KMAN PUBLISHING INSTITUTE
Journal Website

Article history:
Received 12 February 2024
Revised 09 March 2024
Accepted 16 March 2024
Published online 01 April 2024

International Journal of Innovation Management and Organizational Behavior

Volume 4, Issue 2, pp 142-154

IJIMOB
International Journal of Innovation Management and Organizational Behavior

E-ISSN: 3041-8992

The Impact of Interactions between Resources, Technology, and Technical Aspects of Autonomous Vehicles on Urban Smart Spaces

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A r t i c l e   I n f o

Article type:
Original Research

How to cite this article:
Vaziri, I., Ahmadi, F., Talebi Rizi, Z., & Saffarzadeh, M. (2024). The Impact of Interactions between Resources, Technology, and Technical Aspects of Autonomous Vehicles on Urban Smart Spaces. *International Journal of Innovation Management and Organizational Behavior*, *4*(2), 142-154.
https://doi.org/10.61838/kman.ijimob.4.2.17

A B S T R A C T

Objective: As urban populations grow, the demand for smarter and more efficient urban spaces becomes increasingly critical. The advent of autonomous vehicles also presents opportunities and challenges in shaping the future of smart cities. This article examines the complex interactions between resources, technology, and technical aspects of autonomous vehicles and their impact on urban spaces.

Methodology: A comprehensive research methodology was employed to assess the impact of interactions between resources, technology, and technical aspects of autonomous vehicles on smart urban spaces. This included a review of the literature, data analysis, case studies, and simulations. By integrating findings from various sources and methods, a complete understanding of the subject was achieved.

Findings: The findings of this study highlight the multifaceted impact of interactions between resources, technology, and technical aspects of autonomous vehicles on smart urban spaces. Despite their enormous potential to reduce traffic, enhance safety, and improve urban mobility, these interactions raise concerns about privacy, infrastructure compatibility, and equitable access.

Conclusion: Therefore, it is essential for policymakers, urban planners, and technologists to collaborate in developing strong frameworks and regulations to harness the benefits of autonomous vehicle technology while mitigating potential challenges. By promoting innovation and inclusive urban development, cities can leverage the transformative power of autonomous vehicle technology to create smarter, more sustainable, and livable urban environments for all citizens.

Keywords: *Autonomous Vehicles, Smart Urban Spaces, Interactions, Technology Impact*

1 Introduction

Autonomous vehicles represent a revolutionary advance in transportation technology. These vehicles are capable of navigating and operating without human intervention, relying instead on a combination of sensors, cameras, radar, and artificial intelligence algorithms (Stähler et al., 2023). The development and deployment of autonomous vehicles have garnered significant attention from researchers, policymakers, and the public due to their potential to transform our transportation methods and interaction with urban spaces (Barron, 2022).

One of the primary motivations behind the development of autonomous vehicles is the promise of improved safety on the roads. Human errors are a leading cause of road accidents worldwide, resulting in numerous injuries and fatalities annually (Bykov, 2022). Autonomous vehicles, by eliminating human errors such as distracted driving, speeding, and impaired driving, have the potential to significantly reduce the number of accidents. With continuous monitoring of their surroundings and making real-time decisions based on data analysis, autonomous vehicles aim to create safer roads for all users (Schachinger et al., 2022). Besides safety benefits, autonomous vehicles promise increased efficiency and convenience in transportation. These vehicles have the capability to optimize traffic flow, reduce congestion, and decrease travel times using advanced algorithms for route planning and traffic management. Furthermore, autonomous vehicle technology can improve access for individuals with disabilities or mobility restrictions, enhancing their independence and providing new opportunities for their inclusion in society (Sahba & Sahba, 2022).

However, the widespread adoption of autonomous vehicles also leads to a series of ethical, legal, and social questions. Concerns about data privacy, cybersecurity vulnerabilities, and liability in the event of accidents are vital. Additionally, the introduction of autonomous vehicles may disrupt existing industries such as taxi services and transportation, potentially leading to job displacement and economic transformation (Yaqoob et al., 2020). Addressing these complex challenges requires a multidisciplinary approach that considers technological, legal, and social issues (Mahrez et al., 2022).

