



Journal of Highway and Transportation Research and Development

Home page: www.sciopen.com/journal/2095-6215



Innovation of digital transportation's basic theories

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Abstract: Humanity is entering a digital society, and transportation systems are undergoing a phase of transformation. This paper summarizes the developmental trajectory of transportation, analyzes the necessity of researching the basic theories of digital transportation, and proposes a preliminary definition of digital transportation from perspectives including productivity, production relations, transportation scope, traffic scope, management approach, system composition. It describes core characteristics and identifies key research directions for future focus, aiming to stimulate academic discourse and advance basic theoretical research in this field.

Keywords: Transportation; digital transportation system; basic concepts; transportation scope; management; digital society

1 Introduction

Transportation serves as a vital means for humanity to reduce temporal and spatial constraints, forming a crucial foundation for societal development. Transportation transformation interacts with and mutually reinforces overall societal transformation. Advancements in transportation continuously unleash direct demand, thereby driving overall societal progress. The release of this direct demand, in turn, generates new derivative demands for transportation.

Through multiple technological revolutions, transportation in the industrial society has connected the Earth into a global village. Information transmits at tens of gigabits per second at the speed of light, airliners carry passengers at nearly 1,000 km/h, and trucks deliver goods at 100 km/h across highway networks. The advancement of industrial transportation has underpinned the urbanization of industrial society and enabled the globalization of manufacturing.

At present, spatio-temporal information can be collected widely and accurately, vast amounts of information can be transmitted rapidly in real time, while artificial intelligence is developing at an unprecedented pace. These digital technologies are driving human society from an industrial society into a digital one. In this digital society, people's lifestyles and modes of production and organization will undergo profound changes, bringing about a revolutionary transformation in transportation as well.

Based on an analysis of the development stages of transportation, this paper will focus on discussing the necessity of basic theoretical research in digital transportation and will tentatively propose the basic scope of such research, with the aim of attracting greater scholarly attention to this field.

The concept of digital transportation discussed in this paper is defined from the perspective of transportation development stages,

referring to the characteristics of transportation in a digital society, in distinction from those of the industrial society. Integrated transportation is defined from the perspective of the relationships among various modes of transportation. At present, terms such as smart transportation, digital transportation, and digital intelligence transportation are used primarily from a technological perspective to denote transportation systems that employ smart technologies, digital technologies, and artificial intelligence technologies.

In this paper, the term "digital intelligence" will be used in place of the commonly used term "artificial intelligence". The author believes that "digital intelligence" more accurately reflects the essential nature of the intelligence implied by "artificial intelligence".

2 Analysis of transportation development stages

Transportation originated from the need for communication among primitive humans. Starting from the most primitive roads, humanity continuously applied wisdom to create vehicles, invent boats and rafts, construct roads, excavate canals, establish relay stations, and more. This enabled faster transmission of government decrees, greater transportation of military provisions, and access to more distant regions. The need for human travel and the movement of goods gave birth to transportation.

In primitive society, humans lived within purely natural spaces. Transportation was unnecessary, as spatial activities could be accomplished solely through human intellect and physical strength.

In nomadic society, humans domesticated animals, moved within natural spaces, and accumulated material resources. Human physical strength alone could not support the transfer of these resources, giving rise to the most primitive means of transport.

In agricultural society, humans domesticated plants and transformed natural land, settling relatively permanently in semi-natural, semi-artificial spaces. In the early stages of agricultural society, settlements could largely achieve self-sufficiency within their

Received: 13 February 2026; Revised: 9 March 2026; Accepted: 17 March 2026

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DOI: 10.26599/HTRD.2026.9480092

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boundaries. Limited material exchange between settlements led to the initial formation of transportation networks.

As agricultural society developed, social structures grew increasingly complex, giving rise to artificial spaces detached from agricultural production: the city. Cities could not achieve self-sufficiency and required extensive material exchange. They imported essential agricultural products while exporting small quantities of handicrafts and information for social management and control. Transportation became a critical industry for societal functioning. However, constrained by the production capacity of handicrafts, most production and living materials were still addressed through self-sufficiency. Transportation volumes remained relatively small.

