Ghazi M. MAGABLEH, Ph.D.[1]
(Corresponding author)
E-mail: ghazi.magableh@yu.edu.jo
Ahmad A. MUMANI, Ph.D.[1]
E-mail: ahmad.mumani@yu.edu.jo
[1] Yarmouk University, Industrial Engineering Department
Shafiq Irshidat st, 21163, Irbid, Jordan

Traffic Engineering
Original Scientific Paper
Submitted: 20 Mar. 2021
Accepted: 16 July 2021

SIMULATION BASED-MCDM APPROACH FOR EVALUATING TRAFFIC SOLUTIONS

ABSTRACT

Traffic congestion problems have dramatically escalated with the increasing volume of vehicles, pedestrians, and cyclists in the face of limited road capacity. This research aims to reduce the time road users spend in the system (school-zone area) and improve the efficiency of the process of dropping off and collecting children from a crowded school area. The study integrates discrete-event simulation (DES) and multi-criterion decision-making (MCDM) techniques to comprehensively evaluate the proposed alternatives to select an optimal solution based on many performance measures. A real-world case study of the traffic and congestion problems experienced by parents when they drop off and fetch their children from school during peak hours is presented. A heuristic algorithm was developed to simulate the random and unpredictable behaviour of road users. A cost-benefit analysis considered the impact of waiting time, traffic density, number of accidents, additional fuel expenses, and emission reduction. The technique for order of preference by similarity to ideal solution (TOPSIS) and preference selection index (PSI) methods were utilised to select the most appropriate option for parents. The study found that the integration of simulation techniques with MCDM methods could efficiently solve traffic problems.

KEYWORDS

traffic simulation; discrete optimisation; MCDM; TOPSIS; PSI; traffic solutions.

1. INTRODUCTION

Solving traffic-related problems is vital in reducing the number of casualties, costs, wasted time, and the social impact of traffic accidents. A number of researchers have attempted to calculate and predict the current and future traffic flow congestion in roads and networks [1–3]. However, many difficulties have been encountered due to the complexity, ever-changing traffic flow, network-limited capacity, unprecedented increase in the number of vehicles, population growth, poor traffic data, unpredictable driver behaviour, and the increasing volume of cyclists and pedestrians. Traffic becomes even more complex in school areas due to the random actions of students, the limited drop-off and pick-up points, and the behaviour of parents trying to get their children to school on time.

In school zones, there are several factors that greatly affect the performance, efficiency, and effectiveness of traffic control devices. These factors include driver behaviour, environment, weather and visibility, traffic rules and regulations, and roadway geometry [4]. Students who walk to school often have to contend with the traffic and other distractions. The development of infrastructure and facilities strive to create a safer environment for school children, but road users' activities also need to be considered [5]. Transportation officials, city governments, and residents are all concerned with pedestrian safety near schools. Indeed, many countermeasures – such as school-zone speed limits – are commonplace around schools, providing safer areas for school-aged children [6]. Moreover, during peak commuting times, enhancements that would effectively provide a protected zone for children are especially important to consider [7].

There is a great deal of concern and myriad safety measures for children traffic safety and a need to quantify the degree of risk and develop safety evaluation criteria for school zones [8]. Conversely, main streets, side roads, and speed-restricted areas have all been found to be more vulnerable to high concentrations of pollution for children who are on their way to school [9]. Improving enforcement and community awareness have been critical for the long-term decline in school-related traffic fatalities [10]. Driving violations, jaywalking, and disputes between pedestrians and cars, are among the issues that have been raised in school zones [11].

The installation of different traffic safety facilities has been known to reduce accidents in school zones [12].

Traffic accidents are affected by urban infrastructure and other risk factors, and are more likely to occur in areas with more hospitals, people, or schools [13]. Owing to the higher presence of school-aged pedestrians and cyclists, as well as potential speeding problems, traffic accidents in suburban school zones are a serious safety concern [14]. The drivers' behaviours – that is, their response to the presence of pedestrians and their speed – are factors that reduce accidents for drivers (both familiar and unfamiliar) in school zones [15]. Simulation is commonly used to evaluate safety and determine the risks of segment and intersection crashes [14, 16].

The problems faced by users in the school zone under investigation include chaos, randomness, and the extended time employees have to spend in the area, causing them and parents to be late for their respective jobs. In addition to traffic congestion and the resulting pollution, accidents and delays in the on-time arrival of school and university students to their classes increases the system complexity, with congestion also being reflected in nearby city streets and university campuses.

The primary aim of this study is to reduce the delays and improve the efficiency of the process of dropping off and fetching children. The following summarises the contributions and novelty of our research. First, the area under study is unique and complex, representing a school district within the boundaries of a national university, namely Yarmouk University. Yarmouk University has more than 45,000 students and staff members. Because there are no school buses, more than 5,000 vehicles enter and leave the main gates daily. The study area is also unique because it has eight main gates of less than 250 m in length and because delays – especially during peak periods in the morning and evening – are its primary concern, rather than accidents and their consequences. Second, although previous research used different tools and techniques – including simulations, mathematical models, analytical, and statistical analyses – to examine traffic-related problems, valuable engineering and managerial tools – such as multi-criterion decision-making (MCDM) and lean techniques – were not utilised. To support long-term continuous improvement and develop consistent efficiency and quality, such techniques could help to identify and eliminate real problems, minimise waste – that is, anything without added value, such as unnecessary delays, traffic signs, circles, or intersections – and maximise throughput. To the best of our knowledge, this is the first study to use two MCDM techniques – that is, the technique for order of preference by similarity to ideal solution (TOPSIS), and the preference selection index (PSI) – to support the decision-making process in solving road traffic problems in urban and school districts. Third, we used a hybridisation of simulation and MCDM techniques to develop an ideal solution. Fourth, our study is based on complex real-world problems such as limited solutions, randomness in the behaviour of pedestrians and drivers, and the lack of compliance with traffic rules during peak hours.

This study attempts to answer two research questions based on our objectives. First, can MCDM be an effective tool for analysing traffic problems and evaluating alternatives to arrive at the best solution? Second, what solution is the best fit for such complex traffic problems where solutions are limited due to various constraints?

Based on an analysis of the data, the key causes of congestion include a large volume of incoming vehicles, road user behaviour caused by rush-hour and related time pressures, and two-way streets. Because the problem only occurs for two hours a day during peak hours – that is, a total of 500 hours per year (6% of the total hours in a year), the solution caters for worst-case scenarios. A solution is necessary because everyone must arrive at their workplace in time. This case supports the meaningful and practical experimental results beyond simply academic interest.

The remainder of this paper is organised as follows. Section 2 presents related literature. Section 3 describes the study's research methodology. Section 4 discusses the system modelling, including the system description, input data analysis, and simulation system. Section 5 analyses the results, alternative solutions, and evaluates the alternatives using DES-PSI and DES-TOPSIS techniques. Finally, Section 6 concludes the paper and presents future research suggestions.

2. LITERATURE REVIEW

Traffic flow congestion occurs when the traffic density (TD) is greater than the capacity of a road or a network, with congestion in urban areas usually expanding into neighbouring roads. Efficient use of current road networks can only be achieved by adopting innovative solutions and management systems for cities and areas where additional road construction and expansion may be restricted. Traffic flow at intersections is traditionally controlled and regulated using traffic signs and/or traffic lights that limit the maximum capacity at an intersection at the expense of increasing discomfort due to numerous idling intervals and delays [17].

Traffic congestion has been extensively discussed by researchers and several solutions have been proposed. A short-term traffic congestion algorithm to predict current and future traffic streams was used to demonstrate the effectiveness of the proposed solution on real traffic data. The travel time between two locations may not be comparable in terms of distance and variability, both dynamically and stochastically over time [18]. A Markov decision process for estimating the probability distribution of travel times was proposed. Experiments were conducted using real data from a Singapore logistics company, and the solution was based on Monte Carlo simulations [19]. A solution based on incentives to reduce congestion during peak hours by shifting the traffic load to less congested times and reducing the cost of congestion measured in terms of time spent in the system [20]. An algorithm that dynamically partitioned congested networks into small segments and formulated the problem as a mixed-integer program was developed, solving for the minimum metric value and merging neighbouring congested areas [21].

