Multi-attribute decision-making method for prioritizing autonomous vehicles in real-time traffic management: towards active sustainable transport

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Abstract

In order to alleviate traffic congestion, traffic control systems are an important tool. These systems strive to boost the efficiency of road systems to optimize traffic flow on individual road segments. The benefits of real-time traffic control systems might be increased by integrating new telecommunication and autonomous car technology. There is six real-time traffic advancing sustainable development examined in this study: variable message signs and ramp meters, traffic diversion, and the integration of driverless vehicles into other traffic management systems, with four key criteria: economics, community and social, ecologic and traffic security, as well as 13 sub-criteria using MCDM. To do this, we offer unique additions to the WASPAS technique.

Keywords: Autonomous Vehicles; Traffic control; WASPAS; MCDM; Traffic security

1. Introduction

Congestion on the roads is a major constant risk to life, commerce, and the environmental environment. Delays and travel times rise as a result of lower average speeds. Some of the most effective ways to address this issue are via the development of new road networks, public transit networks, and readily available other forms of transportation. It's the technologies that make better use of existing technologies while also improving traffic flow that is known as traffic management systems (TMS). When a city's transportation system is environmentally friendly, it may be considered intelligent[1]. Using traffic management technologies, all passengers may enjoy safe, efficient, and sustainable transportation.

Traffic agencies utilize real-time traffic management systems to flexibly control recurring and nonrecurring traffic in real-time [2], [3][4]. They alleviate the congestion by keeping tabs on traffic conditions and making appropriate decisions as a result[5]. To properly analyze traffic data, intelligent transportation systems (ITS) are essential.

If you have a large amount of traffic-related data, you may store and analyze it using a big data analytics infrastructure for transportation systems (ITS)[6]. Using Internet of Things (IoT) sensors to gather and analyze large data is also a common practice. Smart transportation systems may also be used to address public or government transportation concerns and challenges[7]. Demand and traffic circumstances will evolve, and this necessitates dynamic management. Real-time traffic management is possible due to the availability of actual info[8]. However, it is not always feasible to collect real-time data since certain necessary equipment, like sensors, are not present at every place

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on the road network. Missing data may be estimated using a variety of techniques[9]. However, modern technologies have made it possible to acquire far more accurate data from any place.

Traffic management systems have become much more powerful as a result of technological advancements in the areas of connectivity, computing power, and sense. There is a growing tendency toward developing autonomous vehicle-based systems (AVs). An AV's decision-making algorithms and processing capability make it much superior to a human driver.

No or minimum human intervention is required to travel between two places in these vehicles [10], [11]. A connected autonomous vehicle (CAV) has connectivity capabilities such as a car (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) (CAVs). Improved road condition, traffic safety, and efficiency are among the key advantages of AVs. To fully benefit from these advantages, infrastructures must be modernized in tandem with AV technology as it advances [12]. CAVs and traffic management technologies that have been tested and proved may help improve traffic patterns to a whole new level when used together. Regardless of whether or not automation exists, studies demonstrate that connection and collaboration will play an essential role in future transportation systems [13]. Because they can link to traffic control centers through V2I, these CAVs can operate as actuators in traffic management [14]. Depending on the circumstances, several traffic management strategies offer unique benefits and drawbacks. Setting priorities and choosing the appropriate strategy for a specific situation is critical for traffic managers.

In this work, a SWARA approach is suggested to boost the reliability and efficiency of the decision-making process. When it comes to making decisions, ambiguity, reluctance, and vagueness are all too common. Because of the viewpoints of the decision-makers, there is a lot of uncertainty.

In the literature, several real-time traffic management strategies may benefit from the use of autonomous vehicles. There are several aspects to consider while deciding on the best traffic management approach to minimize congestion, including sensor costs, traffic system prices, technical advances, and political preferences. Because it addresses this requirement, this paper serves as a significant addition.

This is the remainder of the paper. Section 2 focuses on related work. The proposed model in Section 3 of this document. Results and application in Section 4. Section 5 presents the conclusion.

2. Related Work

The key to a more efficient traffic flow is traffic management and control systems. Implementing a traffic management system can reduce travel time, improve safety, and lessen the environmental impact, to name just a few of the benefits. However, different traffic management strategies have unique benefits and drawbacks in certain settings, as should be highlighted. To choose the best traffic management system, simulation approaches and sensor data may be used. Research [15]presents a short-term prediction model with dynamic traffic allocation (DTA). When an event occurs on a road network, the observer may use the approach described to analyze several choices for rerouting traffic.

Many academics are now investigating the efficiency of incorporating linked autonomous vehicles into the traffic flow management system using traffic management approaches, due to advancements in telecommunication and autonomous vehicle technology As a result, traffic management strategies such as dynamic speed restriction, lane control mechanisms (LCS), variable message sign (VMS), ramp metering, and traffic route diversions are merged with an autonomous vehicle used to achieve better outcomes.

