Research on the Value Evaluation of Integrated Sensing and Communication Technology

A Case of Intelligent Transportation

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Abstract. In the background of unprecedented changes in the world, emerging technologies provide new opportunities for transformational development in transportation. The integrated sensing and communication technology can meet the dual requirements of communication and sensing, opening up a new track for intelligent transportation, making "people, vehicles, roads, and the environment" real-time perceptible, connected, and integrated, ensuring traffic safety and improving the operational efficiency of the transportation system. This paper first constructs a universal emerging technologies value evaluation system, and further analyzes the economic value, social value, ecological value, and strategic value of the integrated sensing and communication technology in intelligent transportation scenarios. The analysis can promote the research and application of the integrated sensing and communication, and create infinite possibilities for economic and social development and industry upgrading.

Keywords: integrated sensing and communication (ISAC) · intelligent transportation · emerging technologies value

1 Introduction

The integrated sensing and communication (ISAC) can achieve communication and perception functions on the same set of devices and the same spectrum through joint system design such as signal transmission integration and hardware architecture integration, bringing benefits such as reduced equipment costs and improved spectrum utilization [1]. ISAC is a key technology in the next generation of wireless communication networks, turning the vision of "perception of all things, interconnection of all things, and intelligence of all things" into reality, ushering in a new era of intelligence leading change. At present, ISAC is gradually receiving widespread attention in the industry. Intelligent transportation, as a representative industry of intelligent manufacturing in China's economic development, will promote the construction of smart cities and promote China's upgrading from a "transportation powerhouse" to a "transportation powerhouse". Intelligent transportation is gradually developing towards a path of integration of intelligence and networking, not only for network communication of infrastructure, but also for

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deeper network collaboration such as V2V, V2I (vehicle road communication), V2P (vehicle person communication), etc. In intelligent transportation application scenarios, the dimension of information interaction has expanded from traditional information transmission to information collection and calculation, and the ability to perceive and communicate location and targets has become an indispensable capability requirement [2].

ISAC integrates modern network, communication, and artificial intelligence technologies to achieve real-time interaction and information exchange between vehicles and X (vehicles, roads, people, clouds, etc.), optimize the safe, efficient, comfortable, and energy-saving driving of intelligent connected vehicles, and improve the efficient management of transportation systems and roads. ISAC is an important technical support for intelligent transportation. Through the integration of communication technology, sensor technology, information processing technology and other technologies, the intelligent collaborative operation of vehicles, transportation environment and transport infrastructure will be realized, and the mutual empowerment and collaborative development of automobile, transportation, information communication and other industries will be promoted to form a new industrial ecosystem and further create intelligent connected vehicles The deep organic integration of smart transportation and smart cities.

Technological innovation is influenced not only by the existing technological foundation and innovation capabilities, but also by value goals. Value orientation can promote high-quality development of technology. This paper first constructs a value evaluation system for emerging technologies, and then evaluates the value of ISAC in intelligent transportation. The main structure is as follows: Chapter 1 is the introduction section; Chapter 2 constructs a universal emerging technologies value evaluation system; Chapter 3 takes the intelligent transportation scenario as an example to introduce the value of ISAC; Chapter 4 is a brief summary. This paper helps to promote the application of integrated communication perception technology in intelligent transportation and assist in the implementation of China's transportation power strategy.

2 Value Evaluation System of Emerging Technologies

In the field of emerging technologies, research is generally based on relatively fast-developing innovative technologies arising from the process of knowledge production, and through the identification, tracking, prediction, and management of emerging technologies, and then exploring the potential of emerging technologies to influence future economic and social development. In terms of research on emerging technologies, Li [3] found that advanced technologies have higher productivity than the average technology in society, driving less labor to create more social value. Wang et al. [4] concluded that high-tech enterprises utilize technological advantages to realize corporate value and fulfill corporate social responsibility.

In the field of emerging technology value assessment, the research mainly focuses on the assessment method model and assessment system. In terms of assessment methods, Yang et al. [5] used a validated factor analysis test to systematically assign weights to each indicator for each measurable variable in the model, and the method has good adaptability to the assessment in the field of emerging technology value. Giffoni et al. [6]

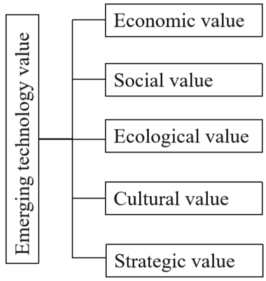

Fig. 1. Emerging technology value system

conducted a study based on the socio-economic impact of infrastructure development driven by emerging technologies and found that cost-benefit analysis is still one of the relatively valid and robust methods available. On the assessment system, Reid et al. [7] evaluated the structure of the socio-economic impact of research infrastructure investment through assessment and monitoring the idea of forming a system with three levels: economic, environmental, and social. Ying et al. [8] constructed a multi-value objective evaluation system to evaluate technical, social, economic, environmental protection, and stakeholder coordination as the main indicators.

