**A Metaverse Assessment Model for Sustainable Transportation Using Ordinal Priority Approach and Aczel-Alsina Norms**

**Abstract**

Metaverse comes from the meta-universe, and it is the integration of physical and digital space into a virtual universe. Metaverse technologies will change the transportation system as we know it. Preparations for the transition of the transportation systems into the world of metaverse are underway. This study considers four alternative metaverses: auto-driving algorithm testing for training autonomous driving artificial intelligence, public transportation operation and safety, traffic operation, and sharing economy applications to obtain sustainable transportation. These alternatives are evaluated on thirteen sub-criteria, grouped under four main aspects: efficiency, operation, social and health, and legislation and regulation. A novel Rough Aczel–Alsa (RAA) function and the Ordinal Priority Approach (OPA) method are used in the assessment model. We also present a case study to demonstrate the applicability and exhibit the efficacy of the assessment framework in prioritizing the metaverse implementation alternatives.

***Keywords:*** Metaverse, transportation engineering, Ordinal priority approach, Multi-criteria decision making, Aczel – Alsina functions.

# Introduction

The metaverse is a cosmos that combines physical reality and digital virtuality in a continual multi-user environment. Metaverse is built on the convergence of technologies, such as virtual reality and augmented reality, enabling multimodal interactions with virtual environments, digital elements, and people. As a result, the metaverse is a web of social, networked, unique experiences in multi-user persistent platforms (Mystakidis, 2021). Even though proto-metaverse has been developed and used in the gaming industry for many years, the potential benefits from metaverse technology have yet to be fully realized (Oxford Analytica, 2022). This promising technology has attracted the attention of many companies, such as Facebook and Nvidia. Facebook changed the company’s name to Meta in October 2021 after investing in metaverse technologies (Kraus et al., 2022). Metaverse is a blockchain-driven technology that has the potential to become the next big thing, where people create avatars for their identities.

A metaverse is a virtual universe where people connect and spend time. Where there are people, there is a need for transportation. Implementing systems such as public transportation and sharing economy applications (car-sharing, bicycle sharing, e-scooter) are promising applications of metaverse systems since identity verification and payment processing are conducted more efficiently via blockchain technology and avatars. Thus, there are enormous advantages and opportunities in implementing transportation systems with metaverse technology (Chen and Yao, 2021). For instance, there is a need for vast data to train autonomous vehicles (Schmidt, 2019). Implementing autonomous vehicles into the metaverse and using these vehicles in the virtual medium is a promising integration. Gathering real-time driving data and training the artificial intelligence (AI) systems of autonomous vehicles through the obtained data is also becoming very popular.

The application of the metaverse will inevitably impact the transportation sector, and the goal of this study is to provide a foundation for decision-makers and policymakers by evaluating the benefits and drawbacks of various transportation alternatives. These alternatives include auto-driving algorithm testing for training autonomous driving artificial intelligence, public transportation operation and safety, traffic operation (traffic management, incident management, etc.), and sharing economy applications (car-sharing, bicycle sharing, e-scooter, etc.).

Nonlinear modeling has been successfully applied to many problems and various applications (Pozna et al., 2012; Christudas et al., 2020; Hedrea et al., 2021; Milosevic et al., 2021). We propose a novel Rough Aczel–Alsa (RAA) function for the nonlinear processing of subjectivity. Aczel–Alsina functions are used to improve the flexibility of the proposed methodology, thus enabling the adaptation of the methodological framework to dynamic environments. In addition to the RAA evaluation methodology, a rough extension of the Ordinal Priority Approach (OPA) method (Ataei et al., 2020) is proposed to determine rough criteria weights. We can point out the following advantages of the OPA methodology:

* Most subjective models for determining criterion/alternative weighting coefficients are based on comparisons in pairs of home matrix elements. This increases the number of comparisons and impairs the solution’s quality. On the other hand, the OPA method is based on defining weighting criteria/alternatives based on predefined ranks, thus eliminating the problem of a limited range of predefined scales for comparing the criteria (Durmic et al., 2020; Dwivedi et al., 2021; Alosta et al., 2021; Pamucar and Dimitrijevic, 2021); and
* The OPA mathematical models can simultaneously define and use expert weights, attributes, and alternatives.

The RAA methodology uses nonlinear aggregation functions to allow for the integration of risk attitudes. The RAA methodology has an original algorithm for the normalization of home matrix elements that enable the preservation of the disposition of natural and normalized attribute values. This eliminates the need for standardizing ​​the normalized cost and benefit criteria values. We can summarize the following advantages:

* The RAA method is a multicriteria framework with a novel methodology for generating rough numbers.
* The RAA methodology’s standardization of home matrix elements is achieved by applying the inverse sorting algorithm, which enables: (i) preservation of the disposition of normalized values ​​on the measuring scale and (ii) absence of domain shift or a distortion of the source data.
* The rough OPA algorithm is based on the prioritization of criteria based on rough numbers, which significantly facilitates the presentation of expert preferences. In addition, this eliminates the problem of the limited range for predefined scales for comparing criteria in some multicriteria methods.
* The proposed rough OPA mathematical model has a dual role. It can be used simultaneously to prioritize and define the weighting coefficients of attributes and alternatives.
* The proposed multicriteria framework can be used for group and individual decision-making.

The remainder of the paper is organized as follows. Section 2 provides a thorough review of the relevant literature. The problem definitions, including the alternatives and the criteria, are presented in Section 3. Sections 4 and 5 introduce the proposed method and the case study. Section 6 presents our conclusion and future research directions.

# Literature Review

Implementation of transportation system alternatives into the metaverse system has many benefits considering the ease of transportation in the virtual reality medium and the development of various transportation technologies, such as autonomous vehicles and traffic operation systems. The recent blockchain innovations and 3D virtual networks have enabled the integration of many transportation systems into the metaverse world. These innovations provide decision-makers with a wide range of options regarding implementing alternative transportation systems.

One alternative transportation system to implement into the metaverse is autonomous vehicles. These vehicles are well-developed and are still evolving technologically (Todorovic et al., 2017). However, the artificial intelligence (AI) system in the vehicle must be trained to allow their integration into the real-life traffic flow, but this date is not readily available (Schmidt, 2019). That is where the metaverse comes in handy since deploying the vehicles in the virtual world has the potential to create a large amount of driver data, which can be used to train autonomous vehicles so that they can be used in real-life.

The utilization of public transportation services in the metaverse is essential since transportation is necessary even if the medium is virtual. Also, the utilization of public transportation in the metaverse is very promising in terms of optimization and integration of the public transportation modes. Optimization studies are done using big mobility data (Wang et al., 2021; Iliopoulou and Kepaptsoglou, 2019). Such data collection is much easier in the metaverse since it can be collected via the user’s avatar through blockchain technology. Therefore, utilization of public transportation in the metaverse is very beneficial and can be very well optimized.

Traffic operations such as traffic management and incident management require real-time traffic data (Ning et al., 2019). The real-time traffic data can be collected through sensors and transmitted to the algorithm for further processing (Barthelemy et al., 2019). Alternatively, real-time traffic data can be accessed through an interface module placed in the passenger vehicles (Manikonda et al., 2011). While collecting real-time traffic data is costly and time-consuming in real life, this is not the case in the metaverse since data collection, processing, and utilization of traffic operations can be conducted efficiently and quickly through blockchain technology.