Travelers are encouraged to alter their speed under the computed dynamic speed restrictions while using the dynamic speed limit. As traffic and weather conditions vary, these variable speed restrictions adjust accordingly. If the speed restriction is obeyed, there are fewer delays downstream. Passengers are forced to wait for a green time downstream of the flow due to the lack of dynamic speed guidance[16]. A queue-management algorithm and a dynamic speed management algorithm are both envisaged as part of an investigation into the deployment of dynamic speed limitations and dynamic signal management[17].

The proposed algorithm's numerical evaluations indicate that dynamic speed management improves feed speed limit management in large networks by reducing waits, preventing spillbacks, and increasing offset efficiency. Another research simulates the dynamic speed restriction management technology to give commuters downstream a non-stop junction passage [18]. Savings in delays and

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car stops may be seen in the simulation results. Monitoring link travel time is reduced by 45.3 percent and traffic congestion by 29.1 percent when dynamic speed regulation is used, according to separate research[19] Reduced traffic collisions as a percentage of total collisions is a sign of improved traffic safety.

An LCS traffic control approach is used on roads with many lanes to allow for passenger usage of each lane at any one time. As traffic conditions deteriorate farther down the road, LCS signs are reprogrammed. By progressively emptying this lane, LCS controls the upstream whenever a lane is unavailable following an incident or road construction. Research shows that LCS expands merging area and enables efficient lane changeovers in simulation results [20]. However, early lane changes seem to be a contributing factor to the capacity underutilization issue. To save travel time, LCS must be installed and maintained correctly. A survey group participates in a simulated exercise as part of a study on passenger compliance with LCS directions [21]. Varying signal kinds have different effects on passengers' reactions, as shown by these simulations. The horizontal arrow signal seems to be the most efficient. LCS management is tested in separate research using various traffic situations and users accessing compliance rates [22]. LCS seems to have no impact on traffic, even with a high level of compliance, according to the study's findings.

Traffic management systems use a technique known as variable message signs (VMS). Overhead VMS are large billboards that are installed on highways. VMS displays current traffic conditions, dynamic speed restrictions, lane control logic, and other information to alert passengers of the current traffic situation. Research on the impact of VMS on passengers uses a variety of messages, such as event information, route recommendations, and trip time information, to gauge the reaction of passengers to VMS [23]. It has been shown that drivers value information about journey times, which leads them to deviate from their original route.

When it comes to reducing travel times and environmental impact, the data show that VMS has been an effective solution. In a separate study [24], researchers examine how various driver types respond to messages on VSM. The study's findings show that warnings about accidents had a greater impact than those on roadwork or congestion. Passengers with more than six years of travel experience are more likely to alter their route selection in response to information about accidents, road construction, and traffic congestion, which is helpful for the traffic control technique known as route diversion.

Using ramp metering, traffic is managed by adjusting the flow of traffic entering the highway based on the existing flow.
Traffic lights positioned at on-ramps regulate traffic. A comparison of urban corridor traffic with and without ramp metering management is made in an investigation of on-ramp metering's efficacy (Haj-Salem & Papageorgiou, 1995). Traffic conditions on the highway as well as the adjacent arterials and the whole corridor network are improved by ramp metering, according to new research. Ramp metering is described as a cost-effective control technology in another evaluation of its advantages (Meyer, 1997). Additionally, according to the research, ramp metering enhances travel speed by roughly 20 percent, lowers travel time by 30 percent on average and reduces accidents, and increases volumes. The use of a ramp metering control system in a weaving segment is examined in a research study; (Abdel-Aty & Wang, 2017).

Weaving segments have a greater incident risk due to the convergence and divergence of flows, hence ramp metering is used to test its effect on safety. Preliminary simulation findings suggest that metering the ramp may minimize conflict numbers in the weaving section and reduce collision risk.
It has also been shown that metering on ramps cause longer travel times. A queue management algorithm is added to the system to reduce trip times. Lower travel times were achieved while the incident risk was kept low.

3. The MCDM WASPAS Method

The WASPAS method combines the WSM and the weighted product model (WPM), two commonly used MCDM approaches (WPM). The accuracy of the WASPAS approach is superior to that of WPM or WSM alone. First, an evaluation/decision matrix, X has to be improved, with x_{ij} representing the total performance value of choice/alternative i when it is performed in light of criterion j. Multi-Criteria Decision Making Approach WASPAS approach was proposed to have

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robust usefulness. Because of the wide range of MCDM challenges, several approaches have had to be devised to deal with the varying levels of uncertainty. WASPAS is a novel technique based on utility theory. Since then, it was widely used in a variety of philosophies. Since both the "Weighted Sum Model (WSM)" and the "Weighted Product Model (WPM)" has been included in one approach called "WASPAS," the latter provides the highest degree of accuracy, while the former does not. Figure 1. Show the framework of this study.
The WASPAS method's whole process is broken down into the parts listed below.

