



Towards Sustainable Transportation in Baghdad: Identifying Critical Roads and Strategically Locating Weighing Stations

Milad Ghanbari^{1)}, Saad Jasim Mohammed²⁾*

¹⁾ Assistant Professor, Department of Civil Engineering, East Tehran Branch, Islamic Azad University, Tehran, Iran.

* Corresponding Author. E-Mail: Milad.ghanbari@srbiau.ac.ir

²⁾ M.Sc. Graduate, Department of Project Management and Construction, South Tehran Branch, Islamic Azad University, Tehran, Iran. E-Mail: ssq201330@gmail.com.

ARTICLE INFO

Article History:

Received: 11/2/2024

Accepted: 17/5/2024

ABSTRACT

Overloaded vehicle traffic accelerates road degradation, leading to early failures and high maintenance expenses. Identifying critical roads in areas like Baghdad, Iraq, is crucial for effective maintenance planning. Road maintenance involves systematic management to uphold road quality and functionality. However, the absence of weighing stations and awareness about critical roads in Baghdad exacerbated maintenance costs. This study aims to present a robust framework for identifying critical roads that necessitate weighing stations and subsequently determining the optimal locations for these stations in Baghdad. Through statistical analysis of responses collected from 61 road maintenance engineers, 22 influential factors for road criticality and weighing station location were identified. Some key factors emerged as crucial in identifying critical roads, including truck traffic volume, maintenance and construction costs, geopolitical importance and lane count. Furthermore, significant considerations for weighing station placement were identified, such as proximity to industrial hubs and drainage structures. Validation of the model through case studies affirmed its efficacy. Policy implications include the need for feasibility studies before weighing station implementation, data-driven decision-making, road criticality assessment and strategic weighing station placement. This research contributes to improved road management practices, aiding in decision-making for transportation infrastructure enhancement in developing countries like Iraq.

Keywords: Weighing stations, Road maintenance, Critical roads, Locating the station weight in motion.

INTRODUCTION

Frequent The significance of roads has been closely linked to the growth and advancement of human civilization (Sewell et al., 2019; Van Noort and Colley, 2021). The cultural and developmental status of a region can be assessed based on its proximity to or distance

from roads (Zhang et al., 2019; Wang et al., 2020). Insufficient management in road maintenance results in increased damage and criticality of roads (Shadhar and Raoof Mahjoob, 2020; Guan et al., 2022). Effective road maintenance management plays a vital role in preventing gradual pavement deterioration. With the rising number of vehicles, the quality of road services

declines. Pavement maintenance stands as a crucial concern for governmental organizations. Inadequate investment or ineffective maintenance strategies can lead to substantial long-term economic costs (Hasan et al., 2020). To uphold and enhance the quality of services provided by infrastructure projects and avoid potential deterioration, comprehensive planning is imperative (Shadhar and Raoof Mahjoob, 2020).

The issue of overloaded trucks poses a significant challenge on highways, leading to adverse impacts on pavement longevity, performance, bridge durability, road safety, average speed and the overall road service level (Bosso et al., 2020). Overloading represents a critical threat to the sustainability of road networks in many countries (Martínez et al., 2018). Ensuring the safety and integrity of civil infrastructure has become a global concern due to overloaded vehicles. It is crucial to closely monitor heavy vehicles to prevent fatigue-induced deterioration and significant failures within the transportation infrastructure.

In recent times, there has been a growing demand for vehicle weight measurement data in the management of road networks (Maljaars, 2020). The integration of vehicle weight data with conventional traffic data can serve various purposes, including heavy vehicle regulation, road planning, road maintenance, bridge performance assessment, traffic safety enhancement and fostering competitiveness (Haugen, 2016).

Methods currently available for measuring vehicle weight consist of static weighing and weigh in motion (WIM) techniques (Feng et al., 2020). Static weighing is commonly regarded as the standard method for enforcing weight restrictions. Although it can yield accurate results, static weighing is time-consuming, costly to implement and often requires permanent installation of systems, posing logistical challenges (Bosso et al., 2020; Costa et al., 2017). Moreover, this approach involves intercepting specific trucks, leading to disruptions in traffic flow (Feng et al., 2020). On the other hand, WIM is one of the key research areas in remote transportation. Utilizing WIM systems is crucial for the advancement of intelligent systems, the regulation of legal road usage and the preservation of road pavements by preventing overloading and pavement distortions (Grakovski and Pilipovics, 2017).

Roads and highways hold significant importance in Iraq's transportation infrastructure, playing a crucial role in the local economy and the country's overall

development (Mohammed et al., 2017). Iraq's transportation infrastructure has suffered from neglect and underfunding for more than three decades since 1980 (Hasan et al., 2020). Presently, numerous highway agencies in Iraq face the challenge of inadequate databases, lacking detailed information about roads and maintenance activities (Shadhar and Raoof Mahjoob, 2020). Roads experiencing heavy traffic demand more frequent inspections, as they are more vulnerable, particularly in Baghdad province. Neglecting the maintenance of such roads results in increased costs due to failures, highlighting the significance of identifying critical routes that require effective maintenance management to preserve national assets (Shadhar and Raoof Mahjoob, 2020).