In the sharing economy world, car-sharing, bicycle sharing, or e-scooter are challenging for reasons such as customer behavior (Nansubuga and Kowalkowski, 2021). It is much easier to monitor the customers’ behavior in the metaverse since all avatars, vehicles, and services are connected to the blockchain. Therefore, providing a better service for the next customer is easier for the sharing economy authorities. Also, integrating sharing economy applications into the metaverse is very promising. The main challenges faced in the real world are not an issue in the virtual world—only a few studies on implementing transportation system alternatives into the metaverse.

# Problem Definition

Evaluating alternative transportation systems in metaverses is new and challenging due to the complex nature of the problem and the existence of multiple and often conflicting criteria (Chen and Yao, 2021).

## Definition of Alternatives

Metaverse technology provides users with a different experience by reconciling the physical world with the digital world. Integrating virtual reality with the metaverse world is challenging. The metaverse world contains many features from the physical world. The following four alternatives are considered in this study:

*A1: Metaverse uses in auto-driving algorithm testing to training autonomous driving AI:* High-fidelity simulation is critical in autonomous vehicle testing. Specific software, including mathematical representations of the subsystems, should achieve realistic system dynamics. Hundreds of millions of kilometers are required to prove that it provides a statistically safe driving opportunity, and the number of scenarios that can be tested is limited. With metaverse and artificial intelligence, there will be a significant improvement in the number of scenarios to be tested (Schöner, 2018; Huang et al., 2016).

*A2: Metaverse uses in public transportation operation and safety:* Efficient public transportation is a critical concern in today’s cities. When planning a bus route, a tram line, or a subway line, it’s essential to think about how many people will use the service. Strengthening public transportation networks has received little attention thus far. In many cities, these networks were developed in a logical order that no longer meets the needs of the consumers. The shortest distance and shortest route from node x to node y, taking vehicle waiting times into consideration, must be determined to evaluate a public transportation network. A typical complex network consists of many bus routes, and bus stops forming the urban public transportation system. Some researchers have used complex network thinking to investigate public transportation issues. Efficiency and effective management can be achieved by using AI during testing and operation (Baloian, 2015; Wang et al., 2020).

*A3: Metaverse uses in traffic operations and incident management:* AI is used by traffic engineers to predict congestion and collision formation on our roadway networks, providing users with real-time data to help them make smarter travel decisions. The ability of this model to perform effectively in unobserved scenarios with no publicly available data is a significant advantage. With the metaverse, AI can make more accurate and effective decisions (Haque, 2022; Abbink et al., 2020).

*A4: Metaverse uses in sharing economy:* The sharing economy is a phenomenon where people rent or borrow goods and services instead of buying them. The sharing economy has the potential to increase efficiency, save money, monetize unused resources, and benefit society and the environment. Micro-mobility, or the shared use of bicycles, scooters, or other low-speed transport, are innovative modes of transportation. With the Internet and AI, the main applications will show how they should be combined in the system to coordinate human and machine activities. The confusion, friction, and waste caused by poorly aligned operations will be much less, while the synergy created by good cooperation will be significantly increased (Heylighen, 2017; Shaheen and Cohen et al., 2021).

## Definition of Criteria

In this study, thirteen criteria under four aspects are determined and defined as follows:

* + 1. *Efficiency aspect*

*C1: Efficient and smart city gains (benefit)*: A smart city essentially refers to a framework composed of IoT and cloud computing that collects, manages, and analyzes data to help cities be more efficient and responsive to citizens. It has many potential applications, ranging from IoT-enabled traffic management systems that reduce traffic congestion and accidents to smart grids, saving energy and allowing easier penetration of renewable energy. Thanks to the metaverse, integration and productivity increase between different sectors will be realized (Duan et al., 2021)

*C2: Efficient use of labor (benefit)*: Remote work and electronic communication are becoming more common. The future of employment may entail something other than Zoom. Large technology investments point to a metaverse that will allow for new forms of labor, such as the “infinite office,” and transform the digital economy. Users will create an avatar, discuss on a whiteboard with others, stream what’s on their laptops, take notes, and connect with coworkers who video conference in the virtual room while sitting at their physical, real-world workstation (Jeon et al., 2022).

*C3: Efficient public services (benefits)*: With the created institutional spaces, people will have access to public services provided by the state and ease in getting their work done without being exposed to transportation or physical barriers. Thanks to the created avatars, speed and security will be provided in the transactions (Ma et al., 2019).

* + 1. *Operation aspect*

*C4: Improved traffic operation (benefit)*: Increasing efficiency with the active use of technology, which started with smart transportation systems in traffic, will become more effective thanks to the use of metaverse, rapid warnings, directions, and decision-making mechanisms. Metaverse involves creating high-fidelity digital twins of the objects we experience physically—including transportation infrastructure, from big things like airports and highways to bus shelters and bicycle racks—and then managing those things digitally (Sukhadia et al., 2020).

*C5: Improved public transportation operation (benefit)*: In the management of public transportation, which is a complex field, it is expected that the acceleration and impact will increase thanks to AI in the integration and timing of different public transportation alternatives, considering the different sensitivities of people such as demand and time, and evaluating different scenarios together (Kouziokas, 2017). Using collected data to optimize public transportation operations is a promising way to increase sustainability. By optimizing public transportation, the same number of commuters can be served with fewer trips, vehicles, or more efficient routes. Data for optimization can also be collected using technology and the metaverse. Commuter data can be collected using users’ avatars and stored in blockchain technology for further analysis, such as optimization.

*C6: Improved technology uses in transportation (benefit)*: It is expected that technological developments such as enabling convenience in payment transactions and introducing cryptocurrencies would occur due to the avatars produced with metaverse. Virtual reality, a computer-generated simulation of a 3D image or environment, and augmented reality, which superimposes a computer-generated image over a user’s perspective of the real world, will be key in bringing the metaverse to life. Transportation planning, management, and testing are projected to benefit from these technologies (Abduljabbar et al., 2019). Currently, existing transportation network technologies are used to provide services and ease of use. Intelligent transportation systems are an example of the infrastructures that can be obtained due to this increasing technological integration. Because international standards are used instead of state rules in smart payment methods and cryptocurrencies, which have become common in every field except transportation, the determination, and spread of these standards will be rapid.

* + 1. *Social and health aspects*

*C7: Increased social distancing (cost)*: Due to the decrease in participation in real life, since people spend a lot of time in virtual reality, there is a high probability that there will be situations where they will not have real social relations with people and will become increasingly lonely (Venkatesh and Edirappuli, 2020).

*C8: Affordability issues (cost)*: In the world created with the metaverse, situations such as buying space and products in the economic sense, through virtual reality and crypto money, may occur, and situations such as people who do not have the opportunity and power to provide this in economic terms may be victims and laggards (Fleming, 2018). Like all other technologies, the metaverse may not be affordable to all segments when it first becomes widely available. As its usage and applications grow, it is expected that prices will come down. Furthermore, financial incentives are envisioned if encouraged to be used by the state for public services.

*C9: Personal security issues (cost)*: Theft of personal information is possible. Children might be subjected to even more privacy intrusions if metaverse platforms could collect photographs and other personal information from their users. Advertisers may easily flood the metaverse with their messages. Constant video pop-ups, sponsored material, and repeating adverts may be even more annoying to consumers due to the metaverse’s sensory overload. As augmented reality becomes more prevalent, users may be misdirected into potentially dangerous scenarios such as robberies (Pietro and Cresci, 2021).