Step 1: Decision/Assessment Matrix Development

The following equation represents the fundamental structure of the decision matrix utilized in the WASPAS method:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad (1)$$

Where n is the number of criteria and m is the number of alternatives
$i = 1,2,3 \ldots.m; j = 1,2,3 \ldots \ldots.n$

Step 2: The Decision Matrix Has Been Normalized

$$n_{ij} = \frac{x_{ij}}{\max x_{ij}}; positive\ criteria \quad (2)$$

$$n_{ij} = \frac{\min x_{ij}}{x_{ij}}; cost\ criteria \quad (3)$$

Step 3: WSM and WPM Calculation

WSM and WPM methods are used to determine the relative value of each choice.

$$WSM = \sum_{j=1}^{n} n_{ij} w_j \quad (4)$$

$$WSM = \prod_{j=1}^{n} (n_{ij})^{w_j} \quad (5)$$

Step 4: For each choice, the overall relative significance of that alternative is calculated as follows:

The weighted aggregate of additive and multiplicative approaches is combined into a single generalized criterion.

$$Q_i = 0.5 \sum_{j=1}^{n} n_{ij} w_j + 0.5 \prod_{j=1}^{n} (n_{ij})^{w_j} \quad (6)$$

Step 5: Rank the alternatives based on the largest value of Q_i.

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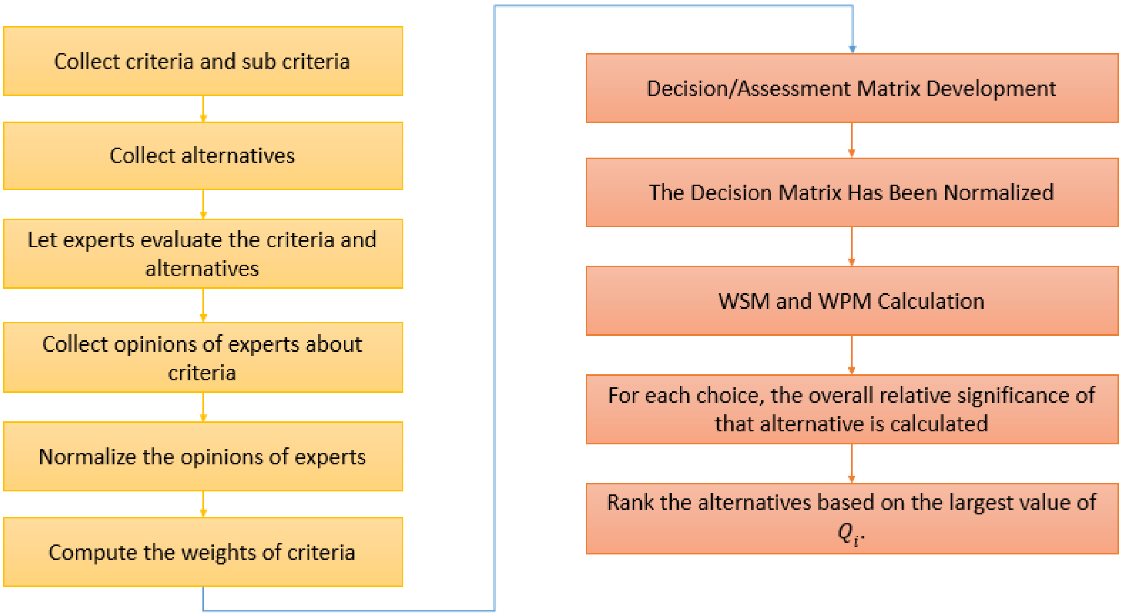

Figure 1: The framework of the study.

4. Application and Results

Traffic management on highways may be done in a variety of ways. There are pros and disadvantages to each of these strategies depending on the scenario. A lack of systematic and objective prioritization of these benefits remains. This paper employs MCDM to prioritize the economic, public and public policy, ecologic, and traffic safety considerations of traffic management methods such as dynamic posted speed, lane control mechanisms (LCS), speed control limit, road design, and traffic detraction and the incorporation of automated driving into other traffic management systems[25]–[33].

Six distinct approaches to traffic management are examined in this research.
This is how they do it.