Moreover, integrating autonomous vehicles into urban environments requires careful planning and infrastructure development. Cities must adapt their transportation systems and regulations to accommodate autonomous vehicles while ensuring the safety and well-being of pedestrians, cyclists, and other road users. Urban planners must also consider the broader impact of autonomous vehicles on land use, public transport, and environmental sustainability to create flexible and livable urban spaces for future generations (Raissi et al., 2019). Thus, autonomous vehicles showcase transformative technology with the potential to revolutionize transportation and urban living. While they offer significant benefits in terms of safety, efficiency, and accessibility, their widespread adoption carries substantial challenges and uncertainties. By promoting collaboration among stakeholders and adopting a proactive approach to addressing ethical, legal, and social issues, we can harness the full potential of autonomous vehicles to create safer, more efficient, and inclusive urban environments.

In summary, the research question relates to the impact of autonomous vehicles on the development of smart urban spaces. With the rapid advancement of autonomous vehicle technology, understanding how autonomous vehicles affect urban environments is crucial for policymakers, urban planners, and technologists. This research aims to provide insights into the opportunities and challenges associated with integrating autonomous vehicles into smart city development strategies. Autonomous vehicles represent a convergence of various resources, including technological advancements, infrastructure needs, and regulatory frameworks. Understanding the complex interactions between these resources and their implications for urban development is essential for shaping future transportation policies and infrastructure investments. By exploring these complex interactions, our research informs decision-makers about the potential implications of autonomous vehicle technology for smart city development. The research question requires a comprehensive approach to analysis, encompassing not only the technical aspects of autonomous vehicles but also their social, economic, and environmental impacts on urban spaces. Adopting a multidisciplinary perspective, our goal is to provide a comprehensive understanding of the challenges and opportunities associated with integrating autonomous vehicles into smart city

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E-ISSN: 3041-8992

ecosystems. As autonomous vehicle technology evolves, new challenges and opportunities arise for smart city development, including issues related to cybersecurity, data privacy, equity, and access. By identifying and addressing these challenges and considerations, our research contributes to the development of robust policies and strategies for integrating autonomous vehicles into smart urban environments in a safe, equitable, and sustainable manner. Autonomous vehicles have the potential to radically transform urban transportation systems and reshape the built environment. By providing new forms of mobility and redefining how people interact with urban spaces, autonomous vehicles promise to enhance efficiency, reduce environmental impacts, and improve the quality of life in cities. However, realizing this transformative potential requires consideration of various factors, including technological feasibility, regulatory frameworks, and social acceptance. The research question opens new avenues for policy research and development in the realm of smart city planning and transportation. By examining the implications of autonomous vehicles for urban development, our research aids future policy decisions and guides investments in infrastructure, technology, and regulatory frameworks. Ultimately, our goal is to promote the creation of smarter, more resilient, and inclusive cities that harness the transformative capability of autonomous vehicle technology to benefit all residents.

2 Methods and Materials

Our research utilizes a mixed-method approach that integrates both qualitative and quantitative analysis to provide a comprehensive understanding of the impact of autonomous vehicles on smart urban spaces.

2.1 Data Collection

We conduct an extensive review of the existing literature on autonomous vehicles, smart city development, and urban planning. This qualitative analysis allows us to identify patterns, trends, and key challenges associated with the integration of autonomous vehicles into smart urban environments.

We study case studies of cities that have implemented or planned to implement autonomous vehicle initiatives. By analyzing these real-world examples, we gain insights into the practical implications of transitioning to autonomous vehicles in urban infrastructures, transportation systems, and community dynamics.

We conduct interviews with experts in the fields of transportation, urban planning, technology, and policy. These qualitative interviews provide valuable perspectives on the opportunities and challenges associated with autonomous vehicles in smart city development.

Quantitative data include metrics such as traffic levels, emissions, and public surveys related to autonomous vehicles.

We integrate findings from both qualitative and quantitative analysis methods through a triangulation approach. By comparing and contrasting perspectives from different sources and methods, we validate our findings and ensure the robustness of our conclusions.

2.2 Resource Perspective

From a resource perspective, the interaction between autonomous vehicles and smart cities involves the allocation and utilization of various resources, including technology, infrastructure, and human capital. Autonomous vehicles require advanced technological resources such as sensors, artificial intelligence algorithms, and communication systems for autonomous operation. On the other hand, smart cities require investments in infrastructures such as smart roads, traffic management systems, and charging stations to support the integration of autonomous vehicles in urban environments. Moreover, human capital plays a vital role in developing and maintaining the technology and infrastructure needed for autonomous vehicles and smart city initiatives.

