Collaborative Mechanisms in Autonomous Transportation Systems: A Scenario Architecture Approach

Jie Wang, Chen Xiong, and Ming Cai

***Abstract*—The convergence and progress in technology have set the stage for the emergence of Autonomous Transportation Systems (ATS), enhancing the autonomy of transportation operations. ATS operates on the principles of autonomous perception, autonomous learning, autonomous decision-making, and autonomous action, necessitating a collaborative mechanism to autonomously cater to dynamic user scenarios. Therefore, building upon the existing ATS architecture, we propose a collaborative mechanism for ATS scenario architecture. First, we categorize business logic based on traffic user demands, introducing professional information from the transportation domain to facilitate understanding demand scenarios. Subsequently, we employ Natural Language Processing techniques to match ATS services with scenario information, responding to scenario demands. Furthermore, we construct physical connections for services based on the principle of information flow triggering and optimize these connections according to the logic of demand business in scenarios. An experimental validation through a random scenario demonstrates the feasibility of our collaborative architecture, achieving a service-matching accuracy of 93%. This study represents an initial exploration into the collaborative mechanisms of ATS, applicable to other transportation scenarios.**

***Index Terms*—Autonomous transportation systems (ATS), collaborative mechanisms, scenario architecