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The Feasibility and Operational Performance of Implementation Median U-turn Intersections: A CRITIC Method

Taqwa I. Alhadidi[1*], Sandra T. Matarneh[1], Ahmad Abu Tahoon[1]

[1] Department of Civil Engineering, Faculty of Engineering, Al-Ahliyya Amman University, Al Salt Road, 19111 Amman, Jordan
[*] Corresponding author, e-mail: t.alhadidi@ammanu.edu.jo

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Abstract

Currently, a growing number of cities are adopting the Median-U-Turn (MUT) intersection design to enhance road capacity and traffic efficiency. The critical question in selecting the right intersection design is how significantly the implementation of MUT can enhance intersection performance, focusing on three key aspects: intersection efficiency, capacity, and the environmental impact of the design. To address this question, an evaluation of operational performance under various prevailing conditions (roadway and control) was conducted using VISSIM, a microscopic simulation platform. This evaluation involved five scenarios: conventional intersections (with increased cycle length, grade separation with a signalized at-grade intersection, grade separation with a roundabout), MUT, and signalized crossover MUT at a dense urban arterial intersection in Amman, Jordan's capital. The performance was compared using several metrics: average control delay, number of stops, average travel speed and time, average stopped delay, Carbon Monoxide (CO) emissions, fuel consumption, and vehicle safety. The Criteria Importance Through Intercriteria Correlation (CRITIC) technique was subsequently used to select the optimal design. The findings indicate that the existing intersection configuration is the least effective, while the MUT with signals at the crossing U-turn points is the most efficient solution.

Keywords

delay, median U-turn, MCMD, CRITIC, SSAM

1 Introduction

Globally, traffic congestion has become an increasing issue. This issue arises due to the rapid increase in vehicle ownership relative to population and income growth (Guzman et al., 2020). Unconventional intersections and interchanges (UAIDs) show their capability to reduce traffic congestion, improve traffic operation and increase infrastructure capacity (Alozi and Hussein, 2022; Alzoubaidi et al., 2021; Ciampa et al., 2020; Corriere and Guerrieri, 2013; ElKashef et al., 2021; Hadidi et al., 2022; Jewel et al., 2022; Mane and Pulugurtha, 2020). Fundamentally, UAIDs aim to increase the efficiency of major intersections by reducing the number of turning movements and signal phases. Additionally, they focus on minimizing potential conflict points at intersections, particularly where left-turning traffic intersects with straight-moving traffic (Corriere and Guerrieri, 2013; Shokry et al., 2020).

Like other developing countries, Jordan's population and economic development have resulted in a rise in transportation demand. This increased demand weakens the performance of roads and transportation infrastructure in major urban regions and along vital transportation routes. According to recent projections, if business as usual continues, the country's ability to conduct daily economic activities will be significantly impacted by the end of 2030 (Ministry of Transport, 2023). Jordan's public transportation services have not kept pace with the cities' growth, resulting in de facto traffic congestion as citizens are reliant on private cars. For example, public transportation serves around 59% of Amman's territory, while only about 37% of the whole population has access to public transportation (Al-Masaeid and Shtayat, 2016).

Strategic planning for road traffic safety is the first step in improving the situation. Although traffic safety is improving, the annual cost of traffic accidents in cities still results in significant economic losses. According to the Jordan Traffic Institute (JTI, 2022) traffic accidents cost around $415 million in 2020 to $454 million in 2022 (JTI, 2022). The UAIDs are seen as viable solutions for

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alleviating traffic congestion at signalized intersections while also improving operating efficiency and safety (Kay et al., 2022).

Previous works have been done to assess the possibility of implementing several types of UAIDs in Jordan. These studies evaluate the performance of UAIDs in different roadways and traffic characteristics (Alhadidi, 2021; Hadidi et al., 2022; Naghawi et al., 2018a; 2018b). Naghawi et al. (2018a; 2018b) conducted the first study to evaluate the performance of superstreet in Jordan. In their study, results showed that the proposed superstreet reduced the average delay per vehicle by up to 87% and reduced the maximum queue length by almost 97% (Naghawi et al., 2018a). In another work, researchers evaluated the effect of implementing four UAIDs namely, superstreet, median U-turn, single quadrant, and jughandle intersection on a major arterial road using SYNCHRO microscopic simulation software (Trafficware, 2020). Results show that the jughandle has the highest construction cost due to the associated cost of acquiring land; however, there is an increase of the average travel speed by 35%, and a decrease of the average stopped delay by 28.68% on the arterial road (Naghawi et al., 2018b). Then, a study was conducted to evaluate the operational performance of three UAIDs namely, MUT, superstreet, and single quadrant intersection using real traffic data. The authors concluded that MUT and the superstreet do not perform at their best in congested areas (Hadidi et al., 2022). The very few studies related to the implementation of UAIDs in Jordan agree that they have the ability to improve traffic operations (Alsaleh and Shbeeb, 2018; Hadidi et al., 2022; Khasawneh and Alsaleh, 2018; Naghawi et al., 2018a; 2018b). Even though all of these studies compared the performance of UAIDs using delay, travel time, queue length, number of stops, and travel speed. Yet, none of them initiate a framework to evaluate the performance of UAIDs under different conflict metrics, for example, we always aim to reduce delay but that does not grant reducing number of stops. Moreover, the notion of sustainable development is now firmly entrenched in the public consciousness, and it is becoming increasingly important to tackle transportation and environmental challenges together (Şahin, 2021).