*C10: Overall health issues (cost):* In cases such as spending a lot of time in the world created with virtual reality, there is a possibility of health problems because of physical inactivity and psychological problems among people due to the difference between life in a world that is not real in a psychological sense and real-life (Dionisio et al., 2013)

* + 1. *Legislation and regulation aspect*

*C11: The potential liability of the metaverse service providers (cost):* In the metaverse, much of the application of existing laws, as well as the potential development of new laws, is unknown. Existing legal schemes may apply in some circumstances. In other cases, established rules may be incompatible with modern technology, and the courts may be challenged to resolve unique application issues. In other circumstances, current laws may be insufficient to curb undesirable behavior, necessitating the introduction of new legislation. The breadth of all rules and regulations that can or might be implicated in a metaverse is virtually limitless, resulting in many legal concerns (Garon, 2022).

*C12: Disputes over the ownership of the intellectual property in the metaverse (cost)*: There are uncertainties about the legal use of intellectual property and rights. Problems may arise, such as the invalidity of intellectual property agreements determined by licensees or buyers previously determined on the Internet. The protection of license rights in the projects developed remains a significant issue (Omorov,2020).

*C13: Issues relating to the adverse content of the metaverse (cost):* Due to the absence of restrictions and laws in the created 3D world and augmented virtual reality, it is expected that people may be affected psychologically in case of inappropriate content and behaviors (Collins, 2008).

# Proposed Methodology

In this section, some key concepts and the steps of the proposed methodology are presented that are important for defining the multi-criteria framework presented in this study.

## Rough numbers

Rough sets (Pawlak, 1982) are one of the critical tools in soft computing and modeling of decision support systems. Because of their ability to effectively address uncertainties and uncertainties in human reasoning, rough sets have become an indispensable factor in modeling complex systems for rational decision-making (Bozanic et al., 2020; Kazemitash et al., 2021; Sharma et al., 2021, 2022; Ali et al., 2021). Zhai et al. (2009) proposed rough numbers based on the concept of rough sets through the definition of the lower limit, the upper limit, and the rough boundary interval based on subjectivism and uncertainty in the information. One of the essential advantages of rough numbers over other interval theories is that the uncertainty footprint is defined based on the width of the rough boundary interval. If imprecisions and uncertainty are eliminated from the data set, the uncertainty footprint is reduced to zero, transforming the rough number into a crisp number. Also, the imprint of uncertainty in the rough boundary interval is defined based on internal information in the data set, eliminating the need to introduce assumptions when defining thresholds (Zhai et al., 2009).

In this study, a novel methodology for defining rough numbers is proposed, which is based on a new concept for defining lower and upper limits for rough numbers. The traditional concept of rough numbers (Zhai et al., 2009) implies the application of arithmetic averaging to define the boundary values ​​of rough boundary intervals. The new concept proposed in this paper involves introducing Bonferroni functions (Bonferroni, 1950) to define rough sequences’ lower and upper limits. The new methodology enables (1) consideration of mutual relations between a set of objects, (2) flexible representation of rough boundary intervals, and (3) simulation of different levels of risk depending on dynamic environmental conditions. The following section presents a methodology for defining rough numbers based on Bonferroni functions.

Suppose that *K* is a universe containing a set of objects  that are divided into *h* classes that satisfy the condition that . If we assume that  is a collection of , then for each , , , we can define the lower and upper approximation of the class  as follows:

|  |  |
| --- | --- |
|  | (1) |

Based on the lower and upper approximation, we can define the lower and upper limits of  as follows:

|  |  |
| --- | --- |
|  | (2) |

where  and  represent the number of elements in (1), and .

Based on Eqs. (1) and (2), we can define a rough number , i.e., . More details on arithmetic operations with rough numbers and the transformation of rough numbers into crisp values can be found in (Durmic et al., 2020).

## Aczel–Alsina T-norm and T-conorm

*Definition 1* (Aczel and Alsina, 1982): Suppose that  and  are real numbers, then the Aczel – Alsina T-norm and T-conorm between  and  can be defined according to the following:

1. Aczel-Alsina *T*-norm , where :

|  |  |
| --- | --- |
|  | (3) |

1. Aczel-Alsina *T*- conorm , where :

|  |  |
| --- | --- |
|  | (4) |

where  and .

Based on *Definition 1* and the operational laws of rough numbers, we can define arithmetic operations based on Aczel – Alsina t -norms and co-norms.

*Definition 2.* Suppose that  and  are two rough numbers, , and let  be a rough function, then based on Eqs. (3) and (4), we can define arithmetic rules with rough numbers based on the application of Aczel – Alsina t ‐ norms and co-norms:

* + 1. Addition ""

|  |  |
| --- | --- |
|  | (5) |

* + 1. Multiplication ""

|  |  |
| --- | --- |
|  | (6) |

* + 1. Scalar multiplication, where .

|  |  |
| --- | --- |
|  | (7) |

* + 1. Power, where 

|  |  |
| --- | --- |
|  | (8) |

Based on *Definition 2*, we can derive the following relations between any two rough numbers  and , provided that it is :

(1) ;

(2) ;

(3) ;

(4) ;

(5) ;

(6) .

## A Novel Rough Aczel–Alsina framework

In the next section of the paper, the original multi-criteria methodology based on rough Aczel–Alsina norms is presented. The novel rough OPA method was used to determine the weighting coefficients of the criteria in the multi-criteria framework. Aczel–Alsina norms were used to determine weighted strategies in the multi-criteria model, while rough numbers were used to process incomplete and inaccurate information in the home matrix. Aczel-Alsina functions were used to generate rough aggregation strategies that define the final aggregation functions. After determining the criterion functions, the stabilization parameters of the Aczel-Alsina function were used to simulate different levels of risk and validate the initial results. In the next part, the novel RAA methodology is presented in Fig. 1.



**Fig. 1.** Rough Aczel–Alsina OPA methodology.

Suppose that in a multi-criteria model, a set of *m* alternatives (*Hi*) and *n* criteria (*Cj*) were used to evaluate the alternatives. Also, suppose that b experts representing the set *Ee* (*e*=1,2,…,*b*) participate in the research. Then, based on the preliminary settings, we can define the algorithm rough Aczel–Alsina methodology through the following steps.

*Step 1:* Generating an aggregated rough home matrix. Experts from *Ee* (*e*=1,2,…,*b*) evaluate alternatives from the considered set (*Hi*) under *n* criteria (*Cj*). Experts use a predefined scale to evaluate alternatives. Based on Eqs. (1) and (2), expert rough initial home matrices  are formed. For the fusion of rough elements  () the rough geometric Bonferroni function was used, Eq. (9):

|  |  |
| --- | --- |
|  | (9) |

We thus obtain the basic rough decision matrix ; ; *i=1,...,m; j=1,...,n*.

*Step 2:* Standardization of aggregate rough home matrices. By applying Eq. (10), the aggregated rough home matrix elements () are standardized into interval values between zero and one. By applying Eq. (10), we obtain a standardized matrix .

|  |  |
| --- | --- |
|  | (10) |

where .

*Step 3:* Defining weight coefficients of criteria. The following section presents the modified rough OPA methodology algorithm for determining the rough weight coefficients of the criteria.

*Step 3.1*. Defining the linguistic matrix  () in which the relative meanings of criteria/sub-criteria based on expert assessments are presented:

|  |  |
| --- | --- |
|  | (11) |

where  represents the relative importance of criterion *j* defined by expert *y* ().

Relative importance is determined using a predefined linguistic scale. By applying the expressions of Eqs. (1) and (2), the expert estimates from the matrix (11) are transformed into rough values and aggregated by applying the rough geometric Bonferroni function. This is how the aggregated rough linguistic matrix  is defined.

*Step 3.2:* Creating a rough numbers-based linear model for calculating the weighting coefficients of the criteria. From the matrix , the criteria were ranked according to their significance. Rough weighting coefficients of successive criteria by rank should satisfy the condition (12).

|  |  |
| --- | --- |
|  | (12) |

where  represents the significance of the *j*th criterion at the *r*th rank.