Traffic simulation is considered to be one of the most complex systems because of the difficulty in modelling driving behaviour, interaction, and disorganised traffic. Research studies utilising multi-agent simulation of disorganised traffic to assess traffic flow [22], proposed micro-simulation to analyse numerous congested traffic situations on two-way streets [23], and introduced a new traffic simulation environment using Traffic3D, a platform to efficiently evaluate different traffic scenarios [24]. Moreover, an online microscopic traffic simulation model was developed to imitate driving behaviour and investigate traffic parameters in a dynamic environment [25]. Other studies used a combination of simulation and extreme value theory to evaluate traffic safety in urban intersections [26]. Simulations have proven to be efficient for analysing traffic problems and evaluating their solutions.

To increase school-zone operations in terms of traffic efficiency and safety, school-zone traffic management solutions should incorporate standardised procedures that target driver awareness [27]. It is important to install equipment and a sufficient degree of school zones protection, such as protective fencing, skid proofing, and speed cameras. Protective fences have shown to be effective in school zones [2].

Vehicle emissions are a major source of pollution [3, 28, 29], and so carbon dioxide emissions should be part of any performance evaluation model [30]. There are several technical considerations that can reduce emissions and improve safety [31–33]—for example, the COVID-19 lockdown improved air quality [34]. Consequently, finding a solution and an appropriate methodology for measuring environmental issues is critical [31, 34, 35]. Furthermore, the cost of congestion is very high when measured in terms of wasted time and fuel by drivers and vehicles, respectively, in addition to the effects of pollution [36].

Traffic effectiveness measures in school zones include average speed, relative speed difference, and acceleration standard deviation [4, 60]. Measures should focus on preventing severe injuries and fatalities due to vehicle accidents. Multiple stakeholders should be involved in safety plans, emphasising a collaborative and integrative approach [37]. The impact of various countermeasures on school-zone safety can be assessed using simulation modelling [38]. A driving simulator is an effective tool for evaluating traffic control devices deployed in school zones [4, 39].

The TOPSIS method is used for decision-making and as an evaluation tool to assess and rank alternatives [40]. It is a multiple-criteria decision-making technique for ranking preferences through similarity to find the best solution among a limited set of alternatives. TOPSIS is also used to provide a basis for calculating the rank of lean policies [41]. Moreover, fuzzy TOPSIS has been used to choose the best lean policy and generate rankings [42], evaluate the criteria and weights of alternatives to obtain an optimal solution and rank alternatives [43], select optimal solutions and to rank projects [44], and prioritise and order solutions [45]. TOPSIS can be used to improve traditional weight calculations, ignoring the vagueness of the decision-making processes.

The PSI method was used to calculate the overall preference values of alternatives and is considered to be effective when there is conflict in determining the relative importance of attributes. After calculating the PSI for each alternative, the one with the greatest PSI value was selected to be the primary alternative [46]. The PSI technique utilises simple calculations and is appropriate for use in MCDM problems [47]. The use of PSI in a decision-support system can result in an effective decision in which the weighted criteria are determined by the data in a decision matrix [48]. The MCDM-PSI method has shown to be an applicable and accurate way to solve decision-making problems through the design phase of a production system life cycle [49]. The PSI method provided accurate decisions while processing alternatives based on specified criteria [50]. A consistent methodology based on PSI and TOPSIS using the entropy weights technique was proposed to evaluate and rank automated guided means of transportation for the given application, and the effectiveness of the approach was demonstrated [51].

Road safety could benefit from MCDM techniques based on the Pareto evolutionary algorithm that adapts by reducing accidents and removing congestion delays [52]. Three MCDM methods were proposed to solve the problem of selecting a new airport hub [53]. They applied simple additive weighting (SAW), TOPSIS, and AHP methods to a selected set of alternative airports, and a hybrid MCDM method based on analytic network process (ANP) and fuzzy TOPSIS techniques was used to address air traffic congestion [54]. MCDM using SAW, AHP, and fuzzy TOPSIS methods were used to rank European countries based on the evaluation of road safety performance [55]. AHP and rank correlation methods were used to determine the impact on traffic safety of interactions between components of the transport system [56].

Many factors influence the efficacy and efficiency of traffic solutions in school zones, including user behaviour, road geometric features, environmental elements, traffic policies, and control modes. When considering traffic solutions in school zones, it is necessary to determine whether the solution of a traffic system is suitable, and whether it effectively complements and enhances the effectiveness of the traffic system.

Although previous studies have had mixed results and lack specific methodological guidance, in this study a general methodology is developed to analyse and evaluate the effectiveness of various solutions that can be deployed in school zones through DES-MCDM experiments. A DES-MCDM using PSI and TOPSIS techniques was developed to improve the applicability of the solution(s), and a representative school zone was chosen to be the testbed. Analyses were conducted to extract information from the integrated DES-MCDM approach. Multiple measures of effectiveness were utilised for traffic solution performance quantification.

3. METHODOLOGY

In this research, a DES technique was used to simulate the traffic situation occurring when parents brought their children to school in the morning and picked them up in the afternoon.

Two MCDM methods – that is, TOPSIS and PSI – were utilised to evaluate and rank the solutions before the best one was selected. The TOPSIS method differs from the PSI method in that it uses weights, while the latter does not. The selection criteria were based on multiple conflicting criteria related to the study area and road traffic parameters. The results were compared with the simulation model outcomes to verify the validity and effectiveness of the methods. Although the MCDM could be used separately, without relying on the simulation outputs, the DES-MCDM approach uses the simulation outputs as inputs to the TOPSIS and PSI solutions – such as average waiting time – to ensure the accuracy of the results in selecting the best solution. An integrated-traffic-management (ITM) technique was used to mimic the randomness and irregular behaviour of road users that were not expressed in the simulation software. The ITM heuristic algorithm functions as a subroutine inside the simulation, making comprehensive calculations, and updating model variables each time a decision needs to be made.

AnyLogic simulation software was used to analyse, solve, and manage the problem. Data were collected from the study area through direct observations, questionnaires, and interviews with key people (drivers, traffic experts, and school management). The mean time vehicles or pedestrians spent in the system were used as performance measures. A comparison between alternative solutions was performed based on the mean time spent