As the transportation and environmental challenges depend on different criteria to handle the problems, the comprehensive way to solve these problems is done by utilizing Multi-criteria decision-making (MCDM). MCDM is an operation research area in which the optimal outcome is used to analyze different criteria weights, by a scientific and effective strategy, considering the weights of many indicators and use pairwise comparison in order to rate them all (Kumar et al., 2017; Yannis et al., 2020).

The Criteria Importance Through Intercriteria Correlation (CRITIC) method is one of the MCDM can be used to determine the weights of various criteria in the context of evaluating and selecting the best intersection design. This method eliminates the need for pairwise attribute comparisons and reduces the assessment process's reliance on decision makers (Gaur et al., 2022; Liu and Ma, 2019; Sujana et al., 2022; Wang et al., 2019). The CRITIC method is a subset of Multiple Criteria Decision Making (MCDM) that employs objective weighting against criteria to provide a comprehensive decision-making approach (Sujana et al., 2022). Furthermore, the CRITIC method was used to combine individual judgments into a collective choice, resulting in flexible classification schemes (Liu and Ma, 2019). The CRITIC method's objective weight is an abstract representation of the inherent relationship between all evaluation objects, providing a solid foundation for decision-making (Liu and Ma, 2019).

In this paper, the CRITIC method was used to evaluate the overall intersection performance of different traffic alternatives scenarios. In essence, different performance metrics were used for intersection efficiency, we used queue length, vehicle safety, and number of stops. While average running speed, average travel time, and average delay were used to report the intersection capacity. For environmental impact, CO emissions, and fuel consumption were used. Finally, the CRITIC technique was used to ascertain the best option of the various proposed scenarios.

Speaking of the structure of the paper, the existing literature review is presented in Section 2. In Section 3, the research methodology, data collection, the CRITIC method, and the proposed alternatives are presented. Section 4 presents the proposed conventional and unconventional solution analysis of the simulation results. It also presents the CRITIC method and the process of calculating the difference indicators' weights, and the alternative selection. Finally, Section 5 outlines the study conclusions and recommendations.

2 Literature review

The design and study of UAIDs have received much interest because of their multiplicity and ability to optimize the operational performance of traffic flow, expansively improving the capacity and safety of intersections as well as decreasing emissions. Researchers have been exploring different types of UAIDs to obtain more capacity out of congested intersections. Zhao and Ma (2021) combined the benefits of exit lanes for left-turn control (CTE) and tandem control to enhance intersections' operational efficiency under a limited number of travel lanes, and a short taper length to accumulate queued vehicles. In their work, they developed an optimization algorithm to improve intersection capacity under predefined traffic and roadway conditions (CTE design). In their proposed algorithm, they integrated the allocation of the mixed-usage lane, signal timings, and lane markings in order to maximize the intersection capacity. The results of their study reveal that the CTE design has a great potential to improve the capacity especially in low to medium volume-to-capacity ratio for the left turning traffic, as well as when the average queue length is limited (<200 m) (Zhao and Ma, 2021). In another work, researchers simulated and assessed the effect of a signalized unconventional roundabout configuration on road capacity, delay, and queue length. The study found that signalized roundabout intersections efficiently improved capacity by up to 50% in some situations, largely reduced delay, and queue duration, and maximized performance of the roundabout (Osei et al., 2021). ElKashef et al. (2021) investigated the impact of implementing unconventional intersection designs, in Cairo, Egypt, to improve the operational performance in a congested urban arterial corridor in Egypt. In their work they studied the impact of implementing two types of UAID including MUT and Superstreet. The results of their study showed that, there is substantial improvement when implementing the MUT along the corridor as compared with the current status and implementing the superstreet; where the average total delay of the corridor was minimized by 43%, and the travel time of the corridor was reduced by 39%. Moreover, the vehicular average speed along the corridor was doubled compared with the current average speed (ElKashef et al., 2021).

Khliefat et al. (2021) investigated the effect of modifying Double Continuous Flow Intersections (DCFI) layout geometric features on improving single point intersection. The authors concluded that changes to the cross-over intersection angle increase safety levels by providing better channelization of traffic movements on the minor intersections of the DCFI and reducing the intersection footprint to be used at high-density urban locations (Khliefat et al., 2021). Using vehicle traffic microsimulation tools and sweeping route analysis, Ciampa et al. (2020) compared the efficacy of unconventional design schemes to conventional solutions. The study analyzes the performance of the current state of the intersection with two design options, conventional and unconventional, in terms of average speed, queue length, time lost, vehicle maneuvering size, and so on. The obtained findings demonstrate the usefulness of unconventional designs for improving traffic and safety characteristics as well as limiting harmful emissions into the atmosphere (Ciampa et al., 2020). Other researchers investigated the UAIDs' applicability under heterogeneous traffic complexities (e.g., the diversity of some static and dynamic properties of vehicles, and aggressive driving behavior, which results in non-lane-based traffic systems). The authors in the study compared the operational efficiency of existing conventional signalized intersections with two proposed UAIDs schemes namely, the Displaced Left-Turn (DLT) intersection and Superstreet Median (SSM) intersection. It was concluded that the proposed UAIDs reduced the overall delay and the total travel time while the average speed increased. However, it was also concluded that the heterogeneous traffic influenced the proposed UAIDs' efficiency (Shokry et al., 2020). To improve the operational and safety characteristics of an existing major signalized arterial intersection in Saudi Arabia, a work investigated the efficiency of implementing an unconventional intersection design, the Double Continuous Flow Intersection (DCFI) configuration. The study found that the proposed DCFI unconventional intersection design decreased the average delay per vehicle by 99 seconds and improved the Level of Service at the intersection from level F (152 s/vehicle average delay) to level D (53 s/vehicle average delay) (Bashir et al., 2021). The safety performance of the new mega elliptical roundabout interchange was analyzed and compared with eight other interchange designs and it was concluded that the mega elliptical roundabout interchange has good safety performance compared to other interchanges studied by (Mane and Pulugurtha, 2020). Researchers evaluated the performance of three unconventional intersection designs (Median U-turn (MUT), superstreet, and continuous green T-intersection (CGT)) over existing pretimed signalized intersection design along Highway 49 in the city of Charlotte, North Carolina, USA. The results obtained indicate that the use of unconventional intersection designs could reduce the average delay per vehicle at the corridor level. However, the use of unconventional intersection designs could result in an increase in the total number of stops at the corridor level (Xiang et al., 2016).