Based on condition (12), we can define rough numbers based linear model as follows:

|  |  |
| --- | --- |
|  | (13) |

where  represents the rough weighting coefficient of the *j*th criterion.

*Step 4:*Calculate the utility function of alternatives. Based on *Definitions 1 and 2*, we can define a rough Aczel–Alsina weighted averaging function () and a rough Aczel–Alsina weighted geometric averaging function (). In the following section, the theorem defining the rough Aczel–Alsina functions  and  is presented.

*Theorem 1:* Let  (;) be the set of elements of the rough matrix  and let *δ*≥0. If we denote by  () the rough vector of the weight coefficients of the criteria, then the RAA averaging function ( and ) can be represented as follows:

1. Rough Aczel–Alsina weighted averaging function ():

|  |  |
| --- | --- |
|  | (14) |

1. Rough Aczel–Alsina weighted geometric averaging function ():

|  |  |
| --- | --- |
|  | (15) |

, where  () is the vector of the weight coefficients of the criterion, while . Then  represents the rough Aczel–Alsina weighted averaging function, while  RAA weighted geometric averaging function. The proof for *Theorem 1* is presented in *Appendix A****.***

*Step 5:* Calculate the integrated value rough Aczel – Alsa function (), Eq. (16).

|  |  |
| --- | --- |
|  | (16) |

The alternative should have as higher as the possible integrated value of the RAA function.

# Application of Rough Aczel–Alsina Framework

In this application, we formulate a multi-criteria decision-making problem to examine the impact of metaverse technology on sustainable transportation. We consider an environment with a dense population, high education level, intense use of technological tools, and busy transportation activities. We focus on the suitability of the solution and the sustainability of metaverse technology by formulating four different alternatives and thirteen criteria. Experts from academia and the relevant business sectors are contacted, and the literature is reviewed to develop the set of criteria and alternatives. Six decision-makers are interviewed to assess each alternative against the decision criteria.

In the following section, the application of the RAA methodology for the evaluation of proposed solution variants is presented.

*Step 1*: Six experts participated in the research. Experts evaluated four alternatives under thirteen criteria grouped into four clusters, Table 1.

**Table 1**

The metaverse criteria list.

|  |  |  |
| --- | --- | --- |
| Main-criteria | Sub-criteria | Types |
| Efficiency Aspect (MC1) |  |  |
| C1 | Efficient and smart city gains | Benefit |
| C2 | Efficient use of labor | Benefit |
| C3 | Efficient public services | Benefit |
| Operation Aspect (MC2) |  |  |
| C4 | Improved traffic operation | Benefit |
| C5 | Improved public transportation operation | Benefit |
| C6 | Improved technology use in transportation | Benefit |
| Social and Health Aspect (MC3) |  |  |
| C7 | Increased social distancing | Cost |
| C8 | Affordability issues | Cost |
| C9 | Personal security issues | Cost |
| C10 | Overall health issues | Cost |
| Legislation and Regulation Aspect (MC4) |  |  |
| C11 | The potential liability of the metaverse service providers | Cost |
| C12 | Disputes over the ownership of the intellectual property in the metaverse | Cost |
| C13 | Issues relating to the adverse content of the metaverse | Cost |

A nine-point scale was used to evaluate alternatives: Extremely Low (EL) – 1; Medium Low (ML) – 2; Low (L) – 3; Medium (M) – 4; Medium-High (MH) – 5; High (H) – 6; Very High (VH) – 7; Extremely High (EH) – 8; Perfect (P) – 9. Based on expert assessments, a home matrix of expert assessments was formed, Table 2.

**Table 2**

Expert alternative assessments

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Crit. | A1 | A2 | A3 | A4 |
| C1 | VH; P; P; VH; VH; P | EH; EH; EH; P; P; M | VH; EH; VH; EH; H; H | MH; P; H; VH; EH; VH |
| C2 | MH; H; EH; ML; M; H | EH; VH; H; M; VH; EH | M; H; EH; VH; L; VH | VH; L; H; VH; EH; M |
| C3 | H; H; EH; L; L; L | P; P; VH; EH; P; P | VH; EH; VH; H; VH; M | H; M; VH; H; EH; M |
| C4 | VH; P; VH; EH; EH; P | EH; P; H; EH; MH; VH | P; P; EH; P; P; P | VH; EH; MH; H; MH; M |
| C5 | H; VH; VH; M; MH; MH | P; P; VH; P; P; P | VH; H; VH; MH; H; M | H; VH; M; EH; M; ML |
| C6 | P; EH; H; P; P; EH | VH; H; H; VH; H; MH | H; P; VH; H; P; P | EH; P; VH; VH; EH; H |
| C7 | M; MH; ML; EH; H; H | L; H; ML; VH; EH; P | L; P; H; EH; L; L | ML; EH; L; L; H; MH |
| C8 | M; ML; L; H; ML; ML | L; M; L; EH; P; P | M; M; L; EH; EL; ML | L; ML; L; M; M; VH |
| C9 | ML; H; L; VH; H; M | EL; H; ML; VH; M; L | ML; L; ML; H; ML; EL | L; M; L; ML; M; M |
| C10 | M; L; ML; ML; L; ML | ML; EH; ML; M; P; P | ML; L; ML; EL; H; EL | L; VH; L; VH; VH; EH |
| C11 | L; ML; H; VH; L; EL | ML; ML; ML; EH; L; EH | EL; ML; ML; VH; L; EL | L; L; L; L; ML; EL |
| C12 | M; L; MH; EH; H; MH | ML; L; L; EH; EH; EH | EL; EH; M; VH; P; M | ML; EH; MH; L; L; ML |
| C13 | L; P; M; EH; P; VH | ML; L; MH; EH; ML; H | ML; EH; M; EH; P; P | L; P; ML; H; ML; L |

Using Eqs. (1) and (2), the expert estimates from Table 2 were transformed into rough values. Rough expert estimates were aggregated using the rough Bonferroni function (9), and an aggregated rough home matrix  was formed, which is given in Table 3.

**Table 3**

Aggregate rough home matrix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | A1 | A2 | A3 | A4 |
| C1 | [7.33,8.31] | [8.10,8.59] | [6.74,7.61] | [6.06,8.14] |
| C2 | [3.61,6.69] | [5.49,7.31] | [4.34,7.02] | [4.99,7.26] |
| C3 | [4.09,6.60] | [7.91,8.72] | [6.62,7.42] | [5.35,7.18] |
| C4 | [7.34,8.32] | [6.27,8.22] | [8.54,8.82] | [5.51,7.13] |
| C5 | [5.07,6.54] | [8.21,8.79] | [5.75,6.62] | [4.82,6.98] |
| C6 | [7.51,8.69] | [6.13,6.62] | [6.69,8.27] | [7.34,8.32] |
| C7 | [3.61,6.69] | [3.51,7.23] | [4.21,7.53] | [3.14,6.20] |
| C8 | [2.59,4.69] | [3.94,7.28] | [2.57,5.92] | [2.79,4.59] |
| C9 | [3.52,6.10] | [2.35,5.73] | [2.36,4.23] | [2.77,3.66] |
| C10 | [2.40,3.38] | [3.15,7.07] | [1.89,4.31] | [4.34,6.64] |
| C11 | [3.07,5.65] | [2.47,5.18] | [1.94,4.82] | [2.62,2.92] |
| C12 | [4.14,6.74] | [3.46,6.47] | [3.32,7.74] | [3.07,6.05] |
| C13 | [4.96,8.14] | [2.78,5.93] | [4.29,7.91] | [2.90,6.62] |

The following section presents the transformation of expert estimates at position A1-C1 into rough values. Based on the expert estimates from Table 2 at position A1-C1, we can form a set of expert sequences . Using the Eqs. (1) and (2) and provided that *d1=d2=1*, we can define the lower and upper limit of the defined sequences according to the following:

a) Lower limits:

;

;

b) Upper limits:

;

.