1) Systems for regulating lane use on motorways are at the heart of lane control systems. Electronic traffic signs above each lane are used to display lane usage information, speed restrictions, or other alerts. AVA1

2) As a result of integrating autonomous vehicles into current traffic management systems, compliance, efficiency, and safety are all enhanced, resulting in better overall performance. AVA2

3) Traffic diversion is the process of diverting traffic away from a primary route to lower the traffic load on that primary route. Effective traffic diversion can reduce travel time and expense. AVA3

4) Dynamic speed limit: helps drivers adjust their speeds based on dynamic speed limitations that have been computed. Weather and traffic conditions have a significant impact on dynamic speed restrictions. It is hoped that the use of this technique would reduce congestion downstream of the traffic flow and improve traffic safety. AVA4

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5) To reduce certain congestion consequences, such as wasted time and pollution levels, ramp metering may be used to distribute the carload on a motorway. By restricting the number of vehicles entering the motorway through a ramp signal, ramp metering is an efficient and direct method of controlling and upgrading freeway traffic. An individual's approach determines how often they are metered. AVA5

6) As part of this system, a traffic control center is linked to the motorway through changeable traffic signs. Instead of the typical static signs, these signs show the regulation or recommended speed restrictions. AVA6

Interviewing experts and utilizing their comments as inputs to the MCDM model helps to prioritize the economic, public and legal, ecological, and traffic safety elements of these chosen traffic management strategies. The following list outlines the factors that experts believe should be given top priority in this investigation.

Aspects of the Economy
Traffic management systems can't function without sensors (AVC1). It is critical to reduce the price of this technology to increase its appeal.

There is a cost associated with staffing traffic control centers and traffic management systems. That method will be preferred if the cost of employees can be reduced (AVC2).

Traffic equipment cost (AVC3): This displays the entire cost of adopting the traffic management system, which includes the costs of sensors and traffic lights. These sensors can also help AVs get about in a smart city. In the literature, frameworks for more efficient use of these sensors, particularly with AVs, are being created.
Reduced equipment costs make the system more appealing.
The aspect of the Public and the Political
There are several ways in which traffic congestion may be reduced without the need for additional road infrastructure, such as using traffic management systems. The public's quality of life should increase when traffic congestion decreases(AVC4).

It's important to note that various traffic management methods might have different benefits and drawbacks depending on the situation. For example, the most effective way to reduce pollution levels caused by traffic congestion is to determine the optimal speed limit. However, the effectiveness of this strategy is heavily reliant on how well drivers comply. Aside from the positive effects of technology advancements in AV, there may be negative implications, such as increased transportation demand and modal shift, which should be taken into consideration.

Improved technology (AVC5): Increasing rates of benefit by optimizing operational expenses is possible with improved technology. It is better to use technical approaches to improve the system rather than to develop new facilities.

City attractiveness (AVC6): The adoption of technical and effective traffic management measures will provide a feeling of safety and increase the city's appeal to tourists from other cities.

To improve the quality of life for its residents, it is essential to improve traffic conditions. It is also possible to garner significant political favor in this manner (AVC7).

The Impact on the Environment
Implementing effective traffic management would reduce CO_2 emissions (AVC8). In addition to improving traffic problems, these technologies also have environmental benefits.

Traffic management systems (AVC9): Instead of constructing new infrastructure, such as better roads, traffic management systems may increase the efficiency of existing infrastructure.
Traffic safety is a factor

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Many real-time traffic control solutions depend on drivers adhering to the instructions given to them by signs. Autonomous vehicles (AVs), for example, have the potential to eliminate accidents caused by driver mistakes or adherence to the norms of the road. This will have a significant positive impact on traffic safety (AVC10).

A lack of uniformity in traffic speeds (AVC11) leads to more encounters and overtaking maneuvers on freeways with substantial speed variances. Since accidents are more likely when traffic speeds are consistent, this makes sense. AVs, for example, is predicted to be much more capable than human drivers. The significant disparities in speed between various vehicles may be decreased, making traffic significantly safer, thanks to the AVs' ability to follow speed values far more efficiently than human drivers.

One of the top causes of mortality in the United States (US) is traffic collisions. Using real-time traffic management technologies to increase traffic safety and reduce fatalities is a significant benefit to public health (AVC12).

AVC13: Lane management is one of the main causes of congestion since drivers often change lanes without realizing it. Improved traffic conditions may be achieved by requiring automobiles to stay in their lane and avoid needless lane changes.