In recent years, there has been little valuable research work undertaken to discuss methods of evaluating different UAIDs and selecting the most suitable design such as the multi-criteria decision making (MCDM). MCDM entails maximizing one or more objective functions across a defined set of solutions corresponding to the many alternatives available, where the objective refers to the system condition under consideration. In the field of transportation, MCDM methods are the most commonly utilized methodologies to aid decision making. The AHP technique has been used extensively to solve practically all forms of transportation issues.

Chaipanha et al. (2018) conducted a study to evaluate the effect of median U-turns on multilane primary highway capacity in Thailand. Their research focused on using traffic micro-simulation models to estimate the impact of median U-turns on driving behavior and highway capacity. This study is particularly relevant as it directly addresses the evaluation of median U-turns on highway capacity, which is a key aspect of the multi-criteria decision-making process in transport engineering (Chaipanha et al., 2018). In addition, Al-Sahili et al. (2018) investigated and modeled illegal U-turn violations at medians of limited access facilities. While their study primarily focused on predicting and analyzing the contributing factors to crossover crashes resulting from intentional illegal U-turn violations, it provides valuable insights into the safety implications of median U-turns. Understanding the safety aspects is essential when evaluating median U-turns using multi-criteria decision-making, as safety considerations are one of the critical criteria in the decision-making process (Al-Sahili et al., 2018). Furthermore, Dong et al. (2015) applied the analytic hierarchy process (AHP) to evaluate intelligent U-turn behavior of unmanned vehicles. Although their study is not directly related to highway capacity or traffic engineering, it highlights the application of AHP in evaluating U-turn behavior, which can be relevant in the context of multi-criteria decision-making for median U-turns. AHP is a commonly used method in MCDM, and understanding its application in evaluating U-turn behavior can provide insights into the decision-making process for median U-turns (Dong et al., 2015). Moreover, Alluri et al. (2016) conducted a study on the safety impacts of converting two-way left-turn lanes to raised medians and associated design concerns. While their research focused on a different type of median (raised medians), it provides valuable insights into the safety implications of median modifications, which are essential considerations in the evaluation of median U-turns using multi-criteria decision-making. Safety performance is a critical criterion in MCDM, and understanding the safety impacts of median modifications can inform the decision-making process for median U-turns.

3 Methodology

In this section, the proposed research methodology is presented. In fact, in order to develop this research, we followed two methodological approaches, namely, traffic simulation modeling and CRITIC method.

3.1 Simulation modeling and decision matrix

Traffic simulation modeling aims to mimic the operational performance at intersections. It needs collecting the required geometric and traffic data to develop the base model. Intersection performance is defined as a set of factors, each defined by a set of related factors or metrics.

One of the very well-known and widely used software is VISSIM (PTV, 2022) which is used in this work. The VISSIM microsimulation system was created by the PTV firm. Vehicle locations are updated every 0.1–1 seconds in Vissim, which simulates traffic volumes. Private cars, public transportation, and pedestrians are all part of the traffic types that VISSIM can simulate. Many advanced signal timing schemes, such as ramp metering, variable speed messages, variable speed limits, and route guidance, made extensive use of VISSIM in the modeling efforts. For the purpose of controlling the signals in a multimodal network, it is necessary to model traffic that uses multiple modes of transportation, such as Light Rail Transit (LRT), buses, and trams (Fellendorf and Vortisch, 2010).

In fact, to evaluate the operational performance of any intersection, intersection efficiency, capacity and the environmental impact should be assessed using different metrics. Speaking of intersection efficiency, we used average stopped delay, and vehicle safety. While intersection capacity was evaluated using average travel time, average control delay, and running speed; meanwhile, the intersection's environmental impact was measured using CO emission and Fuel consumption. The operational performance evaluation matrix is illustrated in Fig. 1.

Over and above these metrics, the safety factor is a major criterion for evaluating the different alternatives to improve operational performance. Traffic safety is a major criterion to report traffic safety performance.