Based on the defined limit values of the rough boundary interval, we can define rough numbers  and . Using Eq. (9), the rough values were fused into the aggregated rough number . The residual values in the aggregated rough home matrix were obtained similarly (see Table 3).

*Step 2*: Using Eq. (10), the standardization of the elements of the aggregated rough matrix (see Table 3) was performed. The standardized matrix is presented in Table 4.

**Table 4**

The standardized rough initial matrix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | A1 | A2 | A3 | A4 |
| C1 | [0.854,0.968] | [0.943,1.000] | [0.784,0.886] | [0.706,0.948] |
| C2 | [0.494,0.916] | [0.751,1.000] | [0.594,0.961] | [0.683,0.994] |
| C3 | [0.468,0.756] | [0.907,1.000] | [0.759,0.851] | [0.614,0.823] |
| C4 | [0.832,0.944] | [0.711,0.932] | [0.968,1.000] | [0.625,0.808] |
| C5 | [0.577,0.745] | [0.935,1.000] | [0.654,0.754] | [0.548,0.795] |
| C6 | [0.864,1.000] | [0.705,0.762] | [0.770,0.952] | [0.845,0.958] |
| C7 | [0.497,0.935] | [0.509,0.863] | [0.417,0.823] | [0.559,1.000] |
| C8 | [0.539,0.986] | [0.353,0.630] | [0.541,0.818] | [0.511,1.000] |
| C9 | [0.385,0.600] | [0.577,0.662] | [0.576,0.907] | [0.508,1.000] |
| C10 | [0.542,1.000] | [0.435,0.478] | [0.614,0.869] | [0.267,0.539] |
| C11 | [0.344,0.516] | [0.451,0.600] | [0.544,0.663] | [0.423,1.000] |
| C12 | [0.397,0.911] | [0.484,0.946] | [0.502,0.782] | [0.535,1.000] |
| C13 | [0.341,0.728] | [0.609,1.000] | [0.424,0.757] | [0.594,0.915] |

*Step 3*: In this step, the calculation of criteria weights are presented as follows:

*Step 3.1*: The study involved six experts who evaluated the criteria/sub-criteria using the nine-point scale presented in *Step 1*. Expert assessments of the significance of the criteria are presented in the linguistic matrix (see Table 5).

**Table 5**

Evaluation of the significance of the criteria/sub-criteria by experts.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Criteria | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 |
| MC1 | EH | P | EH | VH | EH | H |
| C1 | EH | EH | VH | VH | P | VH |
| C2 | H | VH | P | EH | VH | P |
| C3 | VH | P | EH | MH | H | EH |
| MC2 | VH | H | VH | M | P | P |
| C4 | H | P | M | EH | P | VH |
| C5 | VH | EH | H | MH | EH | EH |
| C6 | H | VH | MH | P | VH | MH |
| MC3 | EH | EH | M | ML | MH | EH |
| C7 | MH | MH | MH | M | H | H |
| C8 | MH | EH | M | EH | EH | VH |
| C9 | EH | P | L | L | VH | P |
| C10 | H | M | ML | VH | P | EH |
| MC4 | H | VH | L | EH | EH | VH |
| C11 | EH | P | L | EH | P | EL |
| C12 | VH | EH | EL | P | H | L |
| C13 | H | VH | L | L | VH | M |

Using Eqs. (1) and (2), the expert estimates from Table 5 were transformed into rough values. After the transformation of expert estimates into rough values, elements of the linguistic matrix were fused using the Bonferroni function, as given in Table 6.

**Table 6**

Aggregate rough matrix of expert estimates.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | Aggregated values | | Crisp value | Rank |
| Local | Global |
| MC1 | [7.61, 6.92] | - | - | - |
| C1 | [6.03, 6.84] | [45.88, 47.37] | 47.32 | 1 |
| C2 | [5.53, 6.73] | [42.06, 46.60] | 46.04 | 2 |
| C3 | [4.90, 6.67] | [37.28, 46.15] | 44.25 | 3 |
| MC2 | [4.48, 6.42] | - | - | - |
| C4 | [4.75, 6.88] | [21.28, 44.15] | 34.37 | 4 |
| C5 | [4.94, 6.21] | [22.09, 39.83] | 31.81 | 7 |
| C6 | [4.88, 6.45] | [21.85, 41.40] | 32.76 | 5 |
| MC3 | [3.07, 5.70 | - | - | - |
| C7 | [3.81, 4.47] | [11.70, 25.46] | 16.01 | 13 |
| C8 | [4.62, 6.20] | [14.21, 35.32] | 23.51 | 9 |
| C9 | [3.39, 6.19] | [10.40, 35.24] | 20.67 | 10 |
| C10 | [2.99, 6.10] | [9.19, 34.79] | 19.46 | 12 |
| MC4 | [4.08, 6.13] | - | - | - |
| C11 | [4.76, 6.94] | [19.39, 42.53] | 31.97 | 6 |
| C12 | [2.78, 6.43] | [11.31, 39.43] | 24.14 | 8 |
| C13 | [3.29, 5.09] | [13.42, 31.20] | 20.42 | 11 |

Global values of rough experts’ estimates were obtained by multiplying the local values of the criteria with the values of the sub-criteria from the corresponding group of criteria. Criteria ranking was performed using crisp values of criteria.

*Step 3.2:* A rough numbers-based linear model was defined based on the rank of criteria and rough global values from the linguistic matrix (see Table 6).



We have used Lingo 17.0 software to solve the linear model. By solving the rough linear model, the rough weight coefficients of the criteria are defined in Table 7.

**Table 7**

Rough weighting coefficients criteria.

|  |  |
| --- | --- |
| Crit. | Rough weight |
| C1 | [0.1442, 0.2000] |
| C2 | [0.1362, 0.1442] |
| C3 | [0.0997, 0.1362] |
| C4 | [0.0969, 0.0997] |
| C5 | [0.0452, 0.0726] |
| C6 | [0.0726, 0.0729] |
| C7 | [0.0011, 0.0146] |
| C8 | [0.0312, 0.0446] |
| C9 | [0.0146, 0.0273] |
| C10 | [0.0146, 0.0146] |
| C11 | [0.0729, 0.0969] |
| C12 | [0.0446, 0.0452] |
| C13 | [0.0273, 0.0312] |

A graphical representation of the rough values of the criterion weight coefficients is shown in Fig. 2. Based on the visual interpretation of the rough weight coefficients, we can see their significance. Inaccuracies in the initial information directly affect the occurrence of a larger or smaller uncertainty footprint represented by a rough boundary interval (RBI). Thus, from Fig. 2, we notice a larger footprint of uncertainty defined for some criteria (C1, C3, C5, C7, C8, C9, and C11). While with the remaining criteria, minor inaccuracies are represented by a minimal footprint of uncertainty. The presented uncertainties have a direct impact on the final values of the weighting coefficients, as well as on the importance of the aggregated Aczel - Alsa functions.