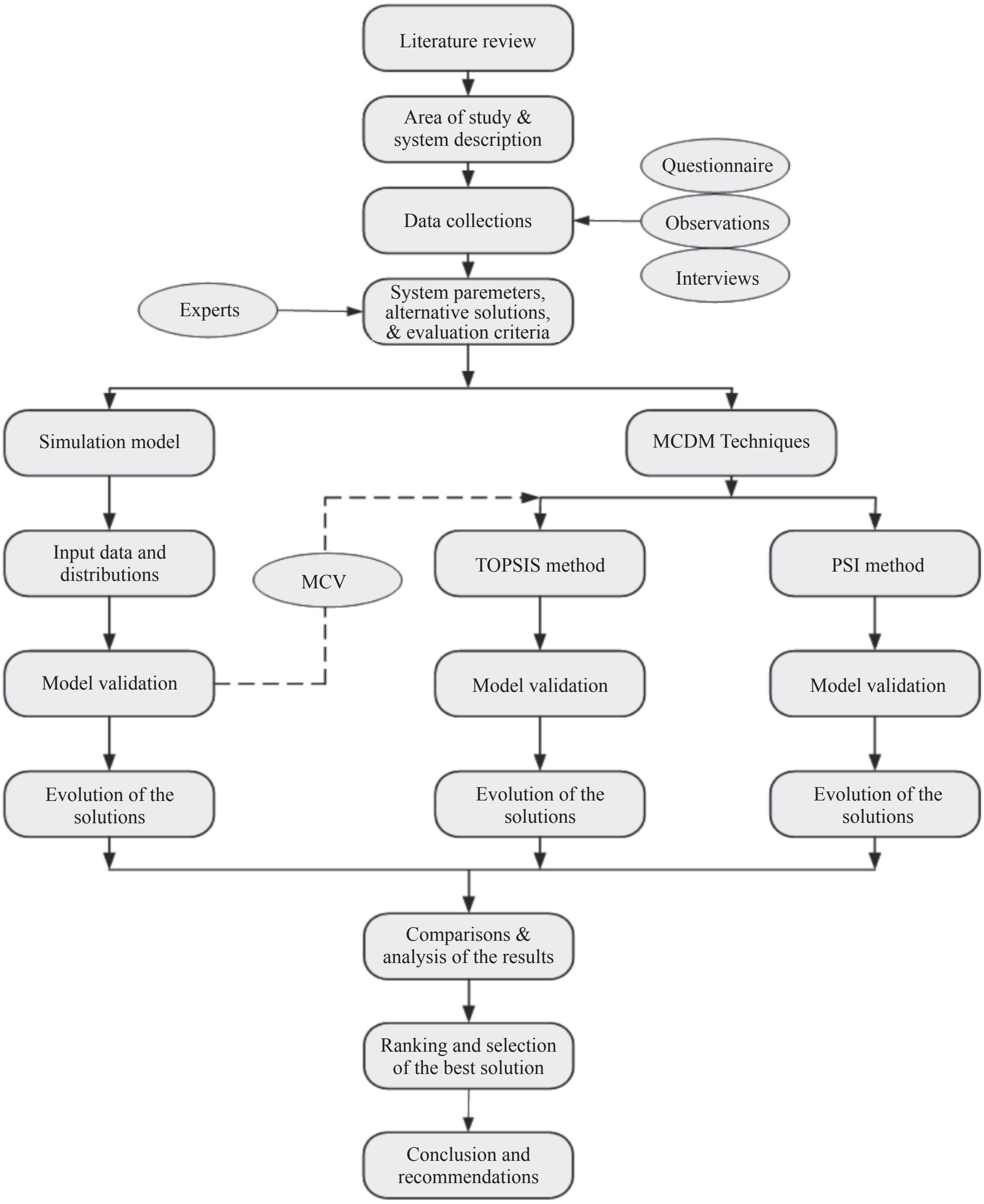

Figure 1 – Research methodology

in the system, cost benefit analysis, cost reduction, and cleanliness of solutions. *Figure 1* summarises the steps of the research methodology. The final system parameters, alternative solutions, evaluation criteria, and the weight of each criterion were determined by a group of experts consisting of two traffic experts, three professors, and four key persons. The experts' inputs were also used to evaluate and validate the ranks of the alternative solutions and in the selection of the best option.

As shown in *Figure 1*, the research steps started with literary reviews related to the subject of the study. Then, the school district was studied, analysed, and the available infrastructure was described. After that, three methods of data collection were used, namely: observations, by observing the study area, recording and determining the entry data (data were collected directly by the researchers and volunteer students for one week, such as the vehicle arrival rate, the time between vehicle arrivals, distances, road dimensions, number of students in each car, drop-off and pick-up times, entrance times, departure times).

A questionnaire was distributed to 50 road users and parents to establish the most important problems faced and the solutions suggested by them

– a questionnaire was designed and distributed to collect data such as vehicle speed, preferred speed inside the school zone, parents waiting time, type of vehicle, type of fuel, year of vehicle, number of students in the vehicle, time they left home, area leaving time, the main problems they faced, and the proposed solutions – and personal interviews were conducted for a number of drivers, road users, and school and university officials (an interview to collect information, for example, the control signs used, the main difficulties and problems they faced, the total number of school students, the total number of university students, the total number of cars with university permits, and the total number of accidents based on official documents and data from police officials).

To ensure that the results were close to reality, a group of experts determined the parameters, alternative solutions, evaluation criteria, and the weight of each criterion. The evaluation process began with a simulation model by determining input data distributions, model validation and verification, running the simulation using different scenarios, and finally evaluating different solutions. Simulation outputs were utilised using MCDM, where two methods – TOPSIS and PSI techniques – were used to evaluate the proposed solutions. Finally, a comparison between the solutions was made, the results being analysed and ranked, the best solution being selected. The research also included conclusions and recommendations for future research.

4. SYSTEM MODELING

4.1 System descriptions

The Yarmouk University Model School is located inside the Yarmouk University near the southern gate. Six roads lead to the school's main gate, which is currently the only gate used. Our case focus was on the school area, as shown in *Figure 2*. The study was directed toward how parents and students could reach the school and how long this would take, from the time they entered one of the university's external gates until they left the study area—that is, they either left the university or entered one of the university's internal gates. There was no specific gate designated for school officials, students, or parents to enter the school area, and they could use any of the university's gates to reach the main school gate inside the university.

Excessive time is spent when congestion occurs in the morning as parents drop their children at school and in the afternoon when parents return to collect their children.

The system in this research is a real-world case representing a school at Yarmouk University in the Irbid District of the Hashemite Kingdom of Jordan. Parents of students enter the school (university) to drop off their children in the morning and to collect them in the afternoon. During peak hours – that is, 7:00–8:00 AM and 1:30–2:30 PM – school areas, neighbouring streets, and intersections suffer from congestion, traffic jams, and high traffic density (TD).

Figure 2 shows the area of interest around the school, consisting of a network of several roads, intersections, entrances, and exits. Based on the current situation, vehicles, cyclists, and pedestrians can enter from any external entrance and leave via any exit appropriate to their destination. The only restriction is that cars and pedestrians who are not university employees should leave via one of the specified exits without entering the university's internal gates.

This study was intended to manage the traffic on roads leading to the school and improve TD to allow the smooth flow of vehicles. To this end, our main focus is on rush hour when parents drop off their children in the morning and return to collect their children in the afternoon.

4.2 Input data analysis

Data collection began with the counting of vehicles entering each road, the number of vehicles exiting, the time between vehicle arrivals, and the time between vehicles exiting. Data were collected daily over a one-week period. A survey was distributed to drivers using the roads in the study area, the collected data including the number of pedestrians entering and leaving the study area during rush hour. Data collection included the behaviour of drivers, parents, and pedestrians (school students and university students). Accident statistics (the number of accidents annually) were obtained from the records of the Public Security Directorate. An interview with the school management was also conducted to determine the number of students and employees, and the difficulties faced by the school due to traffic-related problems. In addition, an interview with

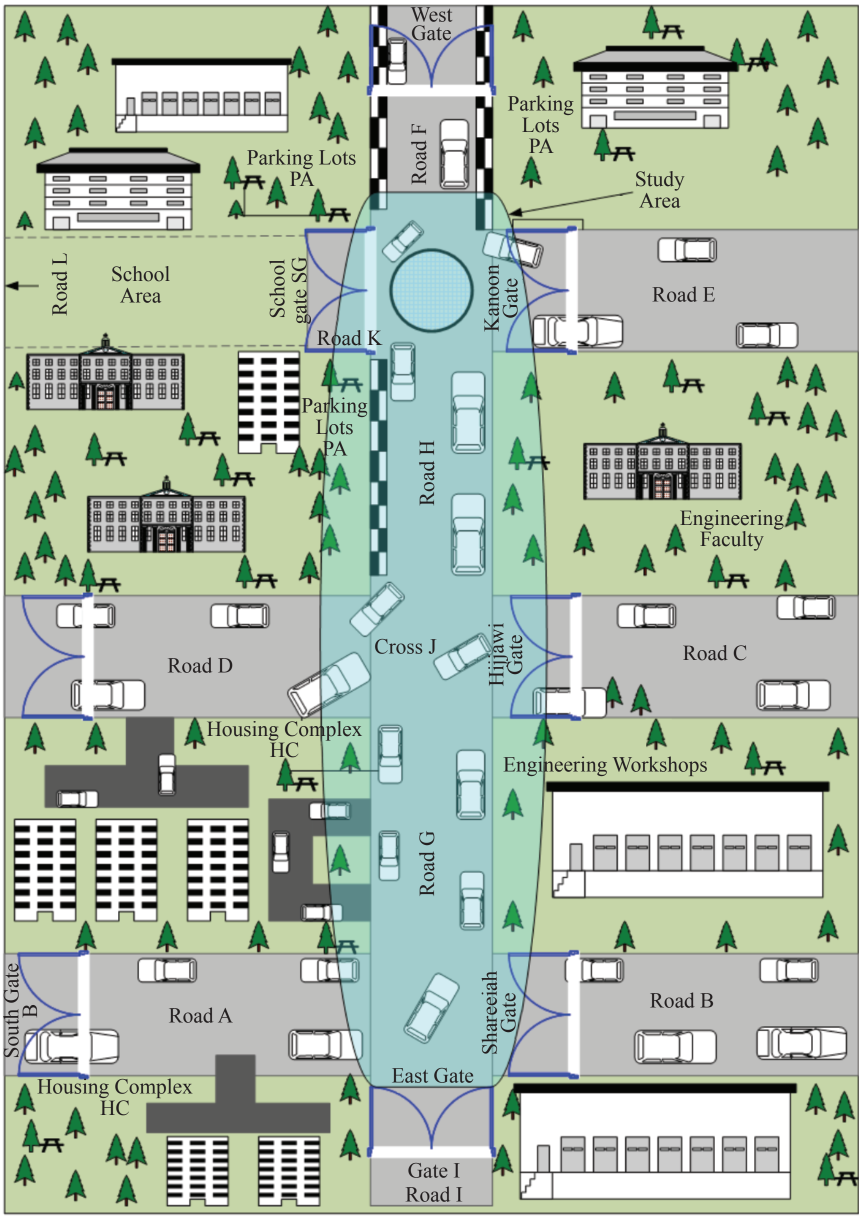

Figure 2 – The study area (to scale)

selected drivers and officials was conducted to reveal the problems facing them in the study area and their suggested solutions.