In industrial society, the primary sphere of human activity shifted into artificial spaces: the city. Large scale industrial manufacturing and specialized social division of labor replaced self-sufficient society. Transportation became a domain requiring daily participation from every member of society.

From the brief developmental trajectory outlined above, it is evident that transportation is inseparable from human production and lifestyles. These generate demands for travel and the movement of goods, while the reach scope, scale, and cost of transport constrain economic activities and social functioning. Each technological revolution has been applied to transportation either first or among the first of all sectors.

3 The necessity of theoretical research on digital transportation

In the emerging digital society, digital intelligence partially replaces human intellect, becoming the foundational source of societal intelligence. This fundamental shift propels humanity's primary sphere of activity into the digital space: an ideal paradise unconstrained by physical laws or human sensory limitations. As a result, lifestyles, modes of production, the spatial scope of social activities, and forms of social organization will undergo earth-shaking transformations. Such transformations will deliver a comprehensive disruptive impact on transportation systems designed for the industrial society.

What makes this disruption unique is that the transportation may be facing a significant overall decline in transport demand for the first time. Throughout human history, regardless of the stage of development, demand for the movement of goods has continuously increased; accordingly, the primary objective of transportation development has always been to enhance transport capacity. However, this trend is likely to be reversed in a digital society. In the new society, some material products will be replaced by digital products, and demand for daily commuting and other travel will diminish. At the same time, the integration of artificial intelligence into the transportation system is not comparable to the replacement of horses and oxen by machines; rather, it represents a complete restructuring of the system, not merely an increase in power.

The current foundational theoretical framework for transportation primarily consists of practical theories addressing industrial society transportation needs. These are divided into fundamental theories for various modes of transport and for the construction and maintenance of infrastructure. While these theories can guide continuous optimization and reinforcement of industrial society transportation systems in detail, they are inadequate for effectively addressing the revolutionary developments in transportation that the digital society will bring. Although in recent years, there has been some research on integrated transportation [1], intelligent transportation [2–3], and smart highways [4–5], studies on transportation conducted from the perspective of adapting to the transformation of a digital society remain very limited [6]. The current digital transformation and digital intelligent development of transportation urgently require theoretical guidance [7].

4 Preliminary analysis of the definition and core characteristics of digital transportation

Digital transportation can be briefly defined as follows: it refers to the aggregate of material elements, digital elements, and related activities required to meet the freight and passenger transportation needs of a digital society by adopting digital productivity forces and digital relations of production. It is an important component of the digital society.

A preliminary analysis of the core features of digital transportation is as follows:

—Productivity

The main supporting technologies for digital transportation are spatio-temporal perception technology and digital intelligence technology. The former is the core technology for establishing a mapping between physical space and digital space. The latter replaces human intelligence and provides transportation with control capabilities. These two technologies are the most critical drivers in evolving industrial transportation into digital transportation.

—Production relations

The production relations of the digital society will evolve from the performance-oriented commodity economy of the industrial society into a public, non-performance-oriented society. Digital transportation will also adopt non-performance-based production relations, extensively utilizing unmanned, on-demand transportation modes.

—Transportation scope

Digital society will generate digital goods in digital space that did not exist in the industrial society. These goods will be transported through novel freight modes within digital space. The transportation scope of digital transportation will encompass passengers, physical goods, and digital goods.

—Traffic scope

The operational domain of digital society will expand beyond daily physical spaces to include the deep sea, underground, and outer space. Digital transportation must expand beyond its current terrestrial and aerial domains to encompass the entire physical space. Simultaneously, the digital space will incorporate mappings of biological entities within it, as well as digital intelligent agents possessing autonomous agency. Digital transportation must connect all entities within the digital space.

—Management approach

All processes and actions of digital transportation are mapped to the digital space. Digital rules will be enforced across all processes and actions through the decision-making and control of digital agents.

—System composition

Corresponding to three categories of transport objects, digital transportation will form three service networks: a travel service network, a physical freight service network, and a digital freight service network—each composed of various foundational elements.