Considering the aforementioned context, the aim of this research is to identify the critical roads in Baghdad that necessitate the establishment of axial weighing stations. The study focuses on the city of Baghdad to provide a framework for identifying these critical roads and determining the optimal locations for the weighing stations. The research seeks to achieve this aim through two objectives: first, identifying the critical roads in Baghdad that require central weighing stations and second, determining the suitable locations for these weighing stations on the identified critical roads.

The next section of the study outlines existing literature concerning weighing systems, emphasizing their significance in Iraq and identifying research gaps. Then, the study details the research methodology, presenting the conceptual model and methods for data collection. Following this, data analysis is conducted and statistical tests are carried out. Subsequently, the results are validated through examination of three case-study roads. Finally, conclusions are provided.

LITERATURE REVIEW

The maintenance of roads encompasses various activities aimed at ensuring the proper condition and functionality of road components, such as pavement, shoulders, slopes, drainage facilities and other technical features (Huang et al., 2021).

Weighing System

The WIM system is a valuable technology for measuring traffic volume and vehicle weight, particularly for vehicles exceeding the road's capacity,

without the need for them to stop (Maljaars, 2020). Road authorities utilize this system to enforce road transport regulations and effectively manage road accidents (Otto et al., 2017). An important advantage of the WIM system is its ability to measure the weight of moving vehicles without requiring them to halt, resulting in time savings, fuel efficiency and reduced manpower requirements (Oskarbski and Kaszubowski, 2016; Zhang et al., 2017; Maljaars, 2020). By deploying sensors on the road surface, the system can identify vehicles exceeding weight limits and provide real-time alerts to traffic police personnel (Otto et al., 2017).

The WIM system incorporates advanced sensors that enable accurate measurements while vehicles are in motion. It can even capture license plate images for identification purposes. Besides weight measurement, these systems are also employed to gather comprehensive traffic information (Lin et al., 2022). Generally, WIM systems can capture data related to vehicle classification (based on weight, number of axles, axle distance and size), total gross weight, axle weight, speed and timestamps for each recorded event (Otto et al., 2017). Furthermore, weighing-in-motion technology can also be applied to assess the weight of trains on railway bridges (Žnidarič et al., 2016; Costa et al., 2017).

The WIM technology can achieve greater accuracy through the utilization of computer vision techniques (Feng et al., 2020; Hou et al., 2022). According to Mai et al. (2013), it is essential to ensure the quality of data collected from weighing stations. They conducted a correlation analysis to examine unacceptable values in truck weight data, axle load distribution and relationships between variables.

In a study conducted by Mahmoudabadi and Tavakkoli-Moghaddam (2011), weighing stations were ranked based on their performance using a genetic algorithm. The factors considered for performance evaluation included truck traffic volume, overload incidents and the type of scale (portable or fixed). Another research proposed an effective approach for determining the optimal locations to install WIM systems, considering the control of maximum axle loads of trucks (Mahmoudabadi and Seyedhosseini, 2013). Additionally, the optimization of truck weighing station locations in Saudi Arabia's highway network was investigated (AlGadhi, 2002). The research employed a

deterministic flow tracking model with the objective of maximizing the overall flow of trucks traveling on intercity highways.

Simulation of weighing station operation performance using queuing models can help reduce truck delays in weighing queues (Han et al., 2012). Toll booths are identified as suitable locations for installing weighing systems, as they can determine tolls based on vehicle weight and type (Hang et al., 2013; Truong et al., 2020). According to Jacob and Feypell-de La Beaumelle (2010), weighing technology enhances truck safety by addressing the risks posed by overloaded trucks, which include traffic accidents and infrastructure damage. Overloaded trucks also create an unfair competition among shipping methods and companies, underscoring the importance of ensuring compliance with weight regulations.

In Malaysia, vehicle overloading is a major cause of road pavement damage. The implementation of weighing systems for vehicle weight control has improved safety and reduced the instances of weight violations on Malaysian roads (Karim et al., 2014). Additionally, the utilization of weighing systems generates a significant revenue from road users, contributing substantially to the road maintenance budget.

The Importance of Vehicle Weighing Stations in Iraq

The significance of vehicle weighing stations in Iraq has gained attention after years of neglecting the issue of cargo vehicle overload control. In 2010, the Iraqi government initiated a vision to address this concern, leading to the formation of working groups within relevant ministries to establish a legal framework for the establishment of axial weighing stations. This effort resulted in the first amendment of the Iraqi Public Roads Law no. 35 of 2002, which was subsequently approved by Law no. (5) of 2013. Instructions for the operation of these stations were set in 2015. As a result of a tender process, more than 21 axial weighing stations were established in southern provinces, including Basra, Maysan, Wasit, Dhi Qar and Muthanna, with most of them completed after 2015. However, the selection of station locations was not adequately studied, leading to the establishment of stations on roads with minimal vehicle traffic, while neglecting the presence of many roads that required these stations.

Research Gap

Given the increasing traffic of overloaded trucks and commercial vehicles in Iraq and their detrimental impact on road pavement, it is crucial to employ new technologies to mitigate road destruction. The severity of axial load restrictions in a country reflects its economic and social status. In many developing countries, like Iraq, a significant number of heavy vehicles exceed the permissible load limit, resulting in pavement damage. Structural failure or rupture occurs when the stresses on a structure surpass the bearing capacity of its materials.