Traditional technology value research focuses more on economic value and mainly explores the distribution of value at the enterprise or industry level. With the development of new technologies such as the information and communication revolution, the value of technology is no longer limited to the economic dimension, and the development trend of value objectives is multidimensional. This study innovatively adopts the "five-in-one" overall layout of emerging technology value, and subdivides the technology value system into five dimensions: economic value, social value, ecological value, cultural value, and strategic value based on the United Nations Sustainable Development Goals, and devotes itself to solving social challenges. Figure 1 shows the emerging technology value system we proposed.

Economic value is a monetary measure of the economic benefits obtained in the process of technology transformation and application, which is manifested in the expected benefits of commercialization, cost reduction, efficiency increase brought by digital efficiency improvement. Social value is the value generated by technology applications in promoting social progress, mainly including the value generated by enhancing digital inclusion and building a modern social governance system. Ecological value is the green and low-carbon effect brought by technological innovation, including the green and low-carbon value of the technology itself and the green and low-carbon value brought by empowering other industries to digitally transform. Cultural value is the value of technological innovation to promote cultural dissemination and enhance national cultural confidence, including the value of enhancing the popularity of cultural content and the value of innovation of cultural dissemination methods, etc. Strategic value is the value of technological innovation to enhance national competitiveness, including the promotion of the goal of a strong transportation country and the value of technology-driven high-level scientific and technological self-improvement.

3 Value Evaluation of Integrated Sensing and Communication Technology in Intelligent Transportation

In terms of communication-awareness theory and application research, Peng et al. [9] proposed the need to fully utilize communication devices for communication-perception integration to achieve performance goals such as high transmission rate, low transmission delay, and high-precision wide-range sensing.In terms of application scenarios, Xu et al. [10] formed the evaluation of the application effect of communication-aware integration technology from the demand of typical application scenarios of communication-aware integration, focusing on the key scenarios of traffic scenarios and low-altitude scenarios. In the field of transportation, Zhang et al. [11], and Fan et al. [12] romote the deep integration of sensing and communication, and their research mainly focuses on the optimal design of sensing and communication integration and the integration of hardware and software resources.

This article will take the intelligent transportation scenario as an example and introduce the value of ISAC based on the general emerging technologies value evaluation system built in the previous chapter. Due to the fact that ISAC does not involve cultural value, the following value evaluation is mainly introduced from four dimensions: economic value, social value, ecological value, and strategic value.

3.1 Economic Value

According to the data disclosed by the Intelligent Transportation Association, the market size of the intelligent transportation industry in 2022 was 213.3 billion yuan. Based on multiple factors such as current policy support, technological progress, urbanization process, and the continuous increase in motor vehicle ownership, the compound growth rate of the intelligent transportation market size is about 14.39%. In 2030, the intelligent transportation market size is predicted to be 579.6 billion yuan.

ISAC will promote the intelligent upgrading of automobiles in intelligent transportation. The "Intelligent Connected Vehicle Technology Roadmap 2.0" points out that in 2025, the market share of L2 and L3 level intelligent connected vehicles in China will exceed 50%. By 2030, the shares of L2 and L3 levels will exceed 70%, and the shares of L4 levels will reach 20%.

ISAC will promote the transformation and upgrading of vehicle networks in intelligent transportation. The Chinese market is the first to apply 5G in vehicles internet, and it is expected that the proportion of 5G network applications in 2025 will exceed 50%.

This paper constucts a modified GM(1,N) model to predict the market size of intelligent transportation.

The traditional GM(1,N) model [13] as follows:

The characteristic data sequence of the system is,

$$X_1^{(0)} = (x_1^{(0)}(1), x_1^{(0)}(2), \cdots, x_1^{(0)}(n)) \tag{1}$$

The data sequence of system related factors are,

$$X_{\mathrm{i}}^{(0)} = (x_{\mathrm{i}}^{(0)}(1), x_{\mathrm{i}}^{(0)}(2), \cdots, x_{\mathrm{i}}^{(0)}(n))(\mathrm{i} = 2, 3, \cdots, \mathrm{N}) \tag{2}$$