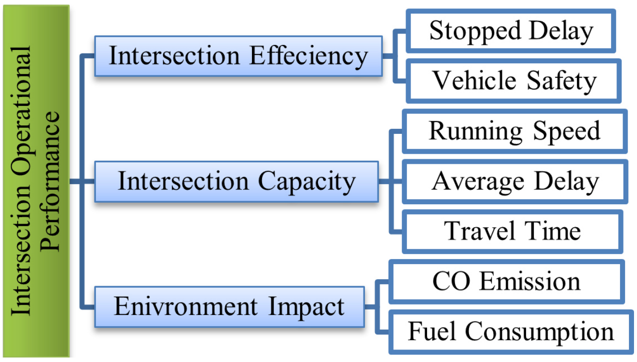

Fig. 1 Intersection operational evaluation matrix

3.2 Framework

Considering this, improving intersection performance to satisfy transportation system performance measures such as efficiency, effectiveness, safety, energy, and environmental compatibility helps achieve a more sustainable transportation system in a developing country, such as Jordan. Intersections in Jordan suffer from long queue lengths, excessive delays, high travel time, higher emissions, and high fuel consumption (Abojaradeh et al., 2014). The framework of this paper was presented earlier in Fig. 2. First, traffic data were collected and used to model the base scenario using VISSIM. Validation and calibration of the existing model were conducted before suggesting any possible alternative. In total, five alternatives were suggested based on their feasibility of design and acceptance by both network travelers and decision-makers. These five alternatives have different geometric and traffic signal controlling. In essence, the variation was handled by using geometric design characteristics for the conventional intersection. While the optimum signal timing and phasing scheme for signal control was done using VISSIM Signal Optimization. Afterward, eight metrics were selected by reviewing state-of-the-art, executors, and researchers' opinions. Then, we asked four practitioners and five academicians in the field of transportation to determine the weight for each metric. The average weight was used along with the results from VISSIM in order to rank the different proposed scenarios and select the best performance analysis.

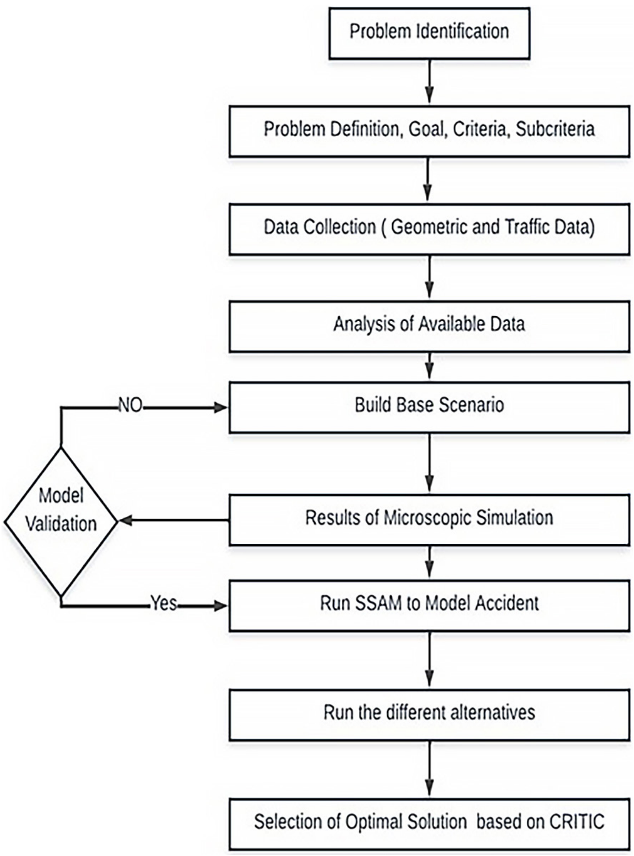

Fig. 2 Research framework

3.3 Criteria importance through intercriteria correlation (CRITIC)

CRITIC method overcomes different types of MCMD by its ability to disregard the attributes' independency and the ability to transform the qualitative attributes to quantitative ones.

The core notion of CRITIC method is to establish the objective weights of the indicators on two key concepts:

1. The first concept is the contrast intensity, which represents the extent of the difference in standard deviation between the results of each proposed alternative for the same indicator. In other words, the standard deviation value represents the magnitude of the difference between the values of each alternative considering the same criterion. The greater standard deviation indicates the greater difference between the values of each scheme.
2. The second concept is the conflicting character of the assessment criteria, which is determined by the correlation between indicators. For example, a significant positive correlation between indexes implies that the conflicting nature of two indicators is minimal.

   Based on the contrast intensity of the evaluation indicators and the conflicting nature between them, the CRITIC technique gives a complete estimate of the objective weights of indicators. It considers the magnitude of the variability of the indicators as well as the correlation between the indicators, implying that the results are not evaluated solely on the largeness of the number, but that the objective properties of the data are fully utilized to ensure scientific and comprehensive evaluation. Hence, it is reasonable to utilize the CRITIC method to assign the weights of indexes such as delays, number of stops, number of cars, CO emissions, and fuel consumption.

Essentially, the CRITIC method consists of four different stages for identifying the weight and ranking of the different attributes. In essence, CRITIC method uses the correlation coefficient between the different attributes in order to obtain and assign the relation between the different attributes. The general steps of the CRITIC method are presented in the following subsections.

3.3.1 Calculation of weighting of indicators

The simulations were conducted for five considered timing scenarios. Seven indicators were chosen for the analysis. Therefore, each solution had its own set of simulation outcomes.