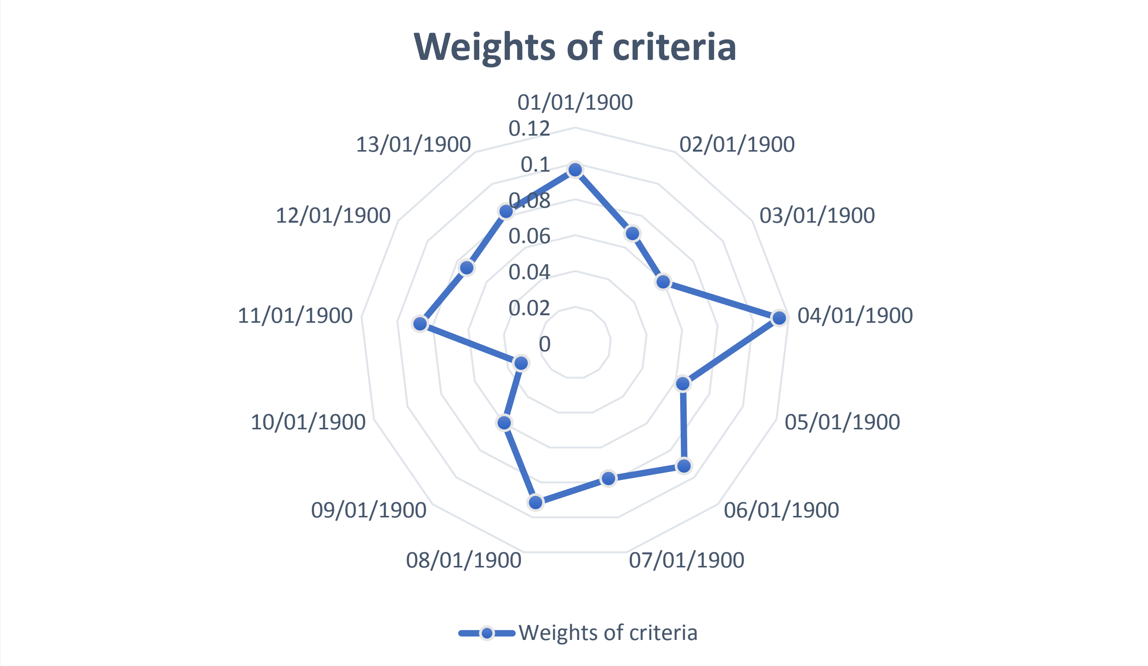

Figure 2: The weights of criteria.

This study used three experts who have expertise in this field to evaluate criteria and alternatives. Then obtain three decision matrices by the decision-makers. Then aggregate these matrices into one matrix as shown in table 1.

Table 1: The combined opinions of experts.

	AVC 1	AVC 2	AVC 3	AVC 4	AVC 5	AVC 6	AVC 7	AVC 8	AVC 9	AVC 10	AVC 11	AVC 12	AVC 13
AV A1	8.333 333	6.333 333	5	4.333 333	6	7	2.666 667	6	5.666 667	5	4.666 667	6.666 667	4.666 667
AV A2	5	5	6	5.666 667	7	7.666 667	6.666 667	8	5.666 667	4	6	6	4
AV A3	2.333 333	3.666 667	3.333 333	5	4	5	4.333 333	6	3	5	4.333 333	7.666 667	5.666 667
AV	5	5.333	5.666	6.333	7.333	5.666	3.333	4.666	5	7.333	4.333	3.333	8

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A4		333	667	333	333	667	333	667		333	333	333	
AV A5	6	4.333 333	8	2.666 667	2.666 667	4.666 667	5.333 333	3.666 667	7	5.333 333	6	5.333 333	7.666 667
AV A6	6	5.666 667	3.333 333	4	3.666 667	6.666 667	2.666 667	5.666 667	4	5.666 667	2.333 333	6.333 333	4.333 333

Then normalize the decision matrix by the positive and cost criteria as shown in table 2. Then let experts evaluate the criteria, then normalized their values to obtain the weights of the criteria as shown in figure 2.

Table 2: The normalization matrix

	AV C1	AVC 2	AVC 3	AVC 4	AVC 5	AVC 6	AV C7	AVC 8	AVC 9	AVC 10	AVC 11	AVC 12	AVC 13
AV A1	1	1	0.625	0.684 211	0.818 182	0.913 043	0.4	0.75	0.809 524	0.681 818	0.777 778	0.869 565	0.583 333
AV A2	0.6	0.789 474	0.75	0.894 737	0.954 545	1	1	1	0.809 524	0.545 455	1	0.782 609	0.5
AV A3	0.2 8	0.578 947	0.416 667	0.789 474	0.545 455	0.652 174	0.6 5	0.75	0.428 571	0.681 818	0.722 222	1	0.708 333
AV A4	0.6	0.842 105	0.708 333	1	1	0.739 13	0.5	0.583 333	0.714 286	1	0.722 222	0.434 783	1
AV A5	0.7 2	0.684 211	1	0.421 053	0.363 636	0.608 696	0.8	0.458 333	1	0.727 273	1	0.695 652	0.958 333
AV A6	0.7 2	0.894 737	0.416 667	0.631 579	0.5	0.869 565	0.4	0.708 333	0.571 429	0.772 727	0.388 889	0.826 087	0.541 667

Then compute the values of WSM and WPM by using Eq. (4,5) as shown in Table 3,4.

Table 3: The values of WSM.