Upon reviewing the existing literature, it becomes evident that previous studies have not adequately addressed the identification of critical roads requiring weighing stations. Understanding the characteristics of these critical roads is essential for determining the appropriate location of weighing systems. Unfortunately, there is a lack of scientific research focused on identifying and maintaining critical roads in Iraq. Consequently, the present study aims to fill this

research gap and provide valuable insights for transportation, road and urban development organizations, industries, companies, associations and individuals involved in these fields.

RESEARCH METHODOLOGY

The process of pinpointing crucial roads that require weighing stations and outlining location markers for installing weighing systems involves considering a variety of different attributes. In this study, these attributes were identified by reviewing existing literature and conducting interviews with road maintenance engineers based in Baghdad province. To collect the insights of these maintenance engineers regarding these attributes, a structured questionnaire was utilized. Table 1 provides a summary of the effective factors for identifying critical roads that require weighing stations in Iraq, as well as the factors that affect locating weighing stations on critical roads.

Table 1. The proposed factors impacting the identification of critical roads and locating of weighing stations in Iraq

No.	Factor/Description	References
Factors affecting identifying critical roads		
1	Road construction cost	(Haugen et al., 2016); (Maljaars, 2020); (Ghanbari & Hasani, 2024)
2	Annual maintenance cost	(Haugen et al., 2016); (Khalifa et al., 2019); (Ghanbari & Hasani, 2024)
3	Annual average daily traffic volume (AADT)	(Ammarapala et al., 2013); (Mai et al., 2013); (Gandupalli et al., 2024)
4	Annual average daily truck-traffic volume	(Ammarapala et al., 2013); (Mai et al., 2013); (Oskarbski & Kaszubowski, 2016); (Kulović et al., 2018)
5	Number of lanes	(Mai et al., 2013); (Gandupalli et al., 2024)
6	Road length	(Maljaars, 2020); (Gandupalli et al., 2024)
7	Maximum allowable speed	(Mai et al., 2013); (Khalifa et al., 2019); (Maljaars, 2020)
8	Road type in terms of topography	(Oskarbski & Kaszubowski, 2016); (Gandupalli et al., 2024)
9	Maximum road gradient	(Haugen et al., 2016); (Abusaleh et al., 2019)
10	Annual number of truck accidents	(Jacob & Feypell-de La Beaumelle, 2010); (Gandupalli et al., 2024)
11	Geopolitical importance of the road	(Jacob & Feypell-de La Beaumelle, 2010); (Gandupalli et al., 2024)
Factors affecting locating weighing stations		
12	Close to alternative routes	(Kulović et al., 2018)
13	Access to road network to serve more	(AlGadhi, 2002); (Kulović et al., 2018)
14	To be away from road intersections	(AlGadhi, 2002); (Oskarbski & Kaszubowski, 2016)
15	To be away from vertical and horizontal curves	(AlGadhi, 2002); (Oskarbski & Kaszubowski, 2016); (Gandupalli et al., 2024)

16	To be away from any drainage structures	(AlGadhi, 2002); (Oskarbski & Kaszubowski, 2016)
17	Proximity to other weighting stations	(Ammarapala et al., 2013); (Kulović et al., 2018)
18	Difficulty for trucks to by-pass the station	(Kulović et al., 2018)
19	Land-use characteristics	(Kulović et al., 2018); (Khalifa et al., 2019); (Gandupalli et al., 2024)
20	Sufficient land availability	(Kulović et al., 2018)
21	Availability of utilities	(Ammarapala et al., 2013)
22	Distance to industrial and agricultural hubs	(Ammarapala et al., 2013)

Conceptual Research Model

In the present study, the identification of critical roads in Baghdad is based on several criteria: 1. Economic conditions, 2. Traffic conditions, 3. Topographical and geometric conditions and 4. Safety and security. Similarly, the location of the weighing stations on these critical roads is determined by the

following criteria: 1. Traffic efficiency, 2. Technical conditions and 3. Economic conditions. The conceptual model of this research, illustrated in Figure 1, outlines the framework for the process of identifying critical roads and subsequently determining the optimal location for the weighing stations on these roads.