Statistical analysis of the collected data was performed to obtain and evaluate parameters such as the mean, standard deviation, and mode, statistical software being used to determine the data distribution and parameters. ProModel-Stat::Fit, which is a software for curve fitting and statistical analysis, was used to find the best distribution representing the collected data. The bases for the input values were built to represent current traffic practices. *Table 1* lists the input parameters, data, and associated distribution information used in the simulation models of this study. The data included inter-arrival times, inter-exit times, the number of vehicles and pedestrians entering and exiting each road, external, or internal gate, the number of students in each vehicle, the stopping time to drop off or pick up students, the time needed for parents to drop off, and collect their children. The initial speed was controlled by a traffic control sign (40 km/h), while the preferred speed inside the school-zone area was determined by questionnaire analysis. The average acceleration and deceleration inside the school zone were assumed by a team of experts based on the collected data and information taken from the Jordan Traffic Institute.

Table 1 – Input data distributions and values

Name	Distribution	Value
Vehicle arrival from road A	Poisson	414
Vehicle arrival from road B	Poisson	133
Vehicle arrival from road C	Poisson	145
Vehicle arrival from road D	Poisson	471
Vehicle arrival from road E	Poisson	124
Vehicle arrival from road F	Poisson	114
Time between vehicle arrivals A	Exponential	U(1,16.43) Second
Time between vehicle arrivals B	Exponential	U(1, 53.22) Second
Time between vehicle arrivals C	Exponential	U(1, 48.66) Second
Time between vehicle arrivals D	Exponential	U(1, 14.34) Second
Time between vehicle arrivals E	Exponential	U(1, 57.14) Second
Time between vehicle arrivals F	Exponential	U(1, 62.58) Second
Distance between B and C	Constant	105 m
Distance between C and E	Constant	110 m
Distance between E and F	Constant	250 m
Distance between D and C	Constant	115 m
Roads width	Constant	12 m with two lanes
Average emission	Gamma	4.6 metric tons of carbon dioxide per year/car
Number of school students in each car	Triangular	T(1,3,7)
Total number of school students	Constant	2650
Total number of school teachers and employees	Constant	215
Total number of traffic accidents	Poisson	37 per year
Vehicle speed	Entering speed (initial speed) Preferred speed Average acceleration Average deceleration	40 km/h 30 km/h 1.8 km/h^2 4.2 km/h^2
Drop-off/pick-up time	Triangular	Tria (11, 25, 120) Second
Parents waiting time (accompany or watch their children to walk from the car to the school gate and vice-versa)	Triangular	Tria (23, 126, 321) Second

4.3 Simulation and system modelling

Because of the specific and unique characteristics of the study area, road users, stakeholders, and random pedestrian behaviour that was not included in the inherent characteristics of the software, an integrated-traffic-management (ITM) method was used to simulate the randomness and unexpected behaviour of drivers and pedestrians. The AnyLogic simulation software, a modelling tool that supports agent-based, discrete events, and system dynamics simulation methodologies, was used to simulate the operation of the traffic system under investigation. AnyLogic can be used to simulate a wide variety of complex systems, including pedestrian dynamics, transportation, and road traffic. The code required for decisions is written into the subroutines. To deal with the various decision points considered in the ITM, there were five key subroutines: waiting, stopping a side, turning around, moving forward, or taking the first exit.

The simulation model was developed to emulate the study area so that the proposed ITM could be evaluated under real-world conditions. When a decision had to be made, the ITM was named as a subroutine from within the simulation model, the simulation model being used to represent the complex traffic study conditions and behaviour. The ITM heuristic algorithm was used any time a driver or pedestrian had to make or alter a decision within the ITM. It received data about current traffic conditions from the simulation model, evaluated potential behaviour, and then selected the best decision.

A signal was sent to one of the five subroutines whenever the ITM model had to respond to an unplanned event: wait, stop on the side, turn around, move forward, or take the first exit. A number of these five subroutines involve both unexpected events and a determination of the next movement priority. The response of the ITM model was expressed in terms of changes in waiting times, the number of vehicles in a given area (TD), and the real traffic flow. An iteration of the ITM heuristic in the ITM simulation model system ended only when the initiating traffic flow was smooth. Waiting times, pick-up or collection times, and moving times all triggered time delays in every traffic system. After each execution of the ITM heuristic subroutine, the ITM heuristic updated related model variables, such as waiting time and traffic flow. After any transaction, the ITM heuristic performed extensive calculations.

Performance metrics denote the main objectives subject to improvement. The overall waiting time, traffic flow, TD, number of injuries, and number of vehicles stuck per period were the key performance indicators (traffic jams). *Table 1* lists the input data for the ITM simulation used in this research, as well as the associated distribution.

By comparing the activities with manual measurements, the model was first validated for a traffic system with a limited number of vehicles and pedestrians entering the system, after which the number of entries was gradually increased. The comparison showed that the test results, when combined with animation-based validation efforts and various manual calculations, proved the ITM simulation model to be valid and functional. The validity of the ITM heuristic algorithm was verified after it was implemented. The model's key checks were carried out by inserting one decision point at a time and comparing the results to those obtained using Excel spreadsheet calculations. The results showed that 31 out of 35 decisions were of the same form as the algorithm solution, indicating that the system was valid.

The experiments had to be designed to test the simulation system under long-run steady-state conditions because it was a non-terminating system. The model's initial waiting time, TD, and other initial conditions that could induce bias were all set to zero. Additionally, neither vehicle movement nor pedestrians from previous times were considered. A graph of the AnyLogic output vs. the warm-up duration for one year and five replications was used to determine the warm-up-period – that is, a value of 100 h was found to mitigate the effects of initialisation bias. A one-year run duration was considered acceptable because the steady state had already been reached after 100 h. For average overall traffic system waiting-time measurements, a sample size of 50 replications was found to be sufficient to guarantee a 98% confidence interval width of less than 0.002, based on a 0.004 bound value.

Time was measured in hours, and the system ran for 2 hours a day, 250 days a year, with a 1-hour decision period. The model input randomness occurrences for vehicle arrivals and exits, accidents, alerts and events, traffic changes, system delay times, waiting times, and processing times at each intersection in the study area.

5. RESULTS AND DISCUSSION

The analysis compares the basic case with the suggested solutions and their alternatives. As discussed previously, the basic system (base case (BC)) represents the current system. All current and suggested alternatives have the same inputs, logic, and system configurations, and for each suggested solution, the study area is modified based on the configuration of the alternative solution.

The comparison between the current system and the suggested solution is based on the output from the simulation model. The system here refers to the study area, with Cross J being the most crowded intersection with the most congestion during peak hours. Ten criteria were selected by the team of experts to evaluate alternative solutions. *Table 3* shows a comparison between the base case and the five alternative solutions in terms of the average mean waiting time (MWT) in seconds, average minimum waiting time (MiWT) in seconds, average maximum waiting time (MaWT) in seconds, average flow rate (FR) in cars/minute, average TD in cars/system, average maximum traffic density (MTD) in cars/system, average time savings (TS) in hours for vehicles only, average reduction in the number of accidents (AR), fuel-consumption reduction (FCR), and the average emission reduction (ER) – that is, the reduction in metric tons of carbon dioxide per

Table 2 – Alternative solutions required implementation costs and time

Alternative solution	Cost (JDs)	Required time (months)	Main modifications
Base case	---	---	---
Alt I	25,000	1	Repositioning of entrances, exits and one-way roads
Alt II	10,000	1.5	Using steel fences, establishing parking spots, applying strict traffic procedures, and temporarily closing and opening roads
Alt III	50,000	2	Opening a path through the school area to the outside, opening gates, and applying one-way use
Alt IV	70,000	8	Adding new roads and applying one-way use
Alt V	40,000	5	Building pedestrian bridges and applying one-way use and forced exit

year. The cost is the total cost required to implement the alternative solutions and is measured in Jordan Dinars (JDs) (1 $=0.71 JD). Total time includes the time for moving distances, the time to drop off or collect students, parents' waiting time, and the delay due to congestion.