The first order accumulation generated sequence is,

$$X_{\mathrm{i}}^{(1)} = (x_{\mathrm{i}}^{(1)}(1), x_{\mathrm{i}}^{(1)}(2), \cdots, x_{\mathrm{i}}^{(1)}(n))(\mathrm{i} = 2, 3, \cdots, \mathrm{N}) \tag{3}$$

Among which,

$$x_i^{(1)}(k) = \sum_{j=1}^{k} x_i^{(0)}(j) k = 1, 2, \cdots, \mathrm{n} \tag{4}$$

The $X_1^{(1)}$'s nearest neighbor mean generating sequence is,

$$Z_1^{(1)} = (z_1^{(1)}(2), z_1^{(1)}(3), \cdots, z_1^{(1)}(n)) \tag{5}$$

Among which,

$$z_1^{(1)}(k) = \frac{1}{2}(x_1^{(1)}(k-1) + x_1^{(1)}(k)) \tag{6}$$

$$x_1^{(0)}(k) + a z_1^{(1)}(k) = \sum_{i=2}^{N} b_i x_i^{(1)}(k) \tag{7}$$

The GM(1,N)'s whitening differential equation is,

$$\frac{dx_1^{(1)}(t)}{dt} + a x_1^{(1)}(t) = \sum_{i=2}^{N} b_i x_i^{(1)}(t) \tag{8}$$

We modify this equation through integration,

$$\int_{k-1}^{k} dx_1^{(1)}(t) + \int_{k-1}^{k} a x_1^{(1)}(t) dt = \sum_{i=2}^{N} \int_{k-1}^{k} b_i x_i^{(1)}(t) dt \tag{9}$$

Then,

$$x_1^{(0)}(k) + a \int_{k-1}^{k} x_1^{(1)}(t) dt = \sum_{i=2}^{N} b_i \int_{k-1}^{k} x_i^{(1)}(t) dt \tag{10}$$

We assume that,

$$x_i^{(1)}(t) = \alpha_i e^{\beta_i t} + \gamma_i, i = 1, 2, \cdots, \mathrm{N} \tag{11}$$

where α_i, β_i, γ_i are undetermined constants,

$$x_i^{(1)}(k) = \alpha_i e^{\beta_i k} + \gamma_i,\ \mathrm{k} = 1, 2,\ \cdots, \mathrm{n},\ \ \mathrm{i} = 1, 2, \cdots, \mathrm{N} \tag{12}$$

The modified GM(1,N) model is,

$$x_1^{(0)}(k) + a D_1^{(1)}(k) = \sum_{i=2}^{N} b_i D_i^{(1)}(k) \tag{13}$$

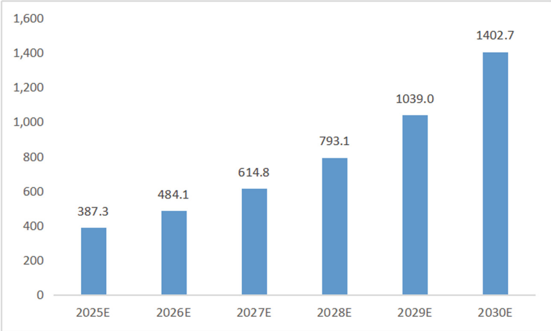

Fig. 2. Scale of intelligent transportaion market with ISAC (billion yuan)

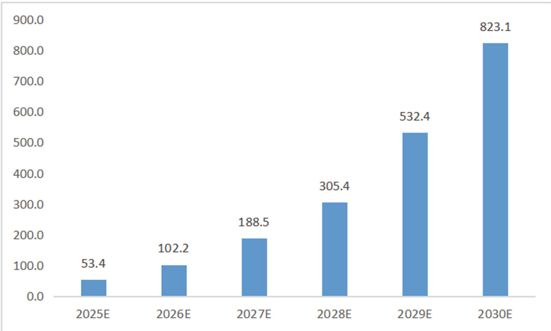

Fig. 3. The economic value of ISAC in intelligent transportation (billion yuan)

Among which,

$$D_i^{(1)}(k) = \frac{x_i^{(0)}(k)}{lnx_i^{(0)}(k) - lnx_i^{(0)}(k-1)} + x_i^{(0)}(1) - \frac{[x_i^{(0)}(k-1)]^{k-1}}{[x_i^{(0)}(k)]^{k-3}[x_i^{(0)}(k) - x_i^{(0)}(k-1)]} \tag{14}$$

We use the modified GM(1,N) model to predict the market size of intelligent transportation, using the application of ISAC as system related factors. The result is shown in Fig. 2. It is estimated that the market size of video content e-commerce will reach 1.4 trillion yuan in 2030. We can roughly estimate the economic value of ISAC in intelligent transportation is 823.1 billion yuan, shown in Fig. 3.