2.3 Data Analysis

It should be noted that in the proposed framework, the effect of each individual's performance in the interactions among team management members leads to the creation of the concept of interdependence among members. By considering factors affecting this concept, the mentioned perspectives are reviewed.

Interactions between members from a resource perspective:

Suppose individuals A and B have an interdependent resource relationship with estimated costs CA and CB such that CA > CB. The coordination of these two individuals in reducing the total resource costs is calculated as follows:

Binary relationships of each individual in terms of resources are shown using a bidirectional (two-way) shortcut between two nodes representing the project team. The contribution of each individual in the team to using the

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E-ISSN: 3041-8992

allocated resources is determined using a square matrix. Their values are indicated with rjk. For example, suppose individuals A and B (indexed j and k, respectively) have mutual resource dependencies. If individual A consumes 20% of the resources and the remaining 80% of the resources are allocated to individual B, the relationship between rjk and rkj is as follows:

rjk=1 - rkj

The simultaneous selection of these two leads to a reduction in the total resource costs, which is indicated by RCjk and written on each node.

Finally, the level of contribution of each issue in reducing the total project costs of the autonomous vehicle due to mutual dependency on resources is shown with RIj and is calculated using the following equation:

RIj=∑_(k≠j. k=1)^n▒〖EF_j×RC_jk×r_jk 〗 ∀ j=1.2.….n

2.4 Technology and Knowledge Perspective

The interaction between autonomous vehicles and smart cities is driven by technological advances and knowledge exchange. Autonomous vehicle technology is rapidly evolving, with advancements in machine learning, computer vision, and sensor technology that allow for greater autonomy and safety. Smart city initiatives utilize these technological innovations to enhance urban mobility, sustainability, and the quality of urban life. Moreover, knowledge sharing among organizations, including researchers, engineers, policymakers, and urban planners, is essential for stimulating innovation and implementing effective solutions that leverage the potential of autonomous vehicles in smart urban environments.

The use of existing knowledge and technologies in autonomous vehicles can accelerate technology transfer and learning. This may lead to a reduction in the time it takes to perform certain activities and, consequently, a overall reduction in execution time. The following steps are suggested for calculating the coordination of technology and knowledge:

Binary relationships of both in terms of shared knowledge and technology are shown with a directed (two-way) node.

The contribution of each pattern to using technology and knowledge in the management team is determined using a square matrix. If individuals A and B (indexed j and k, respectively) have mutual technology dependencies, r'jk represents the percentage of mutual dependency of pattern A on project B.

The percentage of time reduction in performing work by simultaneously selecting two patterns on each node is shown as TPjk.

The level of contribution to reducing work execution time due to joint dependency on technology and knowledge (TLj) is calculated using the following equation:

TLj=∑_(k≠j. k=1)^n▒〖EF_j×TP_jk×〖r'〗_jk ∀ j=1.2.….n〗

2.5 Technical Factors Perspective

From a technical perspective, the interaction between autonomous vehicles and smart cities involves various aspects such as interactivity, safety, and reliability. Interactivity refers to the ability of autonomous vehicles to communicate and interact with existing transportation infrastructure, including traffic lights, road signs, and other vehicles. Ensuring the safety and reliability of autonomous vehicles requires testing, validation, and compliance with regulations, which reduces risks and ensures public confidence in autonomous vehicle technology. Additionally, technical factors such as cybersecurity, data privacy, and system resilience are crucial for protecting against vulnerabilities and potential threats.

The interaction of each component for using technical factors by the executive team is determined using a square matrix, indicated by PEjk. For example, if patterns A and B (indexed j and k, respectively) have mutual technical dependencies. If the success of individual A depends on the selection and success of individual B, then the conditional success probability of A, considering their joint distribution, is obtained from the following equation. Thus, the success of pattern A is enhanced by the amount of PEjk.

PEjk= (PA ,PB)= PA|B= Psuccess of P_A |success of P_B= (P_((success of P_A.success of P_B)))/P_((success of P_B))

2.6 Management Team Perspective

The management team perspective involves strategic decision-making and coordination efforts required to integrate autonomous vehicles optimally into smart urban environments. This involves collaboration among various types of institutions, including governmental bodies, private sector companies, higher education institutions, and community organizations. A multidisciplinary approach

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involving expertise in technology, urban planning, policy development, and public engagement is essential for addressing the complex challenges and opportunities associated with autonomous vehicles and smart city development. Effective leadership and governance structures are crucial for aligning institutional interests, managing risks, and ensuring successful implementation of autonomous vehicle activities within smart city frameworks.