**Fig. 2.** Rough criteria weights.

*Step 4:* The utility functions of the alternatives are defined using Eqs. (14) and (15) and are presented in the following section:

; 

Crisp values of weighting coefficients were used to calculate the RAA averaging function. In the following section, the RAA averaging function of the A1 alternative is presented:

1. By applying Eq. (14), we obtain an RAA weighted averaging function (), as follows:



1. By applying Eq. (15), we obtain a RAA weighted averaging function (), as follows:



The rough Aczel–Alsina functions of the remaining alternatives are calculated similarly.

*Step 5:* Using Eq. (16), the integrated values of the RAA function () were calculated. As a result, the integrated values of the RAA function are shown in the following section:



Based on the integrated values of Aczel–Alsina, the functions of alternatives A2 and A3 stand out as dominant from the considered set, where alternative A2 has an advantage over A3. Dominant alternatives are those alternatives that have the highest values of score functions.

## Sensitivity analysis

In this section, we study the influence of subjectively defined parameters in the multi-criteria model on the final solution. Several subjectively defined parameters were used in the Bonferroni function, the Aczel-Alsina function, and the function used to integrate the Aczel-Alsina function. Five stabilization parameters are identified as follows:

* Parameters *d1* and *d2* are used in the Bonferroni function to define a rough boundary interval;
* Parameter *δ* used in the Aczel-Alsina function; and
* Parameters *ρ* and *α* are used in the function to integrate the Aczel-Alsina function.

The sensitivity analysis simulated the change of the stated parameters within the limit intervals, and in parallel, the initial solution changes were monitored.

*a) Influence of parameters d1* *and* *d2* *on the initial results of the model*

The values *d1*= *d2*= 1 were adopted to calculate the initial solution. This simulates the minimum level of risk when making a decision. In the following section, the dependence of the rough utility function of the alternatives on the change in the values of the parameters *d1* and *d2* is analyzed. During the simulation, the parameters were changed in the interval 1≤*d1*,*d2*≤80. Fig. 3 shows the changes in the integrated functions that occurred due to changes in the values of 1≤ *d1*,*d2*≤80.



**Fig. 3.** Dependence of rough boundary interval on change *d1* and *d2.*

The results in Fig. 3 confirm the influence of parameters *d1* and *d2* on the change in the values of the integrated alternative functions. Since the variations of the parameters *d1* and *d2* affect the change in the value of the Aczel-Alsin function, it is necessary to consider the impact of these changes on the initial results. Fig. 4 presents a comparative overview of the changes in the integrated functions of the considered alternatives.



**Fig. 4.** Comparative presentation of the change of integrated functions for the considered alternatives.

The simulation shown in Fig. 3 and Fig. 4 simulated the increase in risk when making a decision. The results from Fig. 4 indicate a sensitivity of the model to changes in the parameters *d1* and *d2*, which allows the simulation of different levels of risk in the information. Also, the results in Fig. 4 indicate that alternative A2 is the best solution from the set of alternatives, while alternative A1 is the worst solution. During the simulation, it was shown that for the values of parameters 1≤ *d1*, *d2*≤4, alternatives A3 and A4 retain their initial positions. Also, it was shown that the values of the parameters 4≤ *d1*, *d2*≤80 cause the change in the ranks of alternatives A3 and A4. To understand the statistical significance of the changes, the Spearman correlation coefficient was applied. Fig. 5 shows the values of the correlation coefficient through the scenarios.



**Fig. 5.** Spearman’s correlation coefficient across scenarios.

Fig. 5 shows that the increase in the values of the parameters d1 and d2 affects the decrease in the correlation between the initial solution and the considered scenario. However, despite the constant departure from the initial solution, these differences are not statistically significant, as the coefficient of statistical significance does not fall below 0.82. The average value of Spearman’s coefficient through scenarios is 0.88, which indicates a significant correlation. Based on the presented analysis, we can conclude that alternative A1 is the dominant solution, while alternatives A3 and A4 are acceptable solutions.

*b) Influence of parameter δ on model results*

When calculating the initial values of the RAA function, the value *δ*=1 was adopted. Similar to the previous section, the parameter change in the interval 1≤ δ ≤70 was simulated in the next experiment. Fig. 6 shows the influence of parameter 1 ≤ *δ* ≤ 70 on the change of the Aczel-Alsa function. Fig. 6 indicates a dependence of the RAA function on the value of the parameter *δ*. Also, the results show that the variation of the parameter *δ* in interval 1 ≤ *δ* ≤ 70 significantly affects the change of Aczel-Alsa functions because Aczel-Alsa functions are sensitive to changes in the specified parameter. Therefore, it is necessary to consider whether the impact of these changes affects the stability of the initial solution. The comparative differences in the Aczel-Alsa function of all three considered alternatives are considered in Fig. 7.



**Fig. 6.** Influence of parameter 1≤*δ*≤70 on the change of Aczel-Alsa function.

Fig. 7 compares the individual changes in Aczel-Alsine functions presented in Fig. 6.



**Fig. 7.** Comparative overview of changes in Aczel-Alsa function due to parameter changes 1≤*δ*≤70.

From Fig. 7, we can see that for the values of the parameter 1≤*δ*≤58, the initial rank is confirmed, while the values of the parameter 59≤*δ*≤70 cause the change in the ranks of the first-ranked (A2) and second-ranked (A3) alternative. Also, it can be noticed that there are no changes in the alternatives. Therefore, since the dominant alternatives (A2 and A3) confirmed their dominance, we can conclude that alternatives A2 and A3 represent the best solutions from the considered set. Also, we can conclude that alternative A2 has an advantage over alternative A3, as it dominated in 82.8% of scenarios.

*c) Influence of parameters ρ and α on the initial results of the model*

In the following part, the change of the parameter *ρ* in the interval 1≤ *ρ*≤50 is simulated, while the simulation of the parameter *α* is simulated in the interval 0≤ *α* ≤1. Fig. 8 (a) shows the influence of parameter 1≤*ρ*≤50 on the change of integrated functions. In the first scenario, the value of *ρ*=1 was adopted, while in each subsequent scenario, the parameter value was increased by one.



**Fig. 8.** Influence of parameters *ρ* and *α* on the change of initial results.

Fig. 8 (b) shows the influence of the parameter 0≤*α*≤1 on the change of integrated functions. In the first scenario, the value α=0.0 was adopted. In each subsequent scenario, the parameter *α* was increased by 0.02. The results in Figs. 8 (a) and (b) show that these parameters affect the change in the initial values of the integrated functions; however, these changes are not extreme and do not cause a change in the initial results. Based on the analysis presented in this section, the dominance of alternatives A2 and A3 was confirmed, while alternatives A4 and A1 represent the worst solutions.

# Conclusion and future research directions

This study presents a scenario combining three metaverse implementation alternatives in transportation systems. These alternatives are prioritized based on thirteen sub-criteria grouped under four main aspects using the novel RAA function and the OPA method.

Metaverse use in public transportation operations and safety alternatives was chosen as the most suitable alternative, considering sustainability and efficiency criteria. The reason is that every person is affected by traffic daily, whether they have a private vehicle. Applications such as traffic management and accident management are used in the traffic network to make the traffic safe, sustainable, and efficient. Using such traffic operation management in the metaverse world will improve both the traffic and the metaverse transportation network.

We have seen micro-mobility applications routinely in our daily lives, and for this reason, metaverse applications are also considered important in the sharing economy applications. Artificial intelligence technology in autonomous vehicles is an emerging technology. Testing this technology with autonomous driving algorithms or evaluating it in other studies is necessary for sustainable transportation. Therefore, it is possible to use these technologies with metaverses. Metaverse technology can also affect every component of the transportation network. The experts focus on the long-term, most sustainable, and most significant areas where metaverse technology can affect. It is important to look at the operations and safety of public transportation to see what effect metaverse technology will have on the transportation network most effectively. Avoiding social activities because of the pandemic and people gaining practice in running all their businesses from one place can cause an increase in incentives and desires for metaverse applications. Therefore, this research will enable decision-makers to see how the world, which is still under the effect of a pandemic, will affect and benefit from in terms of transportation to metaverse applications.