Step 1: The matrix A_i as shown in Eq. (1), summarizes all simulation results for each solution.

$$A_i = \{Q_i, D_i, SD_i, TT_i, S_i, E_i, F_i, Saf_i\} \tag{1}$$

Where i stands for the scenario number ($i = 1, 2, 3, 4, 5$), $\boldsymbol{Q}$ stands for average queue length, $\boldsymbol{D}$ stands for vehicle delay, $\boldsymbol{SD}$ stands for stopped delay, $\boldsymbol{TT}$ stands for travel time, $\boldsymbol{S}$ stands for number of stops, $\boldsymbol{E}$ stands for carbon monoxide emissions (CO), $\boldsymbol{F}$ stands for fuel consumption, and $\boldsymbol{Saf}$ stands for safety.

Step 2: There will be five matrices $\boldsymbol{A_1}$, $\boldsymbol{A_2}$, $\boldsymbol{A_3}$, $\boldsymbol{A_4}$, and $\boldsymbol{A_5}$ that show the simulations' outcomes for each scenario that can then be summarized into matrix $\boldsymbol{X}$ (Eq. (2)) which is a 5 × 7 matrix. Using the CRITIC method, the weight of each index can be calculated as shown in the following procedure.

$$X = \begin{Bmatrix} Q_1, D_1, SD_i, TT_i, S_1, E_1, F_1, Saf_i \\ Q_2, D_2, SD_2, TT_2, S_2, E_2, F_2, Saf_2 \\ Q_3, D_3, SD_3, TT_3, S_3, E_3, F_3, Saf_3 \\ Q_4, D_4, SD_4, TT_4, S_4, E_4, F_4, Saf_4 \\ Q_5, D_5, SD_5, TT_5, S_5, E_5, F_5, Saf_5 \end{Bmatrix} \tag{2}$$

To begin, each element in the matrix $\boldsymbol{X}$ is represented by $\boldsymbol{y_{ij}}$, where i stands for the scenario number, n stands for total number of scenarios, j stands for the index, and m stand for total number of indexes. For the considered indexes it is expected to be low. Hence, the indexes can be normalized as in Eq. (3). Then the various indexes have distinct scales that must be transformed into a consistent scale for comparison. They must be normalized as in Eq. (4) where $i = 1$ to n, and $j = 1$ to m.

$$y'_j = \begin{Bmatrix} \max\left(y_{1j}, y_{2j}, y_{3j}, y_{4j}, y_{5j}, y_{6j}, y_{7j}\right) - y_{1j} \\ \max\left(y_{1j}, y_{2j}, y_{3j}, y_{4j}, y_{5j}, y_{6j}, y_{7j}\right) - y_{2j} \\ \max\left(y_{1j}, y_{2j}, y_{3j}, y_{4j}, y_{5j}, y_{6j}, y_{7j}\right) - y_{3j} \\ \max\left(y_{1j}, y_{2j}, y_{3j}, y_{4j}, y_{5j}, y_{6j}, y_{7j}\right) - y_{4j} \\ \max\left(y_{1j}, y_{2j}, y_{3j}, y_{4j}, y_{5j}, y_{6j}, y_{7j}\right) - y_{5j} \end{Bmatrix} \tag{3}$$

$$y''_{ij} = \frac{y'_{ij} - \min\left(y'_{1j}, \ldots, y'_{7j}\right)}{\max\left(y'_{1j}, \ldots, y'_{7j}\right) - \min\left(y'_{1j}, \ldots, y'_{7j}\right)} \tag{4}$$

After which the standard deviation is calculated for each scenario to represent the variability of each scenario as in Eq. (5).

$$S_j = \sqrt{\frac{\sum_{i=1}^{n}\left(y''_{ij} - \overline{y}''_j\right)^2}{n-1}} \tag{5}$$

In the CRITIC approach, the standard deviation is utilized to represent the difference and variation of the values taken within each index. A larger standard deviation value implies a greater difference in the index's values, more information that may be represented, and a stronger assessment intensity of the index itself, implying that the index should be given more weight.

Following that, a symmetric matrix with dimensions $m \times m$ and a generic member $\boldsymbol{r_{j,k}}$, which is the linear correlation coefficient between vectors $\boldsymbol{x_j}$ and $\boldsymbol{x_k}$, is built. Then, using Eq. (6), the measure of conflict $\boldsymbol{R_j}$ is computed.

$$R_j = \sum_{k=1}^{m}\left(1 - r_{jk}\right) \tag{6}$$

Next, the amount of information $\boldsymbol{C_j}$ is calculated as in Eq. (7). The more information conveyed by the related index, the greater its relative value in the decision-making process, that is, ***a*** higher evaluation weight. Then, the objective weight is calculated as in Eq. (8).

$$C_j = S_j \times R_j \tag{7}$$

$$w_j = \frac{C_j}{\sum_{k=1}^{m} C_k} \tag{8}$$

3.3.2 Evaluation of solutions

Each solution may be assessed comprehensively based on the weights of the various indexes. Starting by computing the ratio between the value of i-th solution to the sum value of all solutions for the j-th index as in Eq. (9).