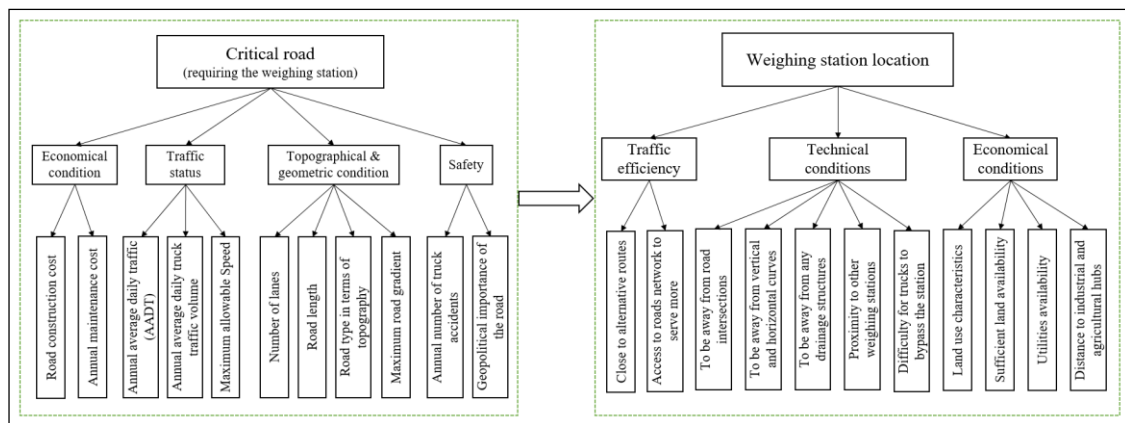


Figure (1): Conceptual model of the research

Data Collection, Population and Sample

For data collection, a questionnaire was utilized in this study. The authors developed a structured questionnaire by extracting the affecting factors from the literature (Table 1). According to the conceptual model presented in Figure 1, the designed questionnaire had two sections; the first section was based on 11 items classified in 3 dimensions and the second section was based on 11 items classified in 3 dimensions. The questionnaire had 31 specialized questions. The research questionnaire utilized a 5-point Likert scale as the answer options for the questions.

The questionnaire was then distributed to experts, specifically maintenance engineers actively involved in road projects in Baghdad province, who possessed a

minimum of a bachelor's degree and had a work experience of more than 3 years. To ensure clarity and accuracy in responding to the questionnaire, the authors provided additional explanations to the experts. The respondents participated in the survey of this research with fully informed consent and since they were mostly maintenance engineers, they were interested in knowing the results of the research for exploitation in their organizations.

A total of 70 maintenance engineers in Baghdad received the questionnaire and 61 engineers responded to all the questions. Hence, the return rate of the questionnaire was 87.14% and the sample size for this research was determined to be 61 engineers. Table 2 provides the demographic characteristics of the

respondents. The majority of the respondents were aged between 30 and 40 years (54.10%), followed by those over 40 years (34.43%). Regarding specialty, civil engineering was the most common specialty (85.25%),

while the majority had an experience ranging from 15 years to 25 years (39.34%). In terms of education, bachelor degree holders were most prevalent (47.54%), followed closely by master degree holders (45.90%).

Table 2. Respondents' demographic characteristics

Characteristics	Category	Frequency	Percentage
Age	> 40	21	34.43%
	30-40	33	54.10%
	< 30	7	11.48%
Specialty	Civil engineering	52	85.25%
	Architecture	2	3.28%
	Electricity	1	1.64%
	Mechanics	3	4.92%
	Other	3	4.92%
Experience	> 25	14	22.95%
	15-25	24	39.34%
	10-14	9	14.75%
	6-9	9	14.75%
	3-5	5	8.20%
Education level	PhD	4	6.56%
	Master	28	45.90%
	Bachelor	29	47.54%

The study's methodology has limitations affecting result interpretation. The questionnaire design might have influenced response quality and depth. The sample's representativeness, mainly Baghdad road maintenance engineers, limits broader applicability. Data collection challenges, like time constraints and accessibility issues, may have impacted data comprehensiveness.

Relative Importance Index Test

To determine the weight or importance of each item, the formula for the Relative Importance Index (RII) was employed based on the data obtained from the experts' questionnaires, as observed in previous studies (Shahsavand et al., 2018; Zidane and Andersen, 2018; Shrestha and Shrestha, 2019;). The RII formula is represented by Equation 1:

$$RII = \frac{\sum_{i=1}^I W_i}{A \times N} \quad (1)$$

where RII signifies the relative importance index and W_i denotes the weight assigned to each factor by the respondents (ranging from 1 to 5). A represents the highest weight (which is 5 in this study) and N signifies

the total number of respondents. The RII value ranges from 0 to 1, with a higher RII indicating a higher level of importance for that particular factor.

By combining the 5-point Likert scale with the RII method, factors with an RII value below 0.6 are considered to be ineffective and not significant in identifying critical roads or determining the location of weighing stations on critical roads. The RII values allow for the prioritization of influential factors based on their level of importance.

RESULTS

Data Analysis Techniques

The data obtained from the questionnaires was subjected to analysis using SPSS 20 software. Various statistical techniques, including tests for data normality, data reliability and correlation, were employed to verify the accuracy and reliability of the collected data.

Data Screening, Reliability and Validity

The questionnaire utilized in this study comprised

two sections. The first section encompassed 11 questions concerning factors influencing the identification of critical roads necessitating weighing stations, while the second section involved 11 questions concerning factors influencing the placement of axial weighing stations. The data obtained from the questionnaire underwent assessment through the Kolmogorov-Smirnov test, affirming normal distribution at a 95% confidence level. To ensure questionnaire validity, insights were gathered from academic professionals and integrated into the questionnaire. Furthermore, input from road maintenance managers in Baghdad government agencies was incorporated. Data reliability, denoting the measurement tool's consistency in yielding similar outcomes under comparable circumstances, was gauged via Cronbach's alpha. Utilizing SPSS software, the reliability coefficient was computed at 0.83. Given that this figure surpasses the threshold of 0.7, it indicates the questionnaire's requisite reliability (Sekaran and Bougie, 2016; Hinton and McMurray, 2017).