With the metaverse technology, it is possible to assess the effect of transportation systems on traffic from many perspectives. For this reason, all alternatives in the research were evaluated by experts. The metaverse use in public transportation operation and safety alternative was the most advantageous alternative. Even though each of the alternatives assessed in the study is related to the others, it is necessary to prioritize which transportation alternative will be used by the metaverse and determine what benefits and harms it will face. As a result, it is intended to assist decision-makers and planners in determining which transportation alternative to prioritize for the metaverse by evaluating various scenarios for the assessing criteria.

One limitation of the proposed methodology is the computational complexity. This limitation can be eliminated by creating user-oriented software that would possess the modules presented in this judge. Another limitation of the proposed methodology is the inability to address neutrality in information adequately. Therefore, it is necessary to direct future research towards improving the performance of the proposed method through the application of intuitionistic fuzzy sets and picture fuzzy sets. This would enable more accurate processing of expert assessments.

We showed that metaverse technology is expected to enter our daily lives in the future. However, metaverse implementation alternatives in transportation engineering can be realized if cities keep pace with this new technology. Future research on the relationship between the metaverse and the transportation sector is expected to focus on obtaining and using transportation travel data, observing many scenarios for different vehicles using artificial intelligence, financial affordability, and its effects on daily life and traffic management.

# References

Abbink, D. A., Hao, P., Laval, J., Shalev-Shwartz, S., Wu, C., Yang, T., ..., Haque, M., 2020. Artificial Intelligence for Automated Vehicle Control and Traffic Operations: Challenges and Opportunities. In Automated Vehicles Symposium (pp. 60-72). Springer, Cham. <https://doi.org/10.1007/978-3-030-80063-5_6>

Abduljabbar, R., Dia, H., Liyanage, S., Bagloee, S. A., 2019. Applications of artificial intelligence in transport: An overview. Sustainability, 11(1), 189. <https://doi.org/10.3390/su11010189>

Aczel J, Alsina C., 1982. Characterization of some classes of quasilinear functions with applications to triangular norms and to synthesizing judgements. Aequationes Mathematicae, 25(1), 313‐315. <https://doi.org/10.1007/BF02189626>

Agarwal, S., Dandge, S.S., Chakraborty, S., 2020. Parametric analysis of a grinding process using the rough sets theory. Facta universitatis series: Mechanical engineering. 18(1), 91-106. <https://doi.org/10.22190/FUME191118007A>

Ali, Z., Mahmood, T., Ullah, K., Khan, Q., 2021. Einstein Geometric Aggregation Operators using a Novel Complex Interval-valued Pythagorean Fuzzy Setting with Application in Green Supplier Chain Management. Reports in Mechanical Engineering, 2 (1), 105-134. <https://doi.org/10.31181/rme2001020105t>

Alosta, A., Elmansuri, O., Badi, I., 2021. Resolving a location selection problem by means of an integrated AHP-RAFSI approach. *Reports in Mechanical Engineering*, *2*(1), 135-142. <https://doi.org/10.31181/rme200102135a>

Ataei, Y., Mahmoudi, A., Feylizadeh, M.R., Li, D.-F., 2020. Ordinal Priority Approach (OPA) in Multiple Attribute Decision-Making. Applied Soft Computing Journal, 86, 105893. <https://doi.org/10.1016/j.asoc.2019.105893>.

Baloian, N., Frez, J., Pino, J. A., & Zurita, G., 2015. Efficient planning of urban public transportation networks. In International Conference on Ubiquitous Computing and Ambient Intelligence (pp. 439-448). Springer, Cham.

Barthélemy, J., Verstaevel, N., Forehead, H., & Perez, P., 2019. Edge-computing video analytics for real-time traffic monitoring in a smart city. *Sensors*, *19* (9), 2048. <https://doi.org/10.3390/s19092048>

Bertini, R. L., El-Geneidy, A., 2004. Advanced Traffic Management System Data. Assessing the Benefits and Costs of ITS, 287–314. <https://doi.org/10.1007/1-4020-7874-9_15>

Bonferroni, C., 1950. Sullemedie multiple di potenze. Bollettinodell' Unione Matematica Italiana, 5, 267–270.

Bozanic, D., Randjelovic, A., Radovanovic, M., Tesic, D., 2020. A hybrid LBWA - IR-MAIRCA multicriteria decision-making model for determination of constructive elements of weapons. Facta universitatis series: Mechanical Engineering, 18(3), 399-418. <https://doi.org/10.22190/FUME200528033B>

Chen, C., Yao, M. Z., 2021. Strategic use of immersive media and narrative message in virtual marketing: Understanding the roles of telepresence and transportation. Psychology & Marketing, 39(3), 524–542. <https://doi.org/10.1002/mar.21630>

Christudas, F., Vijula Dhanraj, A., 2020. System Identification Using Long Short Term Memory Recurrent Neural Networks for Real-Time Conical Tank System. Romanian Journal of information science and technology, 23, T57-T77.

Collins, C., 2008. Looking to the future: Higher education in the metaverse. Educause Review, 43(5), 51-63.

Di Pietro, R., Cresci, S., 2021. Metaverse: Security and Privacy Issues. In 2021 Third IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA) (pp. 281-288). IEEE.

Dionisio, J. D. N., III, W. G. B., Gilbert, R., 2013. 3D virtual worlds and the metaverse: Current status and future possibilities. ACM Computing Surveys (CSUR), 45(3), 1-38.

Dionisio, J. D. N., III, W. G. B., Gilbert, R., 2013. 3D Virtual worlds and the metaverse. ACM Computing Surveys, 45(3), 1–38. <https://doi.org/10.1145/2480741.2480751>

Duan, H., Li, J., Fan, S., Lin, Z., Wu, X. Cai, W., 2021. Metaverse for Social Good. Proceedings of the 29th ACM International Conference on Multimedia. <https://doi.org/10.1145/3474085.3479238>

Duan, H., Li, J., Fan, S., Lin, Z., Wu, X., Cai, W., 2021. Metaverse for social good: A university campus prototype. In Proceedings of the 29th ACM International Conference on Multimedia (pp. 153-161).

Durmic, E., Stević, Z, Chatterjee, P., Vasiljević, M., & Tomašević , M., 2020. Sustainable supplier selection using combined FUCOM – Rough SAW model. Reports in Mechanical Engineering, 1(1), 34-43. <https://doi.org/10.31181/rme200101034c>.

Dwivedi, R., Prasad, K., Mandal, N., Singh, S., Vardhan, M., Pamucar, D., 2021. Performance evaluation of an insurance company using an integrated Balanced Scorecard (BSC) and Best-Worst Method (BWM). *Decision Making: Applications in Management and Engineering*, *4*(1), 33-50. <https://doi.org/10.31181/dmame2104033d>

Fleming, K. L., 2018. Social equity considerations in the new age of transportation: Electric, automated, and shared mobility. Journal of Science Policy & Governance, 13(1), 20.

Garon, J., 2022. Legal Implications of a Ubiquitous Metaverse and a Web3 Future. Available at SSRN 4002551.

Haque, M., 2022. Artificial Intelligence for Automated Vehicle Control and Traffic Operations: Challenges and Opportunities. Road Vehicle Automation 8, 60.