The outcome of each autonomous vehicle activity impacts the overall performance of the smart city. The variable SRjk indicates the percentage of income coordination when both individuals j and k are in a team. The income of each project (BN) can be indirectly calculated using expert surveys.

Finally, the score for improving project income resulting from coordination in the management team, due to the shared dependency on team efficiency (MIj), is obtained from the following equation:

MIj=∑_(k≠j. k=1)^n▒〖EF_j×BN_k×SR_jk 〗 ∀ j=1.2.….n

2.7 DEMANTEL Analysis

Step 1: Formation of the direct relation matrix: The relationships between strategies of autonomous vehicles are represented in a matrix format. As opinions from multiple experts are utilized, a simple average of the opinions forms the direct relation matrix.

Step 2: Formation of the normalized direct relation matrix: The normalized matrix is obtained based on the following equations. First, the sum of all rows and columns is calculated. The inverse of the largest value in each row and column produces the value k. Then, the normalized direct relation matrix is obtained by multiplying the value k by the direct relation matrix.

$$k = \frac{1}{\max(\sum_{i,j=1}^{n} a_{ij})}$$

N=k·D

D is the Direct relation matrix and

N is the Normalized direct relation matrix.

Step 3: Calculation of the complete relation matrix: This matrix is calculated according to the following equation:

$$T = N \times (I - N)^{-1}$$

T is the Complete relation matrix and

I is the Identity matrix.

Step 4: Creation of the cause-effect diagram:

The sum of row elements for each factor indicates the level of impact that factor has on other system factors (the level of impact individuals have on each other).

The sum of column elements for each factor indicates the level of dependency of that factor on other system factors (the sensitivity level of individuals).

Thus, the horizontal vector (D + R), known as prominence, indicates the level of influence and effect individuals have in the system. In other words, the higher the D + R value for an individual, the more they interact with other individuals in the system.

Consequently, the vertical vector (D - R), known as dependency, indicates the power of influence each individual has. Generally, if D - R is positive, we consider the variable causal; if it is negative, it is dependent.

Finally, a Cartesian coordinate system is drawn. In this system, the vertical axis shows the values of D + R, and the horizontal axis shows D - R. The position of each individual is defined in the system with a point with coordinates (D + R, D - R), thus obtaining a graphical diagram.

Step 5: Calculation of the threshold value:

To determine the network relationship map, the threshold value must be calculated. Using this method, minor relationships are disregarded, and only reliable relationships in the network are shown. Only relationships whose values in the complete relation matrix exceed the threshold value are displayed in the NRM. To calculate the threshold value, it is sufficient to compute the average of the values present in the complete matrix. Once the threshold intensity is determined, all values in the complete relation matrix that are smaller than the threshold are set to zero, meaning these relationships are not considered significant.

4. Evaluation of Strategic Interactions of Autonomous Vehicles Based on Interdependence

Different models for the development of autonomous vehicles have focused on agreements with smart cities, considering various assumptions and constraints. In this study, the following assumptions have been made:

Relationships between strategies of autonomous vehicles are considered in pairs. In other words, due to high complexity, interdependence between more than two members is not considered.

It is assumed that the costs and expected revenues of each organization have been calculated in the project team's readiness phase. Due to the uncertain nature of costs and revenues, expert surveys can be used.

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E-ISSN: 3041-8992

The values of smart city development criteria, such as time, cost, and revenue, change linearly considering the agreements resulting from the selection of several interdependent strategies.

The identified interdependencies between pairs of members have the following impacts on the choice of strategies for autonomous vehicles:

Interdependence of resources leads to a reduction in financial losses.

Interdependence on learning and technical knowledge leads to a reduction in transportation time.

Technical interdependence increases the probability of success of autonomous vehicles.

Interdependence in the development of autonomous vehicles increases satisfaction in smart cities.

3 Findings and Results

The factors, interactive patterns, and criteria influenced by each factor are listed in Table 1. It should be noted that in the proposed framework, the process of selecting relevant criteria is performed using network analysis.