Correlation Test

Correlation analysis is a statistical linear method used to assess the relationship between two variables or sets of data, without implying causation. It examines the association between variables independently of other factors. Pearson correlation coefficient is commonly employed when the data follows a normal distribution,

while Spearman correlation coefficient is used for non-normally distributed data. Correlation analysis allows us to determine the nature and strength of the relationship between variables. In this study, since the variables exhibited a normal distribution, Pearson's correlation test was conducted using SPSS software. The correlation analysis was performed based on the questionnaire responses of 61 participants.

Identification of Critical Roads

The questionnaire responses from the 61 participants regarding the identification of critical roads requiring weighing stations were analyzed using the RII method. The RII scores for all factors were computed and are presented in Table 3. According to the RII analysis, the top five factors for identifying critical roads requiring weighing stations are as follows:

- Annual average daily truck traffic volume
- Annual maintenance cost (per kilometer)
- Road construction cost (per kilometer)
- Geopolitical importance of the road
- Number of lanes.

From Table 3, it can be observed that among all the characteristics considered for identifying critical roads that require weighing stations, the annual number of truck accidents had the lowest rank. This indicates that this particular factor has a limited influence on determining the criticality of a road and the need for a weighing station.

Table 3. Ranking of factors influencing the identification of critical roads

Code	Factor (Sub-criterion)	RII	Rank
F4	Annual average daily truck-traffic volume	0.911	1
F2	Annual maintenance cost (per km)	0.826	2
F1	Road construction cost (per km)	0.764	3
F11	Geopolitical importance of the road	0.731	4
F6	Number of lanes	0.721	5
F8	Road type in terms of topography (plain terrain; rolling terrain; mountainous terrain)	0.705	6
F7	Road length (km)	0.682	7
F9	Maximum road gradient	0.682	8
F3	Annual average daily traffic (AADT)	0.679	9
F5	Maximum allowable speed	0.662	10
F10	Annual number of truck accidents	0.623	11

Locating the Weighing Stations

The questionnaire responses from the 61 participants

regarding the location of the weighing stations on critical roads were also analyzed using the RII method.

The RII scores for all factors were computed and are presented in Table 4. According to the RII analysis, the top five factors for locating weighing stations on critical roads are as follows:

- Difficulty for trucks to bypass the station to avoid weighing
- Distance to industrial and agricultural hubs
- Land use characteristics
- Proximity to other weighing stations (existing or planned)

- To be away from any drainage structures (e.g. culverts and bridges).

From Table 4, it can be observed that the availability of utilities has the lowest rank among all the factors considered for locating weighing stations. Therefore, it is not a significant factor in determining the location of the weighing stations. On the other hand, the difficulty of the site is identified as a highly important and effective factor in preventing trucks from bypassing the station.

Table 4. Ranking of factors influencing the selection of vweighing station locations on critical roads

Code	Factor (Sub-criterion)	RII	Rank
F18	Difficulty for trucks to by-pass the station to avoid weighing	0.826	1
F22	Distance to industrial and agricultural hubs	0.816	2
F19	Land-use characteristics	0.807	3
F16	To be away from any drainage structures (eg. culverts and bridges)	0.797	4
F17	Proximity to other weighing stations (existing or planned)	0.797	5
F15	To be away from vertical and horizontal curves	0.793	6
F20	Sufficient land availability	0.774	7
F13	Access to road network to serve more	0.767	8
F12	Close to alternative routes	0.764	9
F14	To be away from road intersections	0.757	10
F21	Availability of utilities	0.744	11

Validation

This part of the study focuses on validating the model utilized in the study. To achieve this objective, three primary roads in Baghdad were chosen as case studies to assess the model's performance. The objective is to determine whether these three roads meet the criteria of being classified as critical. Table 5 provides

an overview of the specifications of the selected roads, while Figure 2 displays their respective locations within the province of Baghdad. It should be noted that Kut and Mosul roads have recently been equipped with weighing stations, whereas road number 3, (Baghdad-Floga_) currently lacks a weighing station.

Table 5. Specifications of 3 main roads in Baghdad for model validation

#	Road	Type	Length (km)	Width (m)	Number of lanes	Weighting station
1	Baghdad - Kut	Main	32	10.5	Three lanes	exists
2	Baghdad - Mosul	Main	32	10.5	Three lanes	exists
3	Baghdad - Floga	Main	13	7	Two lanes	does not exist

According to the prioritized characteristics presented in Table 6, a checklist was created to assess the criticality/non-criticality of the roads. All three roads were evaluated based on this checklist and the results are

summarized in Table 6.

The conformity of the current status of these three roads with the characteristics identified in this study was examined in Table 5. According to the checklist, road

no. 3 (Baghdad - Floga) does not require a weighing station, as it is not considered a critical road based on the checklist criteria. Currently, this road does not have a weighing station. However, road no. 1 (Baghdad-Kut) and road no. 2 (Baghdad-Mosul) are considered critical compared to road no. 3, indicating the need for weighing stations. These two roads already have weighing stations

in place. Therefore, the proposed research model demonstrates good performance for all three roads and suggests appropriate criteria for road evaluation. Consequently, the characteristics identified for identifying critical roads and locating weighing stations can be utilized by road maintenance organizations.