5.1 Alternative solutions

The main objective was to reduce the time spent on the system, there being several types of solutions. The first type required major changes, more time, and a large sum of money. One such solution was to add another road with a bridge (road A), making it a one-way road (exit-only). A second solution would have been to change the location of the school, and a third solution would have been to separate the school area from the university area. The second type of solution required only minor changes, smaller sums of money, less effort, and would have been quick to implement. Because all roads are used during the day outside of peak hours, none can be closed or made into one-way roads, so we were looking for solutions that utilised the existing situation. Expert opinions were the main input factors used to determine alternative solutions. After reviewing all the solutions, they were reduced to five main solutions in addition to the base case (current system). *Table 2* shows alternative solutions and their associated costs, expected implementation time, and required amendments.

Alternative solutions descriptions:

Base case (BC): The base case or the current situation – a do-nothing solution.

Alternative I: Open Road I and let cars enter from D and exit at I or A. Cars enter from B, and C can exit from D and A. Cars from F and E can exit from E and F.

Alternative II: Use several temporary parking areas and steel barriers or protective fences.

a) Add an additional four parking lots to drop off and collect school students instead of the current one (roads C, D, G, E, and F) and add four pedestrian-crossing areas at Cross J.
b) Install protective fences beside the roads to prevent student drop offs as permitted in the current situation, forcing students and parents to cross each road at specified locations only.
c) Temporarily close the road headed to the school (road H), limiting it to pedestrian use only during peak hours.
d) Allow no vehicle U-turns at Cross J.
e) Vehicles arriving from roads E and F can use the square and exit from roads E and F only.
f) A parking area beside road F should be allocated to school staff (teachers and employees) who can then only park there.

Alternative III: Open the main school gate road K and let cars that are not allowed to enter the university leave via this exit, opening the road gate in the middle of the school area. This will resolve 26.86% of the congestion, as parents will arrive from the southern gate, drop off their children at the school, and then immediately leave the school area.

a) Vehicles can enter from any street.
b) Cars exit from roads F and K

Alternative IV: Add a new road for cars that use the main street outside the university (road L). Open the road as shown in the figure to allow vehicles to enter the school area and leave via the outside main street without entering the university. Vehicles can enter only from roads A, B, D, C, and E. Roads H and F are one-way only.

Alternative V: Build pedestrian bridges and force the use of one-way roads and exits at specific points. All entrances are open for entry, and only four exits are used, vehicles being able to exit from gates B, C, E, and F only.

Other solutions may include adding a traffic light at Cross J, but this may lead to an increase in congestion as the roads (D, G, H, and C) are very short with limited capacity. The use of school buses instead of parents' cars is not an option for the university for the time being as the students are distributed over more than 300 villages and suburbs. In addition, most students' parents are faculty members or employees at the university. Administrative action should be taken to prevent garbage trucks and tractors or other university utility vehicles from entering the area during peak hours, regardless of the solution selected.

5.2 Simulation study

The simulation system outputs do not define the priorities of the solutions, but rather indicate performance measures. However, it is clear that Alt II was the best solution as the average time spent by vehicles in the system was less than the other alternatives by at least 10%, and 88% better than the current system. Alternative IV was better than Alt I, followed by Alt V, with Alt III being the fifth best. The current situation was the worst in terms of the total time spent in the system. The results for TD, maximum TD, and traffic flow on all roads indicated that Alt II was the best in terms of TD and average flow rate because it had the lowest TD and maximum traffic flow rate. This was followed by Alts I, IV, V, and III. The current system had the worst performance.

The maximum total time a vehicle spent in the current system was approximately 18.8 min, while the maximum total time a vehicle spent using Alt II was less than 4 min. However, this implied no serious traffic problems; owing to randomness and pedestrian and driver behaviour, the current system is not effective and requires improvement as the congestion increases enormously in the area under study and nearby streets. The ER of Alt II was 35 metric tonnes of carbon dioxide per year more than the current system and was 3% better than the next best alternative. Moreover, the average annual reduction in the number of accidents for Alt II was 73%.

The results show that Alt II was the best alternative in all performance measures, whereas Alt I was better than Alt IV in some measures and worse in others. The ranks of Alts V and III remain the same in all measures. Decision-making tools could then be used to compare the alternatives to find the best solution.

5.3 TOPSIS and PSI techniques

The proposed alternatives were simulated, and their performance measures were obtained. TOPSIS and PSI techniques were applied to select the best alternative based on the resulting performance measures. The outputs from the simulation model (*Table 3*) were used as inputs to the MCDM process. The following subsections describe the application of TOPSIS and PSI in the selection process.

TOPSIS Method

TOPSIS is a MCDM used to select the best alternative in terms of multiple, usually conflicting criteria, from among a finite set of decision alternatives. The group of experts determines the weight of each criterion. Solving an MCDM problem using the TOPSIS method consists of the following seven steps:

Step 1. Calculate a normalised matrix:

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} X_{ij}^2}} \quad (1)$$

Table 3 – Comparison between the base case and different alternatives

Alt/Measure	Cost	MWT	MiWT	MaWT	FR	TD	MTD	TS	ER	AR
Base case	--	420.5	120.9	1128.4	16	102	206	--	--	--
Alt I	25,000	121.3	63.6	553.2	23	71	143	60881	32	0.61
Alt II	10,000	94	49.8	201.3	25	66	124	66631	35	0.73
Alt III	50,000	175.9	96.5	655.7	18	89	162	49216	26	0.43
Alt IV	70,000	105.5	54.4	218.2	21	69	135	65012	34	0.34
Alt V	40,000	143	83.1	611.2	19	78	151	56198	29	0.55

Step 2. Calculate a weighted normalised matrix:

$$V_{ij} = \overline{X}_{ij} \cdot W_j \quad (2)$$

Step 3. Calculate the ideal best and ideal worst value:

V^+ – Minimum value for the attributes: cost, waiting time, TD, and the maximum value for the attributes: reduction in emission and reduction in fuel consumption.

V^- – Maximum value for the attributes: cost, waiting time, and TD, and the minimum value for the attributes: reduction in emission and reduction in fuel consumption.

Step 4. Calculate the Euclidean distance from the best:

$$S_i^- = \sqrt{\left[\sum_{j=1}^{m} (V_{ij} - V_j^-)^2\right]} \quad (3)$$

Step 5. Calculate the performance score:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (4)$$

Step 6. Rank the performance scores in a descending manner (the highest performance score has rank 1 and the lowest performance score has rank 5).

Step 7. The best solution is the alternative with the lowest score; in this case, Alt II.

Six factors were used to compare alternatives: cost, average mean waiting time (MWT), TD, ER, accident reduction (AR), and fuel-consumption reduction (FCR). The average reduction in fuel consumption was 1/6 gallons per hour, that is, 0.167 gallons per hour [57, 58]. For example, the average time saving for II was 66631, and the average reduction in fuel consumption was 66631×0.167=11127 gallons per year for the whole system. Based on the simulation outputs, the average time saving was calculated to be the reduction in mean waiting time in the system/school-zone area (average mean time for the base case – average mean time for the alternative solution). The average reduction in emission was calculated based on the total annual reduction in vehicles time spent in the system (4.6 metric tonnes per year × total annual vehicles time savings).

Table 4 shows the performance-score calculations using the DES-TOPSIS methodology. The ranking of the alternative solutions shows that Alt II was the best and Alt IV was the worst. The rank order of the alternatives was Alt II, Alt I, BC, Alt V, Alt III, and Alt IV. Three of the alternatives (Alts I, V, and III) had the same ranks as the simulation models. While these results comply with the simulation model results for the best solution, Alt II, the rank order of the base case and two other solutions (BC, II, IV) were different because weights not considered in the simulation model were applied to the factors and attributes. Moreover, the DES-TOPSIS method considers multi-criteria with confounded interrelationships.

Preference selection index (PSI) method

The PSI method was developed to solve MCDM problems. This method is suitable when there is a conflict in determining the relative rank among attributes. The following steps summarise the calculation steps of the PSI method [18]:

Step 1. Define the problem.

Step 2. Formulate the decision matrix.

Step 3. Normalise the data: If the attribute is beneficial, then larger values are desired, and they can be normalised as:

$$N_{ij} = \frac{X_{ij}}{X_J^{max}} \quad (5)$$

If the attribute is non-beneficial, then smaller values are desired, and they can be normalised as:

$$N_{ij} = \frac{X_J^{max}}{X_{ij}} \quad (6)$$

Table 4 – TOPSIS calculations

Attribute, Criteria	Cost	MWT	ER	FCR	TD	AR	Si+	Si-	Pi	Rank
Weight	0.30	0.25	0.2	0.05	0.05	0.15				
BC	0	0.205	0	0	0.026	0	0.207	0.451	0.685	3
Alt1	0.076	0.059	0.091	0.023	0.018	0.075	0.155	0.372	0.706	2
Alt2	0.03	0.046	0.1	0.025	0.017	0.089	0.148	0.389	0.724	1
Alt3	0.152	0.086	0.074	0.018	0.023	0.053	0.199	0.355	0.641	5
Alt4	0.213	0.051	0.097	0.024	0.018	0.042	0.245	0.36	0.595	6
Alt5	0.122	0.07	0.083	0.021	0.02	0.067	0.179	0.358	0.667	4

where X_{ij} is the attribute measure (i=1, 2, …, N and j=1, 2, …, M).