Table 1

Evaluation of Autonomous Vehicle Development in Smart Cities

Factors Creating Dependency	Interaction Pattern	Mutual Criterion
Shared Resource	Input-Input	Financial value of project team formation
Technology and Knowledge	Input-Input	Qualitative value of project team formation
Technical Factors	Output-Input	Development of organizational infrastructure due to project team formation
Project Management Perspective	Output-Output	Financial value gained

There are 14 components regarding the impact of interactions between resources, technology, and technical aspects of autonomous vehicles on smart urban environments:

1. **Optimization of Traffic Flow**: Autonomous vehicles, utilizing sensors and advanced algorithms, can help optimize traffic flow in smart cities by monitoring and adjusting the speed and distance between vehicles, reducing congestion and enhancing overall road and highway efficiency.
2. **Energy Efficiency**: By integrating electric and hybrid technologies, autonomous vehicles can significantly enhance energy efficiency in smart cities, reducing dependency on fossil fuels, decreasing emissions, and promoting the use of renewable energy sources for transportation.
3. **Environmental Sustainability**: Autonomous vehicles, through electric propulsion systems and green driving behaviors, can contribute to reducing air pollution and greenhouse gas emissions in smart cities, leading to cleaner and healthier urban environments.
4. **Compatibility with Urban Planning**: The introduction of autonomous vehicles necessitates the adaptation of urban planning strategies, including the redesign of road infrastructure, allocation of parking spaces, and implementation of mixed-use development zones to accommodate new patterns and demands in transportation within smart cities.
5. **Infrastructure Development**: The deployment of autonomous vehicles requires significant investments in infrastructure development, including the integration of smart sensors, communication networks, and the implementation of dedicated pedestrian pathways to support safe and efficient operations in urban settings and ensure seamless connectivity with existing transportation systems.
6. **Access to Transportation**: Autonomous vehicles can improve access to transportation in smart cities by providing convenient and affordable transportation options for people with disabilities, the elderly, and underserved communities, enhancing inclusivity and equity in urban transportation.
7. **Enhancement of Public Safety**: With advanced safety features such as collision prevention systems, pedestrian detection, and emergency remediation capabilities, autonomous vehicles can increase public safety in smart cities by reducing the likelihood of accidents and minimizing the

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E-ISSN: 3041-8992

severity of collisions, leading to saved lives and reduced injuries on the roads.

8. **Improvement of Emergency Response Efficiency**: Autonomous vehicles equipped with emergency response gear can help improve the efficiency and effectiveness of emergency services in smart cities by providing faster response times, optimizing routes to incident locations, and offering real-time data to emergency responders for better decision-making.
9. **Traffic Reduction**: By leveraging connected technologies and intelligent routing algorithms, autonomous vehicles can help reduce traffic in smart cities by optimizing traffic flow, decreasing congestion, and dynamically adjusting routes to prevent traffic hotspots, leading to smoother and more efficient transportation networks.
10. **Enhancement of Public Transport**: Autonomous vehicles can complement traditional public transport systems in smart cities by providing first and last-mile connectivity, expanding service coverage to underserved areas, and improving efficiency and accessibility of the entire urban transport network.
11. **Improvement of Air Quality**: Widespread adoption of electric autonomous vehicles can lead to significant improvements in air quality in smart cities, reducing emissions of harmful pollutants such as particulate matter, nitrogen oxides, and carbon dioxide, thereby reducing health risks associated with air pollution and overall improving environmental quality.
12. **Reduction of Noise Pollution**: Electric and hybrid autonomous vehicles generate less noise compared to traditional internal combustion engine vehicles, leading to quieter urban environments and reduced levels of noise pollution, which can help improve the quality of life for residents in smart cities.
13. **Optimization of Land Use**: The introduction of autonomous vehicles can contribute to the optimization of land use in smart cities by reducing the need for parking spaces, promoting shared transportation services, and encouraging dense urban development, leading to more sustainable and livable urban environments with higher density and mixed uses.
14. **Socio-economic Impact**: Autonomous vehicles can generate significant socio-economic benefits in smart cities by creating new job opportunities, promoting innovation and entrepreneurship, and stimulating economic growth through increased productivity, efficiency, and competitiveness in urban transport systems.

Approach 1: Interactions between components of the smart project separately

Interactions between components of autonomous vehicle projects from a resource perspective are shown in Table 2 with matrix rjk values.

The network mapping resulting from these interactions is shown in Figure 5.

