.947	Valid
Internet Of Things (IOT) Monitoring (X1)		0.976	Valid
Road Maintenance_(X2.3)		0.968	Valid
Local Government_(X3.5)		0.965	Valid
Role of Stakeholder (X3)		0.985	Valid
Maintenance, Preservation, and IOT (X2)		0.973	Valid
IoT Backup Plan_(X1.1)		0.853	Valid
Transportation Sensory System_(X1.3)		0.973	Valid
Sub Contractor_(X3.3)		0.949	Valid
Suppliers (X3.4)		0.936	Valid

B. SEM0PLS PATH COEFFICIENTS – T STATISTIC ANALYSIS

Hypothesis testing of research by finding the T-statistic coefficient. The Calculate PLS Bootstrapping command results in the Smart-PLS program producing the T Statistic output. In hypothesis testing, the T-statistic determines the statistical significance of the path coefficient between constructs.

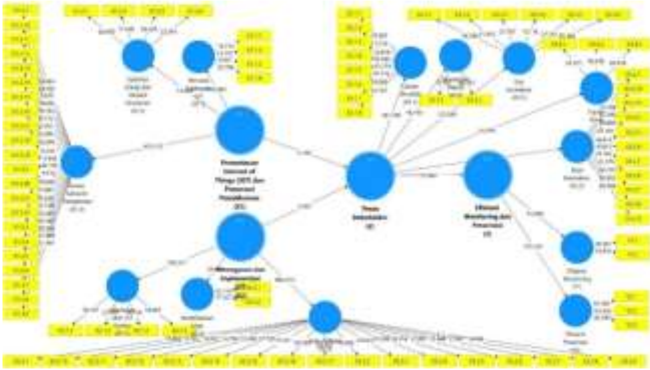

Figure 3 Bootstrapping Results.

Table 6 Composite Reliability Values.

	Original Sample (O)	**T Statistics (|O/STDEV|)**	**P Values**
(X2) -> Application Area_(X2.2)	0.995	948,514	0,000
(X1) -> Transportation sensory system_(X1.3)	0.990	457,003	0,000
(Y) -> Preservation Efficiency_(Y.2)	0.978	233,982	0,000
(X3) -> Owner Owner_(X3.1)	0.977	183,063	0,000
(X2) -> The need for intelligent IoT_(X2.1)	0.969	158,431	0,000
(X3) -> Main Contractor_(X3.2)	0.967	141,990	0,000
(X3) -> Sub Contractor _(X3.3)	0.955	133,884	0,000
(X3) -> Monitoring and preservation efficiency _(Y)	0.944	72,558	0,000
(X1) -> IOT Backup Plan_(X1.1)	0.943	91,862	0,000
(Y) -> Monitoring Efficiency_(Y1)	0.931	51,695	0,000

(X3) -> Local Government_(X3.5)	0.909	47,365	0,000
(X3) -> Supplier_(X3.4)	0.901	53,757	0,000
(X2) -> Road Maintenance _(X2.3)	0.832	24,923	0,000
(X1) -> Energy Optimization and Error Detection _(X1.2)	0.772	14,314	0,000
(X1) -> Role of Stake Holder_(X3)	0.657	6,211	0,000
(X2) -> Role of Stake Holder_(X3)	0.329	3,094	0,000

Interpretation Results Path Coefficient according to the Path Coefficient table is the result taken from the bootstrapping process. To determine the significant effect on the path can be determined by the p value where the results of the analysis show that the path analysis on the indirect effect between Internet of Things (IOT) Monitoring and Preservation of Maintenance, Handling and Implementation of IOT to the Role of Stakeholders and then to Monitoring and Preservation Efficiency has a p value of 0.000 <0.05 and T statistic> 1.976 indicating that the path analysis positively and significantly influences each other.

CONCLUSIONS

From the results of the tests on SEM-PLS (Structural Equation Modelling-Partial Least Squares), it can be concluded that the 5 five) The factors that have the most influence on monitoring the Internet of Things (IoT), with the role of stakeholders for monitoring and preserving road infrastructure, are as follows:

Table 7 The most influential factors in IoT monitoring are stakeholder roles in monitoring and preserving road infrastructure.