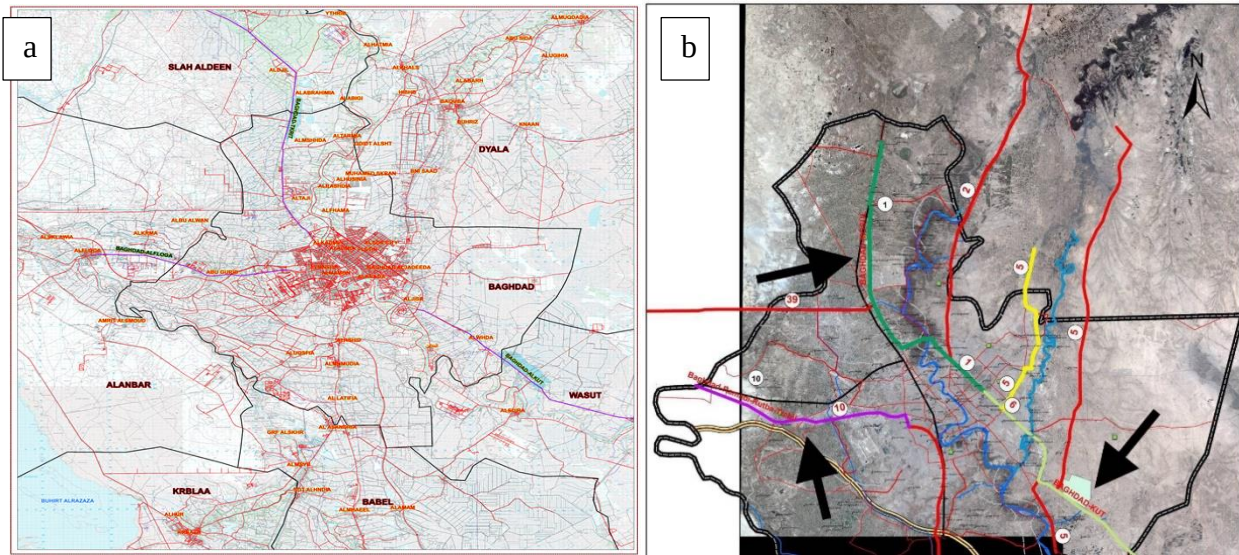


Figure (2): a. Baghdad province; b. The three case study roads

Table 6. Checklist for evaluating the criticality/non-criticality of the studied roads

Factor (Sub-criterion)	Baghdad - Kut	Baghdad - Mosul	Baghdad - Floga
Annual average daily truck-traffic volume	163140	97770	5670
Annual maintenance cost (per km)	0.33 M \$	0.63 M \$	0.2 M \$
Road construction cost (per km)	2.8 M \$	2.8 M \$	2 M \$
Geopolitical importance of the road	Very important	Very important	Important
Number of lanes	3	3	2
Road type in terms of topography (plain terrain; rolling terrain; mountainous terrain)	Plain	Plain	Plain
Road length (km)	32	32	13
Maximum road gradient	1.5%	3%	2%
Annual average daily traffic (AADT)	8020	10248	2657
Maximum allowable speed	100 km/h	100 km/h	100 km/h
Annual number of truck accidents	94	116	23
Overall result	Critical road	Critical road	Non-critical road

In validating the findings of the present study, it is essential to compare and contrast them with those of existing research. The present study aligns with Kulović et al. (2018) in recognizing the significant prevalence of overloaded trucks and the associated damage to road infrastructure. Similarly, Haugen et al. (2016) emphasized challenges related to sensor accuracy and

calibration, reflecting observations regarding the need for precise data collection methods. Furthermore, Oskarbski and Kaszubowski (2016) and Ammarapala et al. (2013) underscored the importance of weighing stations and WIM systems in managing freight traffic and optimizing weighing station locations, respectively, which resonates with the present study's focus on

proposing a robust framework for weighing station placement. Highlighting these agreements strengthens the validity of the findings, situating the study within the broader context of road maintenance and transportation infrastructure management.

CONCLUSIONS AND RECOMMENDATIONS

Effective road maintenance is pivotal for enhancing Iraq's road infrastructure, necessitating a comprehensive strategy integrating modern technologies. Among these technologies, the establishment of axial weighing stations emerges as a critical element in road maintenance management, particularly for identifying and addressing issues on critical roads. This study aimed to discern the key factors influencing the identification of critical roads and the optimal placement of weighing stations within Baghdad province. Through a questionnaire administered to 61 road maintenance engineers, data was collected and analyzed using SPSS 20 software, employing the relative importance index (RII) method to rank influential factors.

The research identified some crucial factors for pinpointing critical roads, including truck traffic volume, annual maintenance and construction costs, geopolitical significance and lane count. Moreover, it pinpointed five significant considerations for weighing station placement: accessibility for trucks, proximity to industrial and agricultural hubs, land use characteristics, distance from drainage structures and proximity to other weighing stations.