Hedrea, E.L., Precup, R.E., Roman, R.C., Petriu, E.M., 2021. Tensor product-based model transformation approach to tower crane systems modelling. Asian Journal of Control, 23, 1313 - 1323. <https://doi.org/10.1002/asjc.2494>

Heylighen, F., 2017. Towards an intelligent network for matching offer and demand: From the sharing economy to the global brain. Technological Forecasting and Social Change, 114, 74-85. <https://doi.org/10.1016/j.techfore.2016.02.004>

Huang, W., Wang, K., Lv, Y., Zhu, F., 2016. Autonomous vehicles testing methods review. In 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC) (pp. 163-168). IEEE.

Iliopoulou, C., Kepaptsoglou, K., 2019. Combining ITS and optimization in public transportation planning: state of the art and future research paths. European Transport Research Review, 11(1).<https://doi.org/10.1186/s12544-019-0365-5>

Jeon, H. J., Youn, H. C., Ko, S. M., Kim, T. H., 2022. Blockchain and AI Meet in the Metaverse. Advances in the Convergence of Blockchain and Artificial Intelligence, 73.

Kazemitash, N., Fazlollahtabar, H., Abbaspour, M., 2021. Rough Best-Worst Method for Supplier Selection in Biofuel Companies based on Green criteria. Operational Research in Engineering Sciences: Theory and Applications, *4*(2), 1-12. <https://doi.org/10.31181/oresta20402001k>

Kouziokas, G. N., 2017. The application of artificial intelligence in public administration for forecasting high crime risk transportation areas in urban environment. Transportation research procedia, 24, 467-473. <https://doi.org/10.1016/j.trpro.2017.05.083>

Kraus, S., Kanbach, D. K., Krysta, P., Steinhoff, M., 2022. Facebook and the creation of the Metaverse: Radical business model innovation or incremental transformation? International Journal of Entrepreneurial Behaviour & Research.<https://doi.org/10.1108/IJEBR-12-2021-0984>

Ma, Y., Ping, K., Wu, C., Chen, L., Shi, H., Chong, D., 2019. Artificial Intelligence powered Internet of Things and smart public service. Library Hi Tech.

Manikonda, P., Yerrapragada, A. K., Annasamudram, S. S., 2011. Intelligent traffic management system. 2011 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT). <https://doi.org/10.1109/student.2011.6089337>

Milosevic, T., Pamucar, D., Chatterjee, P., 2021. Model for selecting a route for the transport of hazardous materials using a fuzzy logic system. Military Technical Courier, 69(2), 355-390

Mystakidis, S., 2022. Metaverse. *Encyclopedia*, *2*(1), 486-497.

Nansubuga, B., Kowalkowski, C., 2021. Carsharing: a systematic literature review and research agenda. Journal of Service Management, 32(6), 55–91. <https://doi.org/10.1108/josm-10-2020-0344>

Ning, Z., Huang, J., Wang, X., 2019. Vehicular fog computing: Enabling real-time traffic management for smart cities. *IEEE Wireless Communications*, *26*(1), 87-93. <https://doi.org/10.1109/MWC.2019.1700441>

Omorov, R. O., 2020. Intellectual property and artificial intelligence. E-Management, 3(1), 43-49. <https://doi.org/10.26425/2658-3445-2020-1-43-49>

Oxford Analytica, 2022. Metaverse holds unknowable societal risks. Emerald Expert Briefings. <https://doi.org/10.1108/oxan-db267012>

Pamucar, D.S., Dimitrijevic, S.R., 2021. Multiple-criteria model for optimal anti-tank ground missile weapon system procurement. Military Technical Courier, 69(4), 792-827. <https://doi.org/10.5937/vojtehg69-32117>

Pawlak, Z., 1982. Rough sets. International Journal of Computer & Information Sciences, 11(5), 341–356. <https://doi.org/10.1007/BF01001956>

Pozna, C., Precup, R., 2012. Aspects Concerning the Observation Process Modelling in the Framework of Cognition Processes. Acta Polytechnica Hungarica, 9(2), 203-223.

Rizwan, P., Suresh, K., Babu, M. R., 2016. Real-time smart traffic management system for smart cities by using Internet of Things and big data. 2016 International Conference on Emerging Technological Trends (ICETT).<https://doi.org/10.1109/icett.2016.7873660>

Schmidt, F. A., 2019. Crowdsourced production of AI Training Data: How human workers teach self-driving cars how to see. Hans-Böckler-Stiftung, Düsseldorf. http://hdl.handle.net/10419/216075

Schöner, H. P., 2018. Simulation in development and testing of autonomous vehicles. In 18. Internationales Stuttgarter Symposium (pp. 1083-1095). Springer Vieweg, Wiesbaden.

Shaheen, S., Cohen, A., 2021. Shared micromobility: policy and practices in the United States. In A Modern Guide to the Urban Sharing Economy. Edward Elgar Publishing.

Sharma, H. K., Kumari, K., Kar, S., 2021. Forecasting Sugarcane Yield of India based on rough set combination approach. *Decision Making: Applications in Management and Engineering*, *4*(2), 163-177. <https://doi.org/10.31181/dmame210402163s>

Sharma, H. K., Singh, A., Yadav, D., Kar, S., 2022. Criteria selection and decision making of hotels using Dominance Based Rough Set Theory. *Operational Research in Engineering Sciences: Theory and Applications*. <https://doi.org/10.31181/oresta190222061s>

Sukhadia, A., Upadhyay, K., Gundeti, M., Shah, S., Shah, M., 2020. Optimization of smart traffic governance system using artificial intelligence. Augmented Human Research, 5(1), 1-14. <https://doi.org/10.1007/s41133-020-00035-x>

Todorovic, M., Simic, M., Kumar, A., 2017. Managing Transition to Electrical and Autonomous Vehicles. Procedia Computer Science, 112, 2335–2344.<https://doi.org/10.1016/j.procs.2017.08.201>

Venkatesh, A., Edirappuli, S., 2020. Social distancing in covid-19: what are the mental health implications?. Bmj, 369. <https://doi.org/10.1136/bmj.m1379>

Wang, L. N., Wang, K., Shen, J. L., 2020. Weighted complex networks in urban public transportation: Modeling and testing. Physica A: Statistical Mechanics and its Applications, 545, 123498. <https://doi.org/10.1016/j.physa.2019.123498>

Wang, Z., Li, X., Zhu, X., Li, J., Wang, F., Wang, F., 2021. Big data-driven public transportation network: a simulation approach. Complex & Intelligent Systems. <https://doi.org/10.1007/s40747-021-00462-2>

Zhai, L. Y., Khoo, L. P., & Zhong, Z. W., 2009. A rough set based QFD approach to the management of imprecise design information in product development. Advanced Engineering Informatics, 23(2), 222–228. <https://doi.org/10.1016/j.aei.2008.10.010>

**Appendix A**

**Proof for Theorem 1**

1. *RAA weighted averaging function (**):*

The expression for arithmetic weighted averaging  is decomposed into segments to derive Eq. (14) gradually. From Eqs. (4) and (7), we get that:

 (A1)

Then, by applying Eq. (5), we obtain a RAA weighted averaging function (14)

 (A2)

where  the rough vector of weighting criteria, while .

1. *RAA weighted geometric averaging function (**):*

The expression for geometrically weighted averaging  is decomposed into segments to gradually derive Eq. (15). From Eqs. (3) and (8), we get that:

 (A3)

Then, by applying Eq. (6), we obtain a rough Aczel–Alsina geometric weighted averaging function (15):

 (A4)

where  the rough vector of weighting criteria, while .