	AVC 1	AVC 2	AVC 3	AVC 4	AVC 5	AVC 6	AVC 7	AVC 8	AVC 9	AVC 10	AVC 11	AVC 12	AVC 13
AV A1	0.096 33	0.068 807	0.037 271	0.078 465	0.052 544	0.083 765	0.031 193	0.068 807	0.048 274	0.021 893	0.067 788	0.063 821	0.048 165
AV A2	0.057 798	0.054 322	0.044 725	0.102 607	0.061 301	0.091 743	0.077 982	0.091 743	0.048 274	0.017 515	0.087 156	0.057 439	0.041 284
AV A3	0.026 972	0.039 836	0.024 847	0.090 536	0.035 029	0.059 832	0.050 688	0.068 807	0.025 557	0.021 893	0.062 946	0.073 394	0.058 486
AV A4	0.057 798	0.057 943	0.042 24	0.114 679	0.064 22	0.067 81	0.038 991	0.053 517	0.042 595	0.032 11	0.062 946	0.031 911	0.082 569
AV A5	0.069 358	0.047 079	0.059 633	0.048 286	0.023 353	0.055 844	0.062 385	0.042 049	0.059 633	0.023 353	0.087 156	0.051 057	0.079 128
AV A6	0.069 358	0.061 564	0.024 847	0.072 429	0.032 11	0.079 777	0.031 193	0.064 985	0.034 076	0.024 812	0.033 894	0.060 63	0.044 725

Table 4: The values of WPM.

	AVC 1	AVC 2	AVC 3	AVC 4	AVC 5	AVC 6	AVC 7	AVC 8	AVC 9	AVC 10	AVC 11	AVC 12	AVC 13
AV A1	1	1	0.972 361	0.957 414	0.987 196	0.991 689	0.931 039	0.973 952	0.987 478	0.987 777	0.978 335	0.989 795	0.956 471
AV A2	0.951 983	0.983 866	0.982 991	0.987 326	0.997 017	1	1	1	0.987 478	0.980 725	1	0.982 17	0.944 375
AV A3	0.884 595	0.963 092	0.949 133	0.973 255	0.961 822	0.961 544	0.966 965	0.973 952	0.950 728	0.987 777	0.972 036	1	0.971 928
AV A4	0.951 983	0.988 245	0.979 646	1	1	0.972 649	0.947 382	0.951 753	0.980 135	1	0.972 036	0.940 7	1

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AV A5	0.968 851	0.974 226	1	0.905 564	0.937 1	0.955 477	0.982 749	0.930 927	1	0.989 827	1	0.973 716	0.996 492
AV A6	0.968 851	0.992 376	0.949 133	0.948 666	0.956 462	0.987 26	0.931 039	0.968 858	0.967 179	0.991 755	0.920 981	0.986 075	0.950 637

For each choice, the overall relative significance of that alternative is calculated by using Eq. (6). Then rank alternatives based on the largest value of Q_i as shown in figure 3. From figure 3. The AVA2 is the best alternative and AVA6 is the worst alternative.