The score of the i-th solution is computed as in Eq. (10), and the total score is computed as in Eq. (11).

$$p_{ij} = \frac{y''_{ij}}{\sum_{i=1}^{n} y''_{ij}},\ j = 1 \text{ to } 7 \tag{9}$$

$$z_{ij} = w_j \times p_{ij},\ i = 1 \text{ to } 5,\ j = 1 \text{ to } 7 \tag{10}$$

$$z_i = \sum_{i=1}^{7} z_{ij},\ i = 1 \text{ to } 5,\ j = 1 \text{ to } 7 \tag{11}$$

3.4 SSAM

The Federal Highway Administration developed the Surrogate Safety Assessment Model (SSAM) tool that predicts road safety using vehicle trajectory data. This tool is commonly used by analyzing the VISSIM produced trajectory files in which SSAM is able to report the types and frequency of crashes. Also, it reports time to collision, speed to collision, and other safety parameters. SSAM technique combines both microscopic simulation and automated conflict analysis. SSAM reports traffic accidents status using three metrics; time-to-collision, post-enforcement time, and rear-end and crossing angles.

3.5 Site description and data collection

To achieve the purpose of this study, the highly congested Al-assaf intersection on Wasfi Altal Street in Amman was selected, as shown in Fig. 3. It is considered one of the most critical arterial roads in Amman because it carries traffic volumes between the most attractive areas such as the Khilda, and Tla'a AlALi.

The Al-Assaf intersection (31°59'45.0"N 35°51'34.8"E) is a four-leg intersection. It consists of four crossing arterial roads, Wasfi Al-Tal (East and West), Al-Muhammadiyah Street (North) and Mirza Wasfi (South), as shown in Fig. 4. All these major roads are divided into four lanes with a width of 3.4 meters along the length of the road.

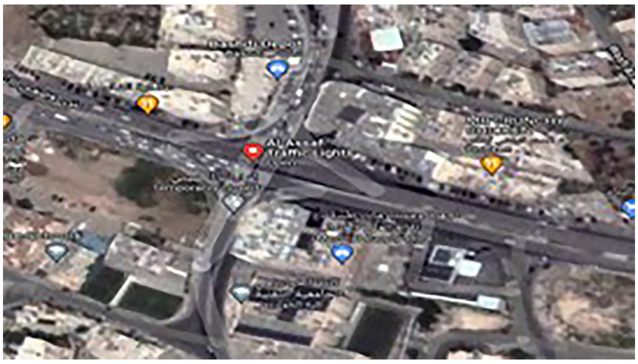

Fig. 3 Aerial view of the selected site

Moreover, at the stop line, each approach contains three lanes of 3.2 meters in width and has a free right from all the intersection approaches. The key traffic data were collected from the traffic operations department at Greater Amman Municipality (GAM), and traffic composition was collected from the field. Traffic data were gathered at the intersections on Tuesday, November 2, 2021. The data included traffic volumes for each direction, including all turning movements, and percentages of heavy vehicles (HV%) as shown in Table 1.

3.6 Model validation

Model validation is an important check to verify the similarity between the simulation model and reality. This process is conducted through visual or statistical models; visual validation such as the verification of vehicle paths, vehicles stopping at signals, and reduced speed areas. At the same time, the statistical validation method uses several statistical metrics to quantify the difference between the observed and the simulated values (Hadidi et al, 2022). Therefore, for this study's purpose, a comparison between the VISSIM generated traffic volumes and the observed volumes was conducted using the most popular goodness of fit measure. These measures are the GEH empirical test (Eq. (12)) and the Root Mean Square Percent Error (RMSPE, Eq. (13)). The GEH statistic is a formula used in traffic modeling to compare two sets of traffic volumes, such as simulation with real-world traffic volumes (Alomari et al., 2016). This formula is usually used instead of simple percentages to compare two sets of volumes because there is a wide range of variation in the traffic volumes in real-world transportation systems.

$$\text{GEH} = \sqrt{\frac{2(M - C)^2}{M + C}} \tag{12}$$

Where C is the real-world hourly traffic count and M is the hourly traffic volume from the traffic model.

$$\text{RMSE} = \sqrt{\frac{(\text{Observed value} - \text{Simulated value})^2}{\text{Simulated value}}} \tag{13}$$

The threshold of using GEH and the RMSE are 5% and 15%, respectively (Hadidi et al., 2022). Several runs were tested. The simulated traffic volumes for these runs are summarized in Table 2. Based on Eq. (19) and Eq. (20), the GEH and RMSPE tests were calculated. The results indicate that the model replicates reality with high accuracy. Speaking of SSAM validation, according to the SSAM manual, as long as VISSIM model is valid, SSAM model is valid as well (Gettman et al., 2008).

Fig. 4 Proposed alternatives: (a) current status, (b) alternative 1, (c) alternative 2, (d) alternative 3, (e) alternative 4, and (f) alternative 5

Table 1 Traffic counts

Approach	Eastbound		Westbound		Southbound		Northbound	
	Through	Left	Through	Left	Through	Left	Through	Left
Volume (Vph)	1370	360	862	449	192	237	670	368
H.V		3.5%		4.5%		2.6%		4.5%

3.7 Alternatives

In this section, the proposed alternatives are presented with their geometric design and the traffic signal timing and traffic movement. Based on Fig. 4, different possible scenarios were proposed to modify the traffic on the AlAssaf intersection using grade separation. A total of six possible alternatives were proposed based on the current situation. These alternatives are presented in Table 3.