3.2 Social Value

The application of ISAC in intelligent transportation can not only solve the coordination between vehicles and roads, but also solve the problem of connecting vehicles and cities. Through the transformation of vehicles, transportation, and road facilities, it promotes the intelligent management of cities.

ISAC can help alleviate traffic congestion, facilitate vehicle communication, collect real-time data, analyze urban traffic flow, and improve navigation planning. When the popularization rate of CACC (Collaborative Adaptive Cruise Control) reaches 50%, the average road traffic capacity can be increased by 22%. With the comprehensive popularization of CACC, the increase rate of traffic capacity is expected to be between 50% and 80%.

ISAC helps to improve traffic safety. According to NHTSA statistics, the safety applications brought by V2X can reduce or even eliminate up to 80% of traffic accidents, including various accidents caused by intersections and lane changes. V2X communication can improve the sensing ability of vehicles outside the line of sight range. In the early development stage of the Internet of Vehicles, driving assistance, partially autonomous driving, and conditional autonomous driving can reduce car traffic safety accidents by 50% -80%, and improve traffic efficiency by 10% -30%.

ISAC can help improve driving conditions. Assist automobile manufacturing enterprises in tracking the operation status of after-sales vehicles, and provide real-time feedback on data related to vehicle performance to automobile manufacturing enterprises. Learn driver habits, automatically adjust to adapt to changes in the driving environment, enhance driving experience, reduce driving burden, and launch new modes such as vehicle entertainment, vehicle sharing, and convenient travel.

3.3 Ecological Value

ISAC will directly improve the energy efficiency of intelligent transportation. ISAC will gain integration and collaboration gains, through sharing spectrum, hardware platform, and even baseband waveform as well as signal processing between communication and sensing, thereby improving the system's spectral efficiency, energy efficiency, and hardware efficiency. Collaboration gains can also be achieved through the mutual assistance and mutual gain of the two functions of communication and sensing, such as communication assisted sensing technology and sensing assisted communication technology.

ISAC will indirectly promote the contribution of the transportation industry to energy conservation and emission reduction. Driven by carbon peaking and carbon neutrality goals, ISAC realizes accurate collection of carbon emission data and information visualization of emissions by building sophisticated and professional urban intelligent infrastructure, serving the detection and management of government departments. On the other hand, the development of intelligent connected vehicles will further promote the overall contribution of intelligent transportation industry technologies such as autonomous driving and operation, intelligent signal control, and intelligent parking to energy conservation and emission reduction.

3.4 Strategic Value

ISAC has broad application prospects in the field of intelligent transportation, which can expand business boundaries, open up more application scenarios, and have the potential to surpass traditional mobile communication network connectivity application space, thus receiving widespread attention from the global industry.

ISAC can improve the core work efficiency of intelligent transportation and achieve leapfrog development. ISAC can significantly reduce the cost of signaling interaction and assist in high dynamic communication beamforming by equipping active sensing function in the base station/roadside unit system, thereby utilizing radar perception to assist in vehicle positioning and tracking. In terms of sensing, it provides new capabilities for efficient sharing of perception data between vehicles and roadside infrastructure, providing new ideas for safe and reliable networked autonomous driving.

ISAC can improve the efficiency of information exchange in intelligent transportation and enhance the safety of autonomous driving, which has become a hot topic of attention in academia and industry in recent years. Existing research has proposed methods and technologies for achieving communication sensing integration in intelligent transportation scenarios, such as utilizing perception information to assist millimeter wave communication, and designing communication perception integration waveforms based on IEEE 802.11ad standards.

4 Conclusions

ISAC can meet the needs of communication and perception, and is expected to achieve ultra-low latency, ultra-high reliability, ultra-high speed, high-precision perception, and wide coverage. It has broad development prospects in intelligent transportation. Firstly, this paper reviews the value evaluation methods of emerging technologies. Secondly, the evaluation dimension of emerging technologies has been expanded, and the value system of emerging technologies has been innovatively proposed. Based on the overall layout of the "Five in One" and the United Nations Sustainable Development Goals, the emerging technologies value system has been subdivided into five dimensions: economic value, social value, ecological value, cultural value, and strategic value. Finally, taking the application of ISAC in intelligent transportation scenarios as an example, the value of emerging technologies is systematically discussed from four aspects: economic value, social value, ecological value and strategic value. This study helps to promote the development of integrated communication perception technology in practical applications and promote the high-quality development of China's future transportation.

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