Step 4. Compute the mean value of the normalised data:

$$N_j = \frac{\sum_{i=1}^{n} N_{ij}}{n} \quad \text{`(7)}$$

Step 5. Compute the preference variation value:

$$\Phi_j = \sum_{i=1}^{n} [(N_{ij} - N)]^2 \quad (8)$$

Step 6. Determine the deviation in preference value:

$$\Omega_j = [1 - \Phi_j] \quad (9)$$

Step 7. Compute the overall preference value:

$$w_j = \frac{\Omega_j}{\sum_{j=1}^{m} \Omega_j} \quad (10)$$

$$\sum_{j=1}^{m} w_j = 1 \quad (11)$$

Step 8. Compute the preference selection index:

$$\theta_j = \sum_{j=1}^{m} X_{ij} \cdot w_j \quad (12)$$

Step 9. Select an appropriate alternative for a given application [18].

The same six factors (cost, MWT, TD, ER, FCR, AR) used previously were used again to compare alternatives using the DES-PSI methodology. Again, the inputs for PSI used the outcomes from the simulation model (*Table 3*). *Figure 3* shows the calculated PSI values for the different alternatives and the BC. The ranking of the alternative solutions shows that Alt II was the best, and the BC was the worst. The rank order of the alternatives was Alt II, Alt IV, Alt I, III, Alt V, and BC.

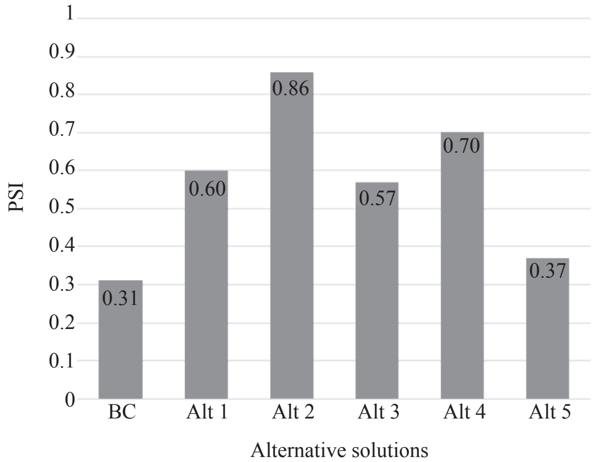

Figure 3 – The calculated PSI –values

Comparison between different solutions

Table 5 shows a comparison between different methods, including the simulation, the DES-TOPSIS, and DES-PSI methods. It is clear that the DES-PSI results complied with the simulation output results in terms of the best solution and rank order of most of the alternative solutions, including the BC, the worst in both cases. While the PSI ranking orders were different from the TOPSIS performance-score ranks, the results showed the simulation results to be very close to the PSI ranking, although there was a difference with the DES-TOPSIS ranks because TOPSIS uses weights not considered in the simulation model and PSI technique but applied to TOPSIS factors and attributes.

Table 5 – Comparison between solutions ranks of different methods

Method	Simulation	DES-TOPSIS	DES-PSI
BC	6	3	6
Alt I	3	2	3
Alt II	1	1	1
Alt III	5	5	4
Alt IV	2	6	2
Alt V	4	4	5

Experts indicated that the results provided by the DES-TOPSIS method could be considered reasonable solutions as they used simulation model outputs and considered multiple conflicting criteria and the weights of the decision criteria. Simulation outcomes were used to compare alternatives based on a single criterion at a time. The DES-PSI method did not consider weights for the decision criteria. However, the DES-TOPSIS consideration of weights provides more realistic solutions and complies with real-world problems. Furthermore, DES-TOPSIS considers multiple criteria with complex interrelationships.

Cost-benefit analysis reflects significant savings if alternative solutions are implemented. For example, when comparing Alt II to the current situation, the results indicate the cost of implementing the solution to be 10,000 JDs, with an annual fuel saving of 42,120 JDs. The average cost of time savings per person was \$8.4/h (6 JDs/h) [59]. Because the average total annual value of travel time savings for Alt II was 399,786 JDs for vehicle drivers only, the implementation of this option was justified by fuel-consumption savings alone, without even considering ER, drivers, pedestrians, the reduction in accidents, and parents' time savings.

The best solution would require creating permanent parking lots for school employees near road F, adding temporary parking lots near roads C, D, G, and E, adding steel barriers to force pedestrians to cross roads at specific locations, temporarily closing road H (during peak hours only), preventing U-turns, and adding four pedestrian-crossing areas at Cross J. Because the cost of implementing the best solution would be about 10,000 JDs and the annual savings would be more than 440,000 JDs, the implementation of the solution would be justified by the annual savings, and the ER and time saved by students, pedestrians, and parents.

For sustainable long-term solutions, parents must be educated about the various modes of transportation available to their children. Using school bus services helps to alleviate traffic congestion at school entrances and nearby roads. For students who live nearby, carpooling is an alternative. It would be necessary to limit the number of entry and exit points in schools. Separate entrances and exits could be built for students walking or cycling to school. A designated drop-off zone away from the parking area would aid in improving the traffic flow. Students in primary, middle, and high schools could have staggered start and finish times. Signboards could be used to build temporary parking spaces for pick-up and drop-off during peak hours. There is no single approach to traffic management, as it depends on the size and location of the school and traffic concerns, although these general guidelines may be followed to prevent traffic congestion at university campuses and school zones.

6. CONCLUSIONS

Traffic control at busy intersections is a hot issue because of the dynamic traffic flow, limited capacity, ever-changing TD, and an increased number of vehicles, cyclists, and pedestrians, which complicate transportation infrastructure and cause substantial delays. High congestion requires improved infrastructure efficiency, and intelligent traffic systems to increase coordination and smooth traffic flow on existing road networks as traffic lights, stop signs, and squares do not mitigate the root cause of the problem. This study presents a hybrid DES-MCDM technique as a low-cost solution that can be quickly implemented to address current traffic congestion problem using available infrastructure and limited area capacity.

The findings indicate that the simulation results were very close to the PSI rankings, although there was a difference in the TOPSIS rankings because the method used factor and attribute weights that were not considered in the simulation model and PSI technique. The results also indicated that integrated DES-MCDM techniques could be an efficient tool for helping decision makers solve traffic problems and prioritise alternative solutions. The DES-TOPSIS utilisation of simulation outcomes and its consideration of weights provided more accurate and realistic solutions.

Analysis of the results revealed that the proposed method provides a generic framework for assessing solutions in school zones and in selecting and ranking traffic solutions for specific areas. It could help planners and decision makers understand the effect of these solutions prior to implementing them in the field and support the decision-making process to find the best solution for a traffic problem. Consequently, the implementation of this solution should be reinforced with educational programs for drivers and road users.

Implementing the best solution could smoothen the traffic flow with lower TD, decrease waiting time and delays, and reduce traffic congestion, fuel consumption, and emissions. The risk of accidents could be considerably reduced, and pedestrians, especially school students, would be safer. The cost-benefit analysis justifies the cost of implementing the best alternative solution; it would save more than ten times the implementation cost in one year.

Due to the complexities of the zone traffic congestion and unique situation, there are still some study limitations. The research did not incorporate the variations of driver behaviour based on their age or gender, emissions during different seasons, and emissions based on the type of fuel (diesel and gasoline). Due to limitations in the available data, this work did not consider all types of emissions, such as NO_x, PM, CH_4, etc., and noise pollution. Further investigation is required to analyse the impact of each solution and design alternatives for nearby roads and suburbs. A more thorough study could be conducted to classify MCDM techniques and determine which approach can be deployed for different types of traffic zones. Further research may help planners and policymakers utilise emerging technologies to provide smart solutions.

Future research may consider additional criterion impact and include utilising lean techniques to study traffic problems and compare alternatives. A heuristic algorithm could be developed to serve as a decision-support system in response to unplanned events and pedestrian behaviour. More street space may also be allocated for traffic flow with less priority for parking and loading actions, and the lowest priority for pedestrians by forcing them to use pedestrian bridge crossings.