Based on the available data, the different alternatives were modeled using AutoCAD (Autodesk, 2022). The developed geometric characteristics were imported as background on VISSIM. The different scenarios were developed mainly

Table 2 Simulated counts

Run	Simulated count	RMSE	GEH
1	4480	0.42	0.42
2	4501	0.10	0.10
3	4507	0.01	0.01
4	4490	0.27	0.27
5	4550	0.63	0.62
6	4520	0.18	0.18
7	4495	0.19	0.19
8	4498	0.15	0.15
9	4506	0.03	0.03
10	4490	0.27	0.27

from four different geometric scenarios, namely: conventional (low-cost), grade separation with signalized intersection (high-cost), grade separation with roundabout (high-cost), and unconventional intersection design. The geometry of the proposed model is shown in Fig. 4.

Fig. 4 (a) shows the geometry of the current intersection. Fig. 4 (c) illustrates the geometry of the grade-separation. This design accommodates the through traffic along the main street using grade separation while the rest of the movements at the intersection are controlled by a signalized intersection. Fig. 4 (d) illustrates the conventional scenario that accommodates the through traffic using the grade separation and the rest of the intersection movements are served using a roundabout. Fig. 4 (e) shows the geometric design of the MUT. This design mainly removes all left turn traffic from the main intersection for both major and minor roads. Left turn movements are converted to right turns at the intersection then, using a unidirectional median crossover to make a U-turn on the major highway, drivers may complete their change in direction. It includes multiple signal illustrations (typically three, one for main intersection (controlled by a 2-phase cycle) and one (coordinated) for each of the two median crossovers) as shown in Fig. 4 (f).

4 Results and discussion

In this section, both the results of the proposed alternatives using VISSIM and the CRITIC method on the different proposed alternatives are presented.

4.1 VISSIM results

Performance values were obtained from microsimulation by considering vehicle delay, queue length, stopped delay, no. of stops, travel time, vehicle safety, CO emission, fuel consumption and total number of accidents for the different intersection alternatives designs. These measures are illustrated in Table 4.

The findings shown in Table 4 demonstrate that, in comparison to the various options, the current scenario exhibits the most prolonged delay, stopped delay, maximum fuel usage, and minimum speed. When considering delay, it is worth noting that the delay in the various alternatives is reduced compared to the current state. Specifically, the delay per vehicle in the alternative scenarios ranges from 3.86 to 131.05 seconds, with Alternative 3 exhibiting the most substantial enhancement. Between Alternative 3 and the present, the number of stops per vehicle varies from 0.19 to 3.45. This indicates that traffic flow has been significantly improved since Alternative 3 has significantly decreased the number of vehicles stops. The provided options result in an increase in the mean velocity from the present 10.06 km/h to a range of 26.36 to 56.7 km/h. Alternative Three maintains its position as the fastest, indicating a significantly accelerated flow of traffic. In contrast to the present circumstance, which requires 914657 seconds, the aggregate travel time has diminished for every option, with Alternative 5 exhibiting the shortest travel duration of 163446 seconds.

In comparison to the current condition, which requires 4.9 seconds, the stopping wait has been drastically decreased in the alternative scenarios, with Alternative 5 requiring the least time at 0.98 g/km. In the

Table 3 Proposed alternatives

Scenario	Geometric	Traffic	Description
A0	As is	As is	In this alternative, the current status is evaluated.
A1	As is	Increase cycle length	In this alternative, an increment in cycle length.
A2	Grade separation	Signalized	Convert the major road to grade separation and control the rest of the movements by signal.
A3	Grade separation	Roundabout	Convert the major road to grade separation and control the rest of the movements by roundabout
A4	MUT	Signalized at the main	Convert the intersection to Median-U-Turn and control the traffic by priority rule at the crossover.
A5	MUT	Signalized as a corridor	Convert the intersection to Median-U-Turn and control the traffic by signalized intersection at the crossover.

Table 4 VISSIM results

Alternative	Delay (s/vehicle)	Stops	Speed (km/h)	Travel time (s)	Stopped delay (s/vehicle)	Emission g/km	Fuel consumption (l/km)	Total number of accidents
Current situation	155.03	3.45	10.06	914657	22.78	4.8	0.06	2327
Alternative 1	131.05	2.45	15.4	325365.5	20.32	4.9	0.058	2688
Alternative 2	11.4	0.39	26.36	220684	11.38	2.32	0.016	2393
Alternative 3	3.86	0.19	56.7	180873	12.8	3.2	0.05	2339
Alternative 4	10.67	0.36	38.37	180892	5.07	1.8	0.04	1549
Alternative 5	6.86	0.28	42.44	163446	2.4	0.98	0.05	1534

alternative, there has been a marginal reduction in emissions. At 0.98 grams per kilometer, Alternative 4 may have a reduced environmental impact due to its lowest emission value. At 0.05 liters per kilometer, Alternative 3 has the lowest fuel use per car, indicating that it is the most fuel-efficient scenario. All alternative scenarios result in a decrease in the overall incidence of accidents. With a mere 1534 accidents as opposed to the present 2327, Alternative 5 exhibits the most substantial improvement. Considering the aforementioned factors, Alternative 3 emerges victorious due to its minimum delay, minimum number of stops, minimum stopped delay, and maximum speed. Contrary to this, the remaining indicators show preference for different alternatives.

4.2 CRITIC method

We collected the data requiring us to assign the criteria weights using an online questionnaire. Furthermore, the size of the expert group has an inverse relationship with the importance of expert competency in group decision making (Taylan et al., 2016). The number of specialists involved in the decision-making process affects the final result. Therefore, it is imperative that the appropriate number of competent experts be chosen in order to ensure consensus during the decision-making process. Research generally shows that a smaller expert population facilitates more efficient participation and faster expert consensus (Nixon et al., 2010). In our questionnaire, they were asked to score each sustainability criterion's importance and compare the criteria pairwise. The rating system is based on Saaty's scale (Saaty, 1987). Table 5 summarizes sample of respondents' information.