Validation of these factors was conducted on three main roads in Baghdad province, affirming their accuracy and the robustness of the research model. Consequently, several recommendations are proposed for the establishment of axial weighing stations,

particularly in developing countries like Iraq. Firstly, feasibility studies should precede station implementation, focusing on critical road identification. Secondly, a comprehensive assessment of economic, traffic, safety and geometric factors is essential in determining road criticality. Thirdly, factors influencing station location, such as proximity to industrial zones and land use characteristics, should be meticulously evaluated. Finally, stations should ideally be strategically positioned to serve incoming traffic from various roads, optimizing their effectiveness.

These recommendations aim to inform decision-making processes and facilitate the implementation of axial weighing stations, thereby enhancing road management practices. Nonetheless, limitations of the study include the focus on Baghdad province, potential bias from data reliance on road maintenance engineers and constraints related to time and accessibility, which may affect the result accuracy.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Declaration of Competing Interests

The authors declare that they have no known or potential competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors appreciate the support of the respondents (road maintenance engineers in Iraq) to the questionnaire of this study.

REFERENCES

- Abusalem, Z., Odeh, I., Al-Hazim, N., Bazlamit, S.M., and Al-Saket, A. (2019). "Analysis of air pollutants' concentrations in terms of traffic conditions and road gradient in an urban area". *Jordan Journal of Civil Engineering*, 13 (3).
- AlGadhi, S.A. (2002). "Optimizing truck weigh stations' locations on the highway network of Saudi Arabia". *Journal of King Saud University-Engineering Sciences*, 14 (2), 147-163.

- Ammarapala, V., Chinda, T., Udomworarat, P., Rongwiriyanich, T., Khampanit, A., Suanmali, S., and Samphanwattanachai, B. (2013). "Selection of weigh station locations in Thailand using the analytic hierarchy process". *Songklanakarin Journal of Science & Technology*, 35 (1).
- Bosso, M., Vasconcelos, K.L., Ho, L.L., and Bernucci, L.L. (2020). "Use of regression trees to predict overweight trucks from historical weigh-in-motion data". *Journal of Traffic and Transportation Engineering (English Edition)*, 7 (6), 843-859.
- Costa, B.J., Martins, R., Santos, M., Felgueiras, C., and Calçada, R. (2017). "Weighing-in-motion wireless system for sustainable railway transport". *Energy Procedia*, 136, 408-413.
- Feng, M.Q., Leung, R.Y., and Eckersley, C.M. (2020). "Non-contact vehicle weigh-in-motion using computer vision". *Measurement*, 153, 107415.
- Gandupalli, S.R., Kokkeragadda, P., and Dangeti, M.R. (2024). "Modeling of risk factors for vulnerable road users' crashes on national highways passing through medium-sized Indian cities". *Jordan Journal of Civil Engineering*, 18 (2). <https://doi.org/10.14525/jjce.v18i2.07>
- Ghanbari, M., and Hasani, Z.K. (2024). "Key success factors in road maintenance management projects: A case study of Maysan province, Iraq". *IJUM Engineering Journal*, 25 (1), 102-114.
- Grakovski, A., and Pilipovics, A. (2017). "Dynamics of interaction between the road surface and vehicle's wheels in fibre-optic system for automatic weighing-in-motion of transport". *Procedia-Engineering*, 178, 5-12.
- Guan, J., Yang, X., You, L., Ding, L., and Cheng, X. (2022). "Multi-objective optimization for sustainable road network maintenance under traffic equilibrium: Incorporating costs and environmental impacts". *Journal of Cleaner Production*, 334, 130103.
- Han, L.D., Ko, S.S., Gu, Z., and Jeong, M.K. (2012). "Adaptive weigh-in-motion algorithms for truck weight enforcement". *Transportation Research-Part C: Emerging Technologies*, 24, 256-269.
- Hang, W., Xie, Y., and He, J. (2013). "Practices of using weigh-in-motion technology for truck weight regulation in China". *Transport Policy*, 30, 143-152.
- Hasan, M.A., Jew, B.K., Abed, F.H., and Msallam, M.S. (2020). "Developing a pavement maintenance management system of multi-lane highway in Iraq". In: *IOP Conference Series: Materials Science and Engineering*, 881 (1), 012171. IOP Publishing.
- Haugen, T., Levy, J.R., Aakre, E., and Tello, M.E.P. (2016). "Weigh-in-motion: Equipment, experiences and challenges". *Transportation Research Procedia*, 14, 1423-1432.
- Hinton, P.R., and McMurray, I. (2017). "Presenting your data with SPSS explained". Taylor & Francis.
- Hou, R., Jeong, S., Lynch, J.P., Ettouney, M.M., and Law, K.H. (2022). "Data-driven analytical load rating method of bridges using integrated bridge structural response and weigh-in-motion truck data". *Mechanical Systems and Signal Processing*, 163, 108128.
- Huang, M., Dong, Q., Ni, F., and Wang, L. (2021). "LCA- and LCCA-based multi-objective optimization of pavement maintenance". *Journal of Cleaner Production*, 283, 124583.
- Jacob, B., and Feypell-de La Beaumelle, V. (2010). "Improving truck safety: Potential of weigh-in-motion technology". *IATSS Research*, 34 (1), 9-15.
- Karim, M.R., Ibrahim, N.I., Saifzul, A.A., and Yamanaka, H. (2014). "Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass and enforcement capability". *IATSS Research*, 37 (2), 124-129.
- Khalifa, N.A., Zulkiple, A., and Sadullah, A.F.M. (2019). "Factors influencing local road (JKR U2/U3) damage in Malaysia". *Jordan Journal of Civil Engineering*, 13 (4).
- Kulović, M., Injac, Z., Davidović, S., and Posavac, I. (2018). "Modeling truck-weigh stations' locations based on truck-traffic flow and overweight violation: A case study in Bosnia and Herzegovina". *Promet-Traffic & Transportation*, 30 (2), 163-171.
- Lin, Y.H., Wu, F., Wang, R., Gu, S., and Xu, Z. (2022). "Spatiotemporal analysis of overloaded vehicles on a highway using weigh-in-motion data". *Journal of Transportation Engineering, Part A: Systems*, 148 (1), 04021098.
- Mahmoudabadi, A., and Seyedhosseini, S.M. (2013). "Improving the efficiency of weigh-in-motion systems through optimized allocating truck checking oriented procedure". *IATSS Research*, 36 (2), 123-128.