—Constituent elements

The fundamental elements encompass data elements, rule algorithms, user elements, and digital intelligence within the digital space; channel networks, energy networks, digital sensing transmission control networks, computing power networks, and intelligent transport vehicles within the physical space; and digital operation service management rules within the management space.

Based on the above analysis, the digital transportation system can be preliminarily outlined as follows: driven by spatio-temporal perception technology and digital intelligence technology, it consists of transportation control platforms and transport service platforms composed of digital space elements such as data, rule and algorithm, user, and digital intelligence. And it controls and utilizes the channel network, energy network, digital perception-transmis-

sion-control network, computing power network, and intelligent vehicles in physical space. Under digital operational, service, and management rules, and adopting non-performance relations of production, the system forms a travel service network, a physical freight service network, and a digital freight service network characterized by deep integration of various transport modes and high level coordination among transport links. It covers the full physical space from the deep sea to outer space, as well as the full digital space encompassing all agents from biological intelligence to digital intelligence, and meets the transport needs of people, physical goods, and digital goods. Collectively, these three networks and all activities based on them constitute the digital transportation system.

5 Key research directions

From the core features of digital transportation outlined above, it can be seen that the foundational theory of digital transportation encompasses multiple dimensions and has rich implications. Research should proceed in the following key directions.

First, conduct systematic research to forecast the digital societal environment relevant to transportation. To develop a theory of digital transportation, it is first necessary to deeply study and accurately predict the productivity, relations of production, modes of social production and life, and forms of social organization within the digital society. These societal conditions determine the spatial distribution of transportation demand and transport volume, dictate the technological means available for transportation, and shape the industry's internal and external relationships. Research in this area is currently the most lacking and the most urgently needed priority. And the research can be integrated with studies on the medium and long-term development planning of transportation, as well as with the specific goals for developing "A country with strong transportation network" by the middle of this century.

Second, an in-depth analysis should be carried out of the various stages in the development of digital transportation. On the basis of accurately understanding the development of digital society, typical stages in the evolution of digital transportation should be identified, and the system composition of each stage should be studied. This should be combined with current initiatives such as the digital intelligent development of highway and the "AI Plus" action plan to comprehensively promote implementation and system construction.

Third, focus on researching management approaches that are suitable for digital transportation. Digital transportation introduces digital goods, incorporates digital intelligent agents, and extends into outer space. These features determine the need to establish new ethical norms and legal governance frameworks, and to address a series of emerging issues, such as the legal liability of digital intelligent agents, the priority between human control and digital intelligent control, and the safety hierarchy between unmanned and manned vehicles. This research can be conducted in conjunction with current management practices for L4 autonomous driving and the digital intelligent development of highway.

Fourth, conduct comprehensive research on digital technologies. Digital technologies represent the core productivity within digital transportation. Researching digital technologies adapted to transportation application scenarios is a highly active field of study today. It should be noted that the characteristics of digital space determine that the cost of information reuse is extremely low, while the characteristics of closed-loop control require comprehensive information acquisition. Research on digital technologies and application systems must be fully integrated. Isolated digital systems are

only suitable for the transportation informatization phase.

6 Conclusion

This paper briefly summarizes the development trajectory of transportation, analyzes the necessity of researching the fundamental theories of digital transportation, preliminarily proposes a definition and core characteristics of digital transportation, and recommends focusing research efforts on four key directions.

Research on the basic theories of digital transportation serves as the core foundation for various specific technologies studies and transportation infrastructure construction in the future. Only with clear theoretical guidance can we avoid fragmented, piecemeal approaches to research and construction. It is hoped that this paper will draw attention from experts and scholars to the importance of basic theoretical research, gradually build a theoretical framework for digital transportation suited to the new era, accelerate the digital transformation of transportation, and contribute to the development of a better international society.

Acknowledgements

The authors would like to thank the anonymous reviewers for their constructive comments and suggestions that helped improve the quality of this manuscript.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

Author contribution statement

Bingqi Zhang: Conceptualization, data curation, funding acquisition, methodology, software, writing-original draft, writing-review & editing.

Use of AI statement

During the preparation of this research, we used ChatGPT to improve grammar and readability. After using this tool, we reviewed and edited the content as needed and take full responsibility for content of the publication.

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