In the CRITIC method, the best alternative is selected based on a pairwise comparison between the different criteria. Specifically, CRITIC starts with normalizing the different criteria to the difference between the best and worst value for each criterion. In this study context, vehicle safety is the best value for the delay with the lowest value, while the worst value for the delay is the highest one. Afterward, the weighted normalized weighted matrix was computed using Eqs. (1)–(6). These weights are shown in Table 6.

Table 5 Sample of respondents' information

Expert number	Gender	Field	Educational level	Experience	Most important factor	Least important factor
1	Female	Academia	Ph.D.	0–5 years	Safety	Delay
2	Female	Industry	Master of engineering	10–15 years	Safety	Delay
3	Male	Industry	Master of science	10–15 years	Safety	Travel time
4	Female	Academia	Ph.D.	10–15 years	Safety	Delay

Table 6 Normalized decision matrix

	Delay	Stops	Speed	Travel time	Stopped delay	Emission	Fuel consumption	Total number of accidents
Delay	1.00	0.99	0.85	0.83	0.87	0.88	0.62	0.56
Stops	0.99	1.00	0.85	0.89	0.87	0.86	0.60	0.52
Speed	0.85	0.85	1.00	0.72	0.70	0.64	0.17	0.47
Travel time	0.83	0.89	0.72	1.00	0.75	0.68	0.47	0.34
Stopped delay	0.87	0.87	0.70	0.70	1.00	0.98	0.42	0.85
Emission	0.88	0.86	0.64	0.64	0.68	1.00	0.53	0.82
Fuel consumption	0.62	0.60	0.17	0.17	0.47	0.53	1.00	0.09
Total number of accidents	0.56	0.52	0.47	0.47	0.34	0.82	0.09	1.00

After computing the normalized matrix, using Eqs. (7)–(11) the different alternative weights were computed. Final weights for the different criteria are shown in Table 7.

Table 7 shows the different attributes' weight, according to the computed values, the most critical attribute is the fuel consumption with a weight of 0.21, and stopped delay, delay and stops are the least critical values as they have the lowest value of 0.08. Using the results from the microscopic simulation in Table 4 and the weights in Table 7, the weight for the different alternatives is shown in Table 8.

Table 8 shows the different total weights for the proposed alternatives using the CRITIC method. Results indicated that the best alternative is Alternative 5, while the worst alternative is the current status.

Several proposed alternatives were examined in this study to improve the AlAssaf intersection, one of the most heavily used and most important intersections in Amman, Jordan. The most efficient alternative was chosen based on microscopic simulation and CRITIC method since choosing the best alternative is a multicriteria problem. According to the different CRITIC method, the current geometric and signal status in the corridor was observed to be the worst compared with the other suggested alternatives. Using the results from the microscopic simulation, the different MCDM showed that Alternative 5 and Alternative 4 are better than the current situation to provide a sustainable solution that accounts for operation and environmental aspects.

Table 7 Different alternative weights

Criterion	Weight
Delay	0.08
Stops	0.08
Speed	0.13
Travel time	0.12
Stopped delay	0.08
Emission	0.10
Fuel consumption	0.21
Total number of accidents	0.20

Table 8 Alternatives ranking

Alternative	Weight
Current situation	106.881.98
Alternative 1	38.403.91
Alternative 2	26.157.77
Alternative 3	21.519.32
Alternative 4	21.360.12
Alternative 5	19.327.59

5 Conclusions

In this study, an evaluation of improvements at the AlAssaf intersection were studied, which is one of the most dense and critical intersections in Amman. The evaluation was conducted based on using the integration between the microscopic simulation and the CRITIC method. Comprehensive scientific and strategic solutions were proposed and tested using microscopic simulation to solve the congestion problem in the area. The proposed methodology helps in obtaining a sustainable solution. The evaluation criteria in the study were vehicle delay, queue length, stopped delay, number of stops per vehicle, travel time, vehicle safety, CO emission, fuel consumption, and the total number of accidents. The most important criterion was safety, and the least essential criterion was vehicle stops. Microscopic modeling was carried out using real traffic counts along the corridor. The different suggested alternatives were evaluated using microscopic simulation. According to the results from microsimulation and different MCDM methods, the best alternative to improve the current intersection is Alternative 5 which is constructing a MUT intersection and controlling the crossing U-Turn opening by traffic signal.

As a result of these improvements, it will be possible to achieve a more sustainable transportation system by considering different criteria. It is anticipated that this improvement will help in reducing traffic congestion, reducing fuel consumption, and improving mobility. Furthermore, if the most superior design analysis is implemented on a large scale, it could present a possible solution to the metropolitan cities problems (environmental and noise pollution, waste of time, fuel consumption) caused by vehicles.

The methodology for selecting the optimal reconstruction solution presented in this paper is applicable to different segments of the urban traffic network of larger and smaller cities and should be validated in future research. A potential challenge for the future is the application of the developed methodology to a wider urban area with more complex traffic and spatial situations. A potential issue is whether the large area should be analyzed as one zone or divided into smaller network segments. As for the traffic microsimulation, one larger zone would give a better understanding of the future functionality of the network and the implications of the reconstruction for the whole area.

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