		Original Sample		T Statistics	Against R Square
				>1.96	
No	**Sub Factors**		**Mean**	**(p< 0.05)**	
1	Location of error and its reasons	0.954	0.955	71,233	0.879
2	Camera System	0.925	0.925	60,560	
3	Vibration Sensor	0.919	0.920	50,270	
4	Piezoelectric Sensor	0.892	0.892	43,789	
5	Non-Intrusive Sensor	0.888	0.888	39,339	

Table 8 The most influential factors on IoT maintenance preservation with stakeholder roles for monitoring and preserving road infrastructure.

		Original Sample		T Statistics	Against R Square
				>1.96	
No	**Sub Factors**		**Mean**	**(p< 0.05)**	
1	Road network resilience	0.969	0.970	92,684	0.879
2	Multi-criteria model for road classification or maintenance evaluation	0.967	0.967	79,027	
3	Troubleshooting Unexpected Outages	0.900	0.901	39,962	
4	Smart Road Network	0.860	0.860	29,853	
5	Smart Traffic Signals	0.832	0.833	29,537	

Table 9 Stakeholder roles in IoT maintenance, monitoring, and preservation for efficient monitoring and preservation of road infrastructure.

		Original Sample		T Statistics	Against R Square
				>1.96	
No	**Sub Factors**		**Mean**	**(p< 0.05)**	
1	Changes in building regulations, such as taxes	0.968	0.968	96,076	0.879
2	Protracted project licensing	0.964	0.963	73,242	
3	Shortage of workforce	0.920	0.920	69,522	
4	Access to mobilise materials to the location	0.941	0.941	65,528	
5	Access to the mobilisation and demobilisation of workers on site	0.928	0.928	57,120	

From the results of the discussion presented to provide answers to the formulation of the problem and research objectives, the following conclusions can be drawn:

The most influential factors in monitoring the Internet of Things (IoT) with the role of stakeholders for monitoring and preserving road infrastructure are:

1. Location errors can affect Internet of Things (Iot) monitoring and preservation of road infrastructure.
2. Camera systems can impact Internet of Things (IoT) monitoring and preservation of road infrastructure.
3. Vibration sensors can influence Internet of Things (Iot) monitoring and preservation of road infrastructure.
4. Piezoelectric sensors can influence Internet of Things (IoT) monitoring and preservation of road infrastructure.
5. Non-Intrusive Sensors can impact Internet of Things (IoT) monitoring on road infrastructure monitoring and preservation.

The most influential factors in the preservation of Internet of Things (IoT) maintenance, with the role of stakeholders for monitoring and preserving road infrastructure, are:

1. Road network resilience can affect the preservation of Internet of Things (IoT) maintenance in monitoring and preserving road infrastructure.
2. Multi-criteria models for road classification or maintenance evaluation can influence Internet of Things (IoT) maintenance preservation in road infrastructure monitoring and preservation.
3. Solving Unexpected Outages can affect the preservation of Internet of Things (IoT) maintenance on road infrastructure monitoring and preservation.
4. Smart Road Network can influence the preservation of Internet of Things (Iot) maintenance on road infrastructure monitoring and preservation.
5. Smart Traffic Signals can impact the preservation of Internet of Things (IoT) maintenance on road infrastructure monitoring and preservation.

Factors of stakeholder roles in monitoring and preserving Internet of Things (IoT) maintenance for efficient monitoring and preservation of road infrastructure

That is:

1. Changes in building regulations, such as taxes, can affect the efficiency of monitoring and preserving road infrastructure.
2. Prolonged project licensing can affect the efficiency of monitoring and preservation of road infrastructure.
3. The shortage of workforce can affect the efficiency of monitoring and preserving road infrastructure.
4. Access to mobilising materials to the location can affect the efficiency of monitoring and preserving road infrastructure.
5. Access to workers' mobilisation and demobilisation on site can affect the efficiency of monitoring and preserving road infrastructure.

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