Table 2

Matrix rjk values

	DMU2	DMU 5	DMU 12	DMU 15	DMU 18	DMU 19	DMU 21	DMU 22	DMU 23	DMU 24	DMU 25	DMU 27	DMU 31	DMU 32
DMU2	0	0.85	0.6	0	0	0	0	0	0	0	0.45	0	0.75	0
DMU5	0.15	0	0.3	0.25	0	0	0	0	0.45	0	0	0	0	0
DMU12	0.4	0.7	0	0	0.8	0.45	0	0	0	0	0	0.5	0	0
DMU15	0	0.75	0	0	0.6	0.75	0.35	0	0	0	0	0	0	0
DMU18	0	0	0.2	0.4	0	0	0	0.2	0.4	0	0.45	0	0	0
DMU19	0	0	0.55	0.25	0	0	0	0.3	0.2	0	0	0.15	0	0
DMU21	0	0	0	0.65	0	0	0	0.25	0.15	0	0	0	0	0
DMU22	0	0	0	0	0.8	0.7	0.75	0	0	0	0	0	0	0
DMU23	0	0.55	0	0	0.6	0.8	0.85	0	0	0.7	0	0	0	0
DMU24	0	0	0	0	0	0	0	0	0.3	0	0.15	0	0	0
DMU25	0.55	0	0	0	0.55	0	0	0	0	0.85	0	0	0	0.8
DMU27	0	0	0.5	0	0	0.85	0	0	0	0	0	0	0.85	0
DMU31	0.35	0	0	0	0	0	0	0	0	0	0	0.15	0	0.5
DMU32	0	0	0	0	0	0	0	0	0	0	0.2	0	0.5	0

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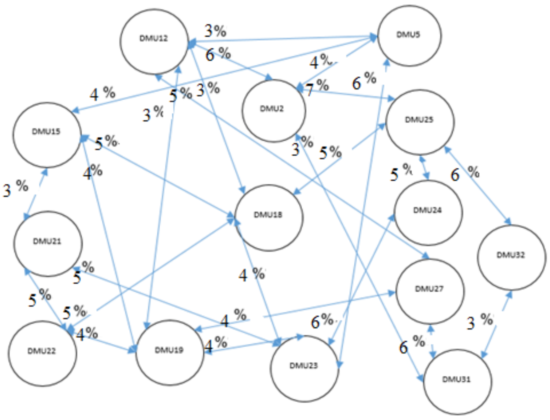
Figure 1

Network Mapping of Resource Interactions



The level of contribution of each component in reducing total management costs as a result of mutual dependency on resource efficiency is shown below.

Table 3

Resource Efficiency Dependency

DMU2	16.938
DMU5	7.025
DMU12	10.815
DMU15	10.944
DMU18	9.424
DMU19	8.846
DMU21	4.136
DMU22	13.124
DMU23	2.970
DMU24	3.550
DMU25	16.151
DMU27	23.870
DMU31	3.792
DMU32	4.604

Interactions between autonomous vehicle components from a technology and knowledge perspective are depicted by matrix r'jk values as follows:

Table 4

Values of Matrix r'jk

	DMU 2	DMU 5	DMU 12	DMU 15	DMU 18	DMU 19	DMU 21	DMU 22	DMU 23	DMU 24	DMU 25	DMU 27	DMU 31	DMU 32
DMU2	0	0.75	0	0.6	0.55	0	0.65	0.7	0.65	0	0	0.6	0	0
DMU5	0.15	0	0	0.3	0.45	0	0.55	0.55	0.45	0	0	0.25	0	0
DMU12	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0

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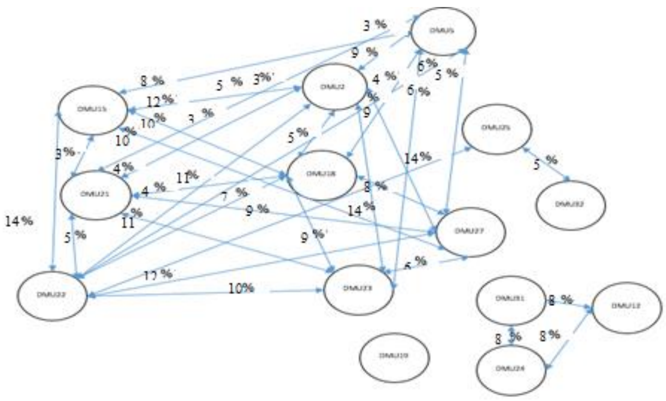
DMU15	0.4	0.7	0	0	0.75	0	0.65	0.5	0	0	0	0.5	0	0
DMU18	0.45	0.55	0	0.25	0	0	0.65	0.35	0.4	0	0	0.45	0	0
DMU19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU21	0.35	0.45	0	0.35	0.35	0	0	0.25	0.15	0	0	0.15	0	0
DMU22	0.3	0.45	0	0.5	0.65	0	0.75	0	0.5	0	0.5	0.65	0	0
DMU23	0.35	0.55	0	0	0.6	0	0.85	0.5	0	0	0	0.5	0	0
DMU24	0	0	0.5	0	0	0	0	0	0	0	0	0	0.5	0
DMU25	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.8
DMU27	0.4	0.75	0	0.5	0.55	0	0.85	0.35	0.5	0	0	0	0	0
DMU31	0	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0
DMU32	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0