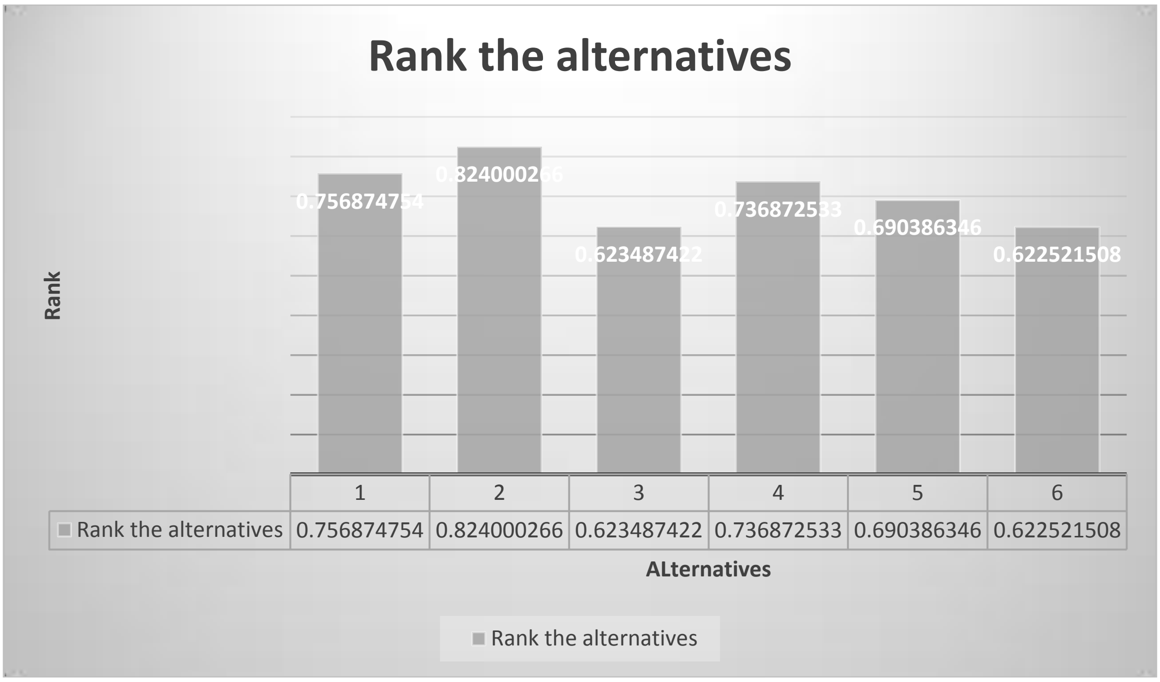

Figure 3: The rank of alternatives.

5. Conclusion

This research intends to offer an efficient WASPAS model to solve the advantage prioritization of real-time traffic management strategies to be discussed here. The three primary phases of the proposed MCDM model are as follows: MCDM inputs like criteria, options, and experts are determined in the first step. The WASPAS is used to compute the weights of criteria in the second step. At this point, each option is rated according to its significant weight. Alternative AVA2 is recommended for real-time traffic management based on the methods presented.

Increased participation of specialists in research and analysis of real-time data, on which the first decision matrix will be built, should be a focus of future research efforts. Decisions would be made in real-time, using the full power of the WASOAS approach. A universal adaptive decision-making tool based on the WASPAS approach should also be investigated further. It is possible to use a varied number of decision criteria depending on the predefined characteristics of a predefined database in the WASPAS approach. Additional uncertainty theories should be considered as part of the suggested method's expansion. On the other hand, implementing each one of the study's six high-priority options can have a varied set of outcomes depending on where it is implemented. Ramp metering, for example, might have a greater impact in regions with a high level of traffic congestion. Therefore, in future investigations, additional real-time traffic management systems or their combinations may be explored as an alternative to the approaches presented in this article.

References

[1] T. Yigitcanlar, M. Kamruzzaman, M. Foth, J. Sabatini-Marques, E. da Costa, and G. Ioppolo, "Can cities become smart without being sustainable? A systematic review of the literature," *Sustainable cities and society*, vol. 45, pp. 348–365, 2019.

Doi : https://doi.org/10.54216/IJWAC.030204
Received: June 05, 2021 Accepted: August 14, 2021

[2] P. Chun and M. D. Fontaine, “Evaluation of the impact of the I-66 active traffic management system,” Virginia Transportation Research Council, 2016.

[3] Z. H. Khattak, H. Park, S. Hong, R. A. Boateng, and B. L. Smith, “Investigating cybersecurity issues in active traffic management systems,” *Transportation research record*, vol. 2672, no. 19, pp. 79–90, 2018.

[4] B. Kuhn, K. Balke, N. Wood, and J. Colyar, “Active Traffic Management (ATM) Implementation and Operations Guide,” United States. Federal Highway Administration, 2017.

[5] N. B. Hounsell, B. P. Shrestha, J. Piao, and M. McDonald, “Review of urban traffic management and the impacts of new vehicle technologies,” *IET intelligent transport systems*, vol. 3, no. 4, pp. 419–428, 2009.

[6] M. Gohar, M. Muzammal, and A. U. Rahman, “SMART TSS: Defining transportation system behavior using big data analytics in smart cities,” *Sustainable cities and society*, vol. 41, pp. 114–119, 2018.

[7] M. M. Rathore, A. Paul, W.-H. Hong, H. Seo, I. Awan, and S. Saeed, “Exploiting IoT and big data analytics: Defining smart digital city using real-time urban data,” *Sustainable cities and society*, vol. 40, pp. 600–610, 2018.

[8] Z. H. Khattak and M. D. Fontaine, “A Bayesian modeling framework for crash severity effects of active traffic management systems,” *Accident Analysis & Prevention*, vol. 145, p. 105544, 2020.

[9] C. Antoniou, H. N. Koutsopoulos, and M. Ben-Akiva, *Kalman filter applications for traffic management*. INTECH Open Access Publisher, 2010.

[10] T. Luettel, M. Himmelsbach, and H.-J. Wuensche, “Autonomous ground vehicles—Concepts and a path to the future,” *Proceedings of the IEEE*, vol. 100, no. Special Centennial Issue, pp. 1831–1839, 2012.

[11] S. A. E. O.-R. A. V. S. Committee, “Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles,” *SAE International: Warrendale, PA, USA*, 2018.

[12] A. Chehri and H. T. Mouftah, “Autonomous vehicles in the sustainable cities, the beginning of a green adventure,” *Sustainable Cities and Society*, vol. 51, p. 101751, 2019.