الدكتور غازي مصطفى مقابله[1]
ghazi.magableh@yu.edu.jo
الدكتور احمد عبدالحفيظ المومني[1]
ahmad.mumani@yu.edu.jo
[1]قسم الهندسة الصناعية، جامعةاليرموك
٢١١٦٣ شارع شفيق ارشيدات
اربد، الاردن

نهج المحاكاة القائم على تقنيات صنع القرار متعدد المعايير لتقييم الحلول المروريه

ملخص المقاله

تصاعدت مشاكل الازدحام المروري مع زيادة عدد المركبات والمشاة وراكبي الدراجات في مواجهة قدرة الطرق المحدودة. يهدف هذا البحث إلى تقليل الوقت الذي يقضيه مستخدموا الطريق في النظام (منطقة المدرسة) وتحسين كفاءة عملية تحميل وتنزيل الطلاب في منطقة مدرسية مزدحمة. تدمج الدراسة محاكاة الأحداث المنفصلة (DES) وتقنيات صنع القرار متعدد المعايير (MCDM) لتقييم البدائل المقترحة بشكل شامل لاختيار الحل الأمثل بناءً على العديد من مقاييس الأداء. وتم تقديم حاله دراسيه حقيقيه لمشكلات المرور والازدحام تتمثل في الصعوبات التي يواجهها الآباء عند إنزال وإحضار أطفالهم من المدرسة خلال ساعات الذروة. تم تطوير خوارزمية إرشادية لمحاكاة السلوك العشوائي وغير المتوقع لمستخدمي الطريق. وتم ايضا تحليل التكلفة والعائد مع الاخذ في الاعتبار تأثير وقت الانتظار، وكثافة حركة المرور، وعدد الحوادث، ونفقات الوقود الإضافية، وخفض الانبعاثات. تم استخدام تقنية ترتيب الاولويات عن طريق التشابه مع الحل المثالي (TOPSIS) وطرق فهرسة اختيار الاولويات (PSI) لتحديد الخيار الأنسب. خلصت الدراسة الى أن دمج تقنيات المحاكاة مع طرق صنع القرار متعدد المعايير يمكن أن يحل مشاكل المرور بكفاءة.

كلمات البحث والدلاله: المحاكاه المرورية، التحسين المثالي المنفصل، تقنيات صنع القرار متعدد المعايير، ترتيب الاولويات عن طريق التشابه مع الحل المثالي، فهرسة اختيار الاولويات، الحلول المروريه.

REFERENCES

[1] Charly A, Mathew TV. Evaluation of driving performance in relation to safety on an expressway using field driving data. *Transportation Letters*. 2020;12(5): 340–348. doi: 10.1080/19427867.2019.1591075.

[2] Kang MS, Kang TE, Ju JH. A study on the efficiency evaluation of the improvement project for school zone using DEA. *Journal of The Korean Society of Civil Engineers*. 2018;38(6): 895–906. doi: 10.12652/Ksce.2018.38.6.0895.

[3] Ikeda E, Hinckson E, Witten K, Smith M. Assessment of direct and indirect associations between children active school travel and environmental, household and child factors using structural equation modelling. *International Journal of Behavioral Nutrition and Physical Activity*. 2019;16(1): 32. doi: 10.1186/s12966-019-0794-5.

[4] Zhao X, et al. A generic approach for examining the effectiveness of traffic control devices in school zones. *Accident Analysis & Prevention*. 2015;82: 134–142. doi: 10.1016/j.aap.2015.05.021.

[5] Zayerzadeha A, Zavareh MF. School zone road safety assessment using the iRAP star rating for schools (SR4S) methodology in Khorasan Razavi Province. *Journal of Injury and Violence Research*. 2019;11(4 Suppl 2).

[6] Heydari S, Miranda-Moreno L, Hickford AJ. On the causal effect of proximity to school on pedestrian safety at signalized intersections: A heterogeneous endogenous econometric model. *Analytic Methods in Accident Research*. 2020;26: 100115. doi: 10.1016/j.amar.2020.100115.

[7] Park BG. The research of existing traffic safety facilities condition for enhancing in school zone safety. *Journal of the Korean Association for Spatial Structures*. 2013;13(2): 101–109. doi: 10.9712/KASS.2013.13.2.101.

[8] Lee SI, Kim SH, Kim JW, Hu E. A development of the integrated evaluation criteria for safety of school zones. *Journal of the Korean Society of Safety*. 2012;27(1): 117–122. doi: 10.14346/JKOSOS.2012.27.1.117.

[9] Prud'homme J. [Children exposure to PM10 on the way to school: Regulatory impact of speed regulation under 30 km/h]. *Revue D'epidemiologie et de Sante Publique*. 2017;66(2): 145–152. doi: 10.1016/j.respe.2017.09.005.

[10] Kim P, et al. 6A.001 An evaluation of the school-based helmet program in Myanmar. *Injury Prevention*. 2021;27(Suppl 2): A1–A79. doi: 10.1136/injuryprev-2021-safety.148.

[11] Reyad P, Sayed T, Zaki MH, Ibrahim SE. School zone safety diagnosis using automated conflicts analysis technique. *Canadian Journal of Civil Engineering*. 2017;44(10): 802–812. doi: 10.1139/cjce-2016-0586.

[12] Lee H. A Comparative Study on Traffic Safety Facilities of Traffic Accident Scene in the School Zone. *Korean Journal of Security Convergence Management*. 2018;7(4): 222–240. doi:10.24826/kscs.7.4.15.

[13] Wang W, et al. Factors influencing traffic accident frequencies on urban roads: A spatial panel time-fixed effects error model. *PLoS One*. 2019;14(4): e0214539. doi: 10.1371/journal.pone.0214539. eCollection 2019.

[14] Díaz DMV, et al. *Evaluation of Safety Enhancements in School Zones with Familiar and Unfamiliar Drivers*. Ph.D. thesis. University of Massachusetts at Amherst; 2019.

[15] Valdés D, et al. Speed Behavior in a Suburban School Zone: A driving simulation study with familiar and

unfamiliar drivers from Puerto Rico and Massachusetts. In: *International Conference on Applied Human Factors and Ergonomics*. Springer, Cham; 2019. p. 319–329.

[16] Rahman MS, Abdel-Aty M, Lee J, Rahman MH. Safety benefits of arterials' crash risk under connected and automated vehicles. *Transportation Research Part C: Emerging Technologies*; 2019;100: 354–371. doi: 10.1016/j.trc.2019.01.029.

[17] Kamal MAS, et al. A vehicle-intersection coordination scheme for smooth flows of traffic without using traffic lights. *IEEE Transactions on Intelligent Transportation Systems*. 2015;16(3): 1136–1147. doi: 10.1109/TITS.2014.2354380.

[18] Jiang P, et al. Congestion prediction of urban traffic employing SRBDP. *Proc-15th IEEE Int Symp Parallel Distrib Process with Appl 16th IEEE Int Conf Ubiquitous Comput Commun ISPA/IUCC 2017*. 2018; p. 1099–106.

[19] Xu H, Duan F, Pu P. Solving dynamic vehicle routing problem using enhanced genetic algorithm with penalty factors. *Int J Performability Eng.* 2018;14(4): 611–20. doi: 10.23940/ijpe.18.04.p3.611620.

[20] Mandayam CV, Prabhakar BS. Traffic congestion: Models, costs and optimal transport. *Perform Eval Rev*. 2014;42(1): 553–4. doi: 10.1145/2637364.2592014.

[21] Saeedmanesh M, Geroliminis N. Dynamic clustering and propagation of congestion in heterogeneously congested urban traffic networks. *Transp Res Part B Methodol.* 2017;105: 193–211. doi: 10.1016/j.trb.2017.08.021.

[22] Paruchuri P, Pullalarevu AR, Karlapalem K. Multi agent simulation of unorganized traffic. *Proc Int Conf Auton Agents*. 2002;(2): 176–83. doi: 10.1145/544741.544786.

[23] Caprani CC, O'Brien EJ, Lipari A. Long-span bridge traffic loading based on multi-lane traffic micro-simulation. *Eng Struct*. 2016;115: 207–19. doi: 10.1016/j.engstruct.2016.01.045.

[24] Garg D, Chli M, Vogiatzis G. Traffic3D: A new traffic simulation paradigm. *Proc 18th Int Conf Auton Agents MultiAgent Syst, 13-17 May 2019, Montréal, Canada*; 2019. p. 2354–6. http://dl.acm.org/citation.cfm?id=3306127.3332110.

[25] Papathanasopoulou V, Markou I, Antoniou C. Online calibration for microscopic traffic simulation and dynamic multi-step prediction of traffic speed. *Transp Res Part C Emerg Technol.* 2016;68: 144–59. doi: 10.1016/j.trc.2016.04.006.