Figure 2

Network mapping of interactions between technology and knowledge



The level of contribution of each component in reducing completion time due to mutual dependency on technology and knowledge efficiency is shown below.

Table 5

Dependency of technology and knowledge efficiency

DMU2	56.689
DMU5	19.522
DMU12	8.048
DMU15	34.685
DMU18	24.288
DMU19	0.000
DMU21	9.894
DMU22	51.128
DMU23	36.552
DMU24	11.136
DMU25	11.352
DMU27	68.572
DMU31	8.792
DMU32	1.705

Technical perspective interactions involve collecting initial data on the likelihood of success and failure of executive pairs with shared technical dependencies. Furthermore, the calculation of joint probability distribution functions during the execution process generates mutual technical dependency scores for each project, shown below.

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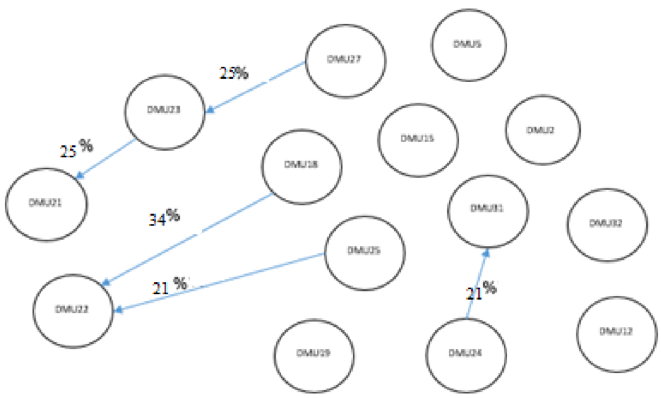
Table 6

Values of the PEjk matrix

	DMU 2	DMU 5	DMU 12	DMU 15	DMU 18	DMU 19	DMU 21	DMU 22	DMU 23	DMU 24	DMU 25	DMU 27	DMU 31	DMU 32
DMU2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU21	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0
DMU22	0	0	0	0	0.34	0	0	0	0	0	0.21	0	0	0
DMU23	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0
DMU24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU27	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU31	0	0	0	0	0	0	0	0	0	0.21	0	0	0	0
DMU32	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3

Network mapping of technical factors interactions



The level of improvement in the success of each component in autonomous vehicles due to mutual dependency as technical factors is shown as follows:

Table 7

Efficiency Dependency of Technical Factors

DMU2	0.000
DMU5	0.000
DMU12	0.000
DMU15	0.000
DMU18	0.000
DMU19	0.000
DMU21	0.262
DMU22	0.684
DMU23	0.295
DMU24	0.000
DMU25	0.000
DMU27	0.000

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DMU31	0.231
DMU32	0.000

Performance data from a management perspective, the goal, and the score for improving the revenue of each component resulting from cohesion in the executive team of autonomous vehicles, and consequently, the mutual dependency on management efficiency, are shown below.

Table 8

Values of matrix SRjk

	DMU 2	DMU 5	DMU 12	DMU 15	DMU 18	DMU 19	DMU 21	DMU 22	DMU 23	DMU 24	DMU 25	DMU 27	DMU 31	DMU 32
DMU2	0	0.05	0	0.1	0	0	0	0.2	0	0	0	0.15	0	0
DMU5	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU12	0	0	0	0	0	0	0	0	0	0.05	0	0	0.1	0
DMU15	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU18	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
DMU19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU21	0	0	0	0	0	0	0	0	0	0	0	0.15	0	0
DMU22	0.2	0	0	0	0.1	0	0	0	0	0	0.15	0	0	0
DMU23	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
DMU24	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
DMU25	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0
DMU27	0.15	0	0	0	0	0	0.15	0	0.1	0	0	0	0	0
DMU31	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
DMU32	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4