[13] M. Makridis, K. Mattas, B. Ciuffo, M. A. Raposo, T. Toledo, and C. Thiel, “Connected and automated vehicles on a freeway scenario. Effect on traffic congestion and network capacity,” *7th Transport Research Arena*, p. 13, 2018.

[14] A. Talebpour and H. S. Mahmassani, “Influence of connected and autonomous vehicles on traffic flow stability and throughput,” *Transportation Research Part C: Emerging Technologies*, vol. 71, pp. 143–163, 2016.

[15] A. Kuraksin, A. Shemyakin, and A. Parshkov, “Integrated assessment of traffic management efficiency in real time based on DTA model,” *Transportation Research Procedia*, vol. 50, pp. 337–345, 2020.

[16] P. Wang, H. Zhao, L. Wang, Z. He, and D. Wu, “A dynamic speed guidance model based on cooperative vehicle infrastructure system,” in *2016 Chinese Control and Decision Conference (CCDC)*, 2016, pp. 3974–3979.

[17] H. Chen and G. Abu-Lebdeh, “Assessment of Capacity and Flow Improvements of Combined Dynamic Signal Control and Dynamic Speed Limits in Signalized Networks,” 2006.

[18] S. Chen, J. Sun, and J. Yao, “Development and simulation application of a dynamic speed dynamic signal strategy for arterial traffic management,” in *2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 2011, pp. 1349–1354.

[19] D. S. Chen, X. X. Yu, K. Q. Hu, X. Sun, and Y. Y. Xia, “Safety-oriented speed guidance of urban expressway under model predictive control,” *International journal of simulation modelling*, vol. 13, no. 2, pp. 219–229, 2014.

[20] M. Jha, D. Cuneo, and M. Ben-Akiva, “Evaluation of freeway lane control for incident management,” *Journal of transportation engineering*, vol. 125, no. 6, pp. 495–501, 1999.

[21] K. A. Harder and J. R. Bloomfield, “Investigating the Effectiveness of Intelligent Lane Control Signals on Driver Behavior,” 2012.

[22] L. Schaefer, J. Upchurch, and S. A. Ashur, “An evaluation of freeway lane control signing using computer simulation,” *Mathematical and computer modelling*, vol. 27, no. 9–11, pp. 177–187, 1998.

[23] K. Chatterjee and M. Mcdonald, “Effectiveness of using variable message signs to disseminate dynamic traffic information: Evidence from field trails in European cities,” *Transport Reviews*, vol. 24, no. 5, pp. 559–585, 2004.

[24] W. Zhao, Z. Ma, K. Yang, H. Huang, F. Monsuur, and J. Lee, “Impacts of variable message signs on en-route route choice behavior,” *Transportation Research Part A: Policy and Practice*, vol. 139, pp. 335–349, 2020.

[25] E. Van den Hoogen and S. Smulders, “Control by variable speed signs: results of the Dutch experiment,” 1994.

[26] P. Kachroo and K. Özbay, *Feedback ramp metering in intelligent transportation systems*. Springer Science & Business Media, 2003.

[27] A. G. Hobeika, R. Sivanandan, S. Subramaniam, K. Ozbay, and Y. Zhang, “Real-time traffic diversion model: Conceptual approach,” *Journal of transportation engineering*, vol. 119, no. 4, pp. 515–534,

Doi : https://doi.org/10.54216/IJWAC.030204

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1993.

[28] A. A. AlZubi, A. Alarifi, M. Al-Maitah, and O. Alheyasat, "Multi-sensor information fusion for Internet of Things assisted automated guided vehicles in smart city," *Sustainable Cities and Society*, vol. 64, p. 102539, 2021.

[29] J. Tang, A. McNabola, and B. Misstear, "The potential impacts of different traffic management strategies on air pollution and public health for a more sustainable city: A modelling case study from Dublin, Ireland," *Sustainable Cities and Society*, vol. 60, p. 102229, 2020.

[30] S. Sohrabi, H. Khreis, and D. Lord, "Impacts of autonomous vehicles on public health: A conceptual model and policy recommendations," *Sustainable Cities and Society*, vol. 63, p. 102457, 2020.

[31] M. Barth and K. Boriboonsomsin, "Traffic congestion and greenhouse gases," *Access Magazine*, vol. 1, no. 35, pp. 2–9, 2009.

[32] M. F. Ballesteros, K. Webb, and R. J. McClure, "A review of CDC's Web-based Injury Statistics Query and Reporting System (WISQARS^{TM}): Planning for the future of injury surveillance," *Journal of safety research*, vol. 61, pp. 211–215, 2017.

[33] I. Gökaşar, "Şerit Kontrol Sistemleri: D 100 Karayolu, İstanbul Örneği," *İMO Teknik Dergi*, vol. 134, pp. 7635–7657, 2016.

Doi : https://doi.org/10.54216/IJWAC.030204

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