- Mahmoudabadi, A., and Tavakkoli-Moghaddam, R. (2011). "The use of a genetic algorithm for clustering the weighing station performance in transportation: A case study". *Expert Systems with Applications*, 38 (9), 11744-11750.
- Mai, D., Turochy, R.E., and Timm, D.H. (2013). "Quality control of weigh-in-motion data incorporating threshold values and rational procedures". *Transportation Research- Part C: Emerging Technologies*, 36, 116-124.
- Maljaars, J. (2020). "Evaluation of traffic-load models for fatigue verification of European road bridges". *Engineering Structures*, 225, 111326.
- Martínez, A.J.T., Josa, S.O., Magrinyà, F., and Gauthier, J.M. (2018). "Cost-effectiveness of enforcing axle-load regulations: The Douala-N'Djamena corridor in Sub-Saharan Africa". *Transportation Research-Part A: Policy and Practice*, 107, 216-228.
- Mohammed, I.A., Burhan, A.M., Rawashdeh, T.M., and Asaaf, M.N. (2017). "Developing an electronic data base for pavement maintenance management system". *International Journal of Civil Engineering and Technology*, 8 (11).
- Oskarbski, J., and Kaszubowski, D. (2016). "Implementation of weigh-in-motion system in freight traffic management in urban areas". *Transportation Research Procedia*, 16, 449-463.
- Otto, G.G., Simonin, J.M., Piau, J.M., Cottineau, L.M., Chupin, O., Momm, L., and Valente, A.M. (2017). "Weigh-in-motion (WIM) sensor response model using pavement stress and deflection". *Construction and Building Materials*, 156, 83-90.
- Sekaran, U., and Bougie, R. (2016). "Research methods for business: A skill-building approach". John Wiley & Sons.
- Sewell, S.J., Desai, S.A., Mutsaa, E., and Lottering, R.T. (2019). "A comparative study of community perceptions regarding the role of roads as a poverty alleviation strategy in rural areas". *Journal of Rural Studies*, 71, 73-84.
- Shadhar, A.K., and Raoof Mahjoob, A.M. (2020). "Pavement maintenance management using multi-objective optimization: Case study: Wasit governorate-Iraq". *International Journal of Engineering*, 33 (11), 2155-2161.
- Shahsavand, P., Marefat, A., and Parchamijalal, M. (2018). "Causes of delays in construction industry and comparative delay analysis techniques with SCL protocol". *Engineering, Construction and Architectural Management*, 25 (4), 497-533.
- Shrestha, K.K., and Shrestha, P.P. (2019). "Change orders on road maintenance contracts: Causes and preventive measures". *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 11 (3), 04519009.
- Truong, T.M.T., Friedrich, H., and Charoenngam, C. (2020). "Success factors for financial sustainability of toll road projects: Empirical evidence from China". *Transportation Research Procedia*, 48, 1848-1860.
- van Noort, C., and Colley, T. (2021). "How do strategic narratives shape policy adoption? Responses to China's belt and road initiative". *Review of International Studies*, 47 (1), 39-63.
- Wang, C., Lim, M.K., Zhang, X., Zhao, L., and Lee, P.T.W. (2020). "Railway and road infrastructure in the belt and road initiative countries: Estimating the impact of transport infrastructure on economic growth". *Transportation Research-Part A: Policy and Practice*, 134, 288-307.
- Zhang, C., Fu, J., and Pu, Z. (2019). "A study of the petroleum trade network of countries along the belt and road initiative". *Journal of Cleaner Production*, 222, 593-605.
- Zhang, Z., Huang, Y., Bridgelall, R., and Lu, P. (2017). "Optimal system design for weigh-in-motion measurements using in-pavement strain sensors". *IEEE Sensors Journal*, 17 (23), 7677-7684.
- Zidane, Y.J.T., and Andersen, B. (2018). "The top 10 universal delay factors in construction projects". *International Journal of Managing Projects in Business*, 11 (3), 650-672.
- Žnidarič, A., Kalin, J., Kreslin, M., Favai, P., and Kolakowski, P. (2016). "Railway bridge weigh-in-motion system". *Transportation Research Procedia*, 14, 4010-4019.