Network Mapping of Management Perspective Interactions

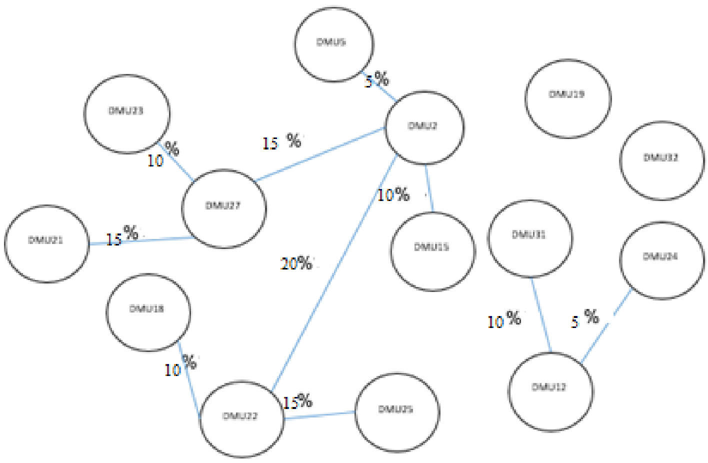

Table 9

Efficiency Dependency of Management Perspective

DMU2	423.46
DMU5	64.1725
DMU12	105.63
DMU15	103.455
DMU18	50.6
DMU19	0
DMU21	125.64

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E-ISSN: 3041-8992

DMU22	398.08
DMU23	94.48
DMU24	97.44
DMU25	61.92
DMU27	678.125
DMU31	153.86
DMU32	0

4 Discussion and Conclusion

Research into internal interactions in the development of autonomous vehicles for smart cities has led to several important findings. First, the study identified complex relationships between various components of autonomous vehicles, including resources, technology, and technical factors. These interactions highlight the need for integration among different elements to enhance overall performance and ensure the success of autonomous vehicle projects. Secondly, the research revealed the critical role of technology exchange and knowledge sharing in shaping the outcomes of autonomous vehicle activities. By leveraging technological advances and sharing domain-specific knowledge, project teams can more effectively confront technical challenges and develop innovative solutions for the needs of smart cities.

Additionally, the research emphasized the impact of technical factors such as infrastructure development and technical expertise on project success. Understanding how these factors interact with each other and influence each other's performance is crucial for optimizing resource allocation and ensuring the efficient implementation of autonomous vehicles in urban environments.

Furthermore, the study underscored the importance of managerial perspectives in determining project outcomes. Effective managerial interactions, including strategic decision-making, resource allocation, and stakeholder engagement, are vital for ensuring project success and aligning project goals with organizational objectives.

Moreover, the research emphasized the implications of these findings for policymakers, industry professionals, and other stakeholders involved in the development of autonomous vehicles. By understanding the dynamics of interactions within autonomous vehicle projects, stakeholders can make informed decisions, reduce risks, and capitalize on opportunities to advance discussions related to the deployment of autonomous vehicles in smart cities.

In the context of developing autonomous vehicles for smart cities, various interactions play crucial roles in shaping project outcomes. One important aspect of these interactions is the interplay between different components from a technology and knowledge perspective. This interaction involves the exchange and integration of technological advancements and expertise among various components of autonomous vehicles. For example, sharing knowledge and leveraging technology between the vehicle's navigation system and sensor technology can enhance the vehicle's ability to navigate better in complex urban environments.

Another significant interaction arises from technical factors. Here, the interaction includes how various technical factors of autonomous vehicles, such as infrastructure development and technical knowledge, affect each other's performance and contribute to project success. For example, advancements in vehicle communication systems can improve the coordination between autonomous vehicles and smart city infrastructure, leading to smoother traffic flow and increased safety.

Additionally, managerial perspectives also play a crucial role in shaping interactions in autonomous vehicle projects. Managerial decisions regarding resource allocation, project planning, and performance evaluation can significantly impact the success of autonomous vehicle activities. Effective management interactions include aligning project objectives with organizational goals, optimizing resource use, and promoting collaboration among various entities. These interactions ensure that managerial decisions positively influence project outcomes and help address challenges related to the development of autonomous vehicles in smart cities.

In conclusion, the research delves into the complex factors that shape the development of autonomous vehicles in smart cities. By recognizing and understanding these interactions, stakeholders can foster collaboration, innovation, and sustainable growth in the field of autonomous vehicle movement.

Authors' Contributions

All authors have contributed significantly to the research process and the development of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethical Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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E-ISSN: 3041-8992