[26] Wang C, et al. A combined use of microscopic traffic simulation and extreme value methods for traffic safety evaluation. *Transp Res Part C Emerg Technol*. 2018;90(March): 281–91. doi: 10.1016/j.trc.2018.03.011.

[27] Hamric K. *An evaluation of school zone traffic control strategies: Phase I*. Mid-Atlantic Universities Transportation Center. No. MAUTC-2010-02, 2013.

[28] Huy LN, et al. Emission inventory for on-road traffic fleets in Greater Yangon, Myanmar. *Atmospheric Pollution Research*. 2020;11(4): 702–713. doi: 10.1016/j.apr.2019.12.021.

[29] Tezel-Oguz MN, Sari D, Ozkurt N, Keskin SS. Application of reduction scenarios on traffic-related NO_x emissions in Trabzon, Turkey. *Atmospheric Pollution Research*. 2020;11(12): 2379–2389. doi: 10.1016/j.apr.2020.06.014.

[30] Kang CC, Feng CM, Liao BR, Khan HA. Accounting for air pollution emissions and transport policy in the measurement of the efficiency and effectiveness of bus transits. *Transportation Letters*. 2020;12(5): 349–361. doi: 10.1080/19427867.2019.1592369.

[31] Kim Oanh NT, et al. Assessment of urban passenger fleet emissions to quantify climate and air quality co-benefits resulting from potential interventions. *Carbon Management*. 2018;9(4): 367–381. doi: 10.1080/17583004.2018.1500790.

[32] Hauptman M, et al. Proximity to major roadways and asthma symptoms in the School Inner-City Asthma Study. *Journal of Allergy and Clinical Immunology*. 2020;145(1): 119–126. doi: 10.1016/j.jaci.2019.08.038.

[33] Keall M, et al. Implications of attending the closest school on adolescents' physical activity and car travel in Dunedin, New Zealand. *Journal of Transport & Health*. 2020;18: 100900. doi: 10.1016/j.jth.2020.100900.

[34] Wang L, et al. Unexpected rise of ozone in urban and rural areas, and sulfur dioxide in rural areas during the coronavirus city lockdown in Hangzhou, China: Implications for air quality. *Environmental Chemistry Letters*. 2020;18(5): 1713–1723. doi: 10.1007/s10311-020-01028-3.

[35] Wu L, et al. Development of the Real-time On-road Emission (ROE v1. 0) model for street-scale air quality modeling based on dynamic traffic big data. *Geoscientific Model Development.* 2020;13(1): 23–40. doi: 10.5194/gmd-13-23-2020.

[36] Schrank D, Eisele B, Lomax T. *TTI's 2012 Urban Mobility Report.* Texas A\&M Transportation Institute, The Texas A\&M University System, 2012. p. 1–4. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/national/national-table9.pdf.

[37] Rothman L, et al. PW 0373 Evaluation of the vision zero school safety zones program in the city of Toronto – Policy makers and researchers working together. *Injury Prevention.* 2018;24(Suppl 2): A50.2–A50. doi: 10.1136/injuryprevention-2018-safety.136.

[38] Rahman MH, Abdel-Aty M, Lee J, Rahman MS. Enhancing traffic safety at school zones by operation and engineering countermeasures: A microscopic simulation approach. *Simulation Modelling Practice and Theory*. 2019;94: 334–348. doi: 10.1016/j.simpat.2019.04.001.

[39] Zhao X, Li J, Ma J, Rong J. Evaluation of the effects of school zone signs and markings on speed reduction: A driving simulator study. *SpringerPlus*. 2016;5(1): 1–14.

[40] Liu C-C, Niu ZW, Chang PC, Zhang B. Assessment approach to stage of lean transformation cycle based on fuzzy nearness degree and TOPSIS. *Int J Prod Res*. 2017;55(23): 7223–35. doi: 10.1080/00207543.2017.1355124.

[41] Prasad S, Khanduja D, Sharma SK. Integration of SWOT analysis with hybrid modified TOPSIS for the lean strategy evaluation. *Proc Inst Mech Eng Part B J Eng Manuf.* 2018;232(7): 1295–309. doi: 10.1177/0954405416666893.

[42] Vinodh S, Thiagarajan A, Mulanjur G. Lean concept

selection using modified fuzzy TOPSIS: A case study. *Int J Serv Oper Manag*. 2014;18(3): 342–57. doi: 10.1080/19397038.2012.682100.

[43] Balioti V, Tzimopoulos C, Evangelides C. Multi-Criteria Decision Making Using TOPSIS Method Under Fuzzy Environment. *Application in Spillway Selection. Proceedings*. 2018;2(11): 637. doi: 10.3390/proceedings2110637.

[44] Vinodh S, Swarnakar V. Lean Six Sigma project selection using hybrid approach based on fuzzy DEMATEL–ANP–TOPSIS. *Int J Lean Six Sigma*. 2015;6(4): 313–38. doi: 10.1108/IJLSS-12-2014-0041.

[45] Yadav G, Seth D, Desai TN. Prioritising solutions for Lean Six Sigma adoption barriers through fuzzy AHP-modified TOPSIS framework. *Int J Lean Six Sigma*. 2018;9(3): 270–300. doi: 10.1108/ijlss-06-2016-0023.

[46] Jian S, Ying S. Preference selection index method for machine selection in a flexible manufacturing cell. *MATEC Web Conf*. 2017;139: 4–7. doi: 10.1051/matecconf/201713900167.

[47] Prasad RV, Rao CM, Raju BN. Application of Preference Selection Index (PSI) method for the optimization of turning process parameters. *Int J Mod Trends Eng Res*. 2018;5(5): 140–4.

[48] Attri R, Grover S. Application of preference selection index method for decision making over the design stage of production system life cycle. *J King Saud Univ - Eng Sci*. 2015;27(2): 207–16. doi: 10.1016/j.jksues.2013.06.003.

[49] Aan M, et al. Determination of education scholarship recipients using preference selection index. *Journal of Scientific Research in Science and Technology*. 2017;3: 230–234.

[50] Sahir SH, et al. The Preference Selection Index method in determining the location of used laptop marketing. *Int J Eng Technol*. 2018;7(3.4 Special Issue 4): 260–3.

[51] Sawant VB, Mohite SS, Patil R. A decision-making methodology for automated guided vehicle selection problem using a preference selection index method. *Commun Comput Inf Sci*. 2011;145: 176–81. doi: 10.1007/978-3-642-20209-4_24.

[52] Vincent T, Benyahia I. Complex application architecture dynamic reconfiguration based on multi-criteria decision making. *Int J Softw Eng Appl*. 2010;1(4): 19–37. doi: 10.5121/ijsea.2010.1402.

[53] Janic M, Reggiani A. An application of the multiple criteria decision making (MCDM) analysis to the selection of a new hub airport. *Eur J Transp Infrastruct Res (EJTIR)*. 2002;2(2). doi: 10.18757/ejtir.2002.2.2.3692.

[54] Bongo MF, Ocampo LA. A hybrid fuzzy multi-criteria decision-making approach for mitigating air traffic congestion. *2016 International Conference on Industrial Engineering, Management Science and Application (ICIMSA), 23-26 May 2016, Jeju, South Korea*; 2016. p. 1–5. doi: 10.1109/ICIMSA.2016.7503982.

[55] Khorasani G, et al. Application of multi criteria decision making tools in road safety performance indicators and determine appropriate method with average concept. *Int J Innov Technol Explor Eng*. 2013;3(5): 173–7.

[56] Podvezko V, Sivilevičius H. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety. *Transport*. 2013;28(4): 389–403. doi: 10.3846/16484142.2013.866980.

[57] Together EU. *Eco-driving: Handout 6 Fuel consumption of car*. 2011; p. 6–8. http://www.together-eu.org/docs/102/TOGETHER_Eco-driving_5_Handout_06.pdf.

[58] Government of Canada. *2019 Fuel Consumption Guide | Natural Resources Canada*. https://www.nrcan.gc.ca/energy/efficiency/transportation/21002.

[59] Belenky P. Revised departmental guidance on valuation of travel time in economic analysis. *Off Transp Policy Reports*; 2011. p. 1–28. Available from: http://ostpxweb.dot.gov/policy/reports.htm.

[60] Zhang J, Wang DZ, Meng M. Optimization of bus stop spacing for on-demand public bus service. *Transportation Letters*. 2020;12(5): 329–339. doi: 10.1080/19427867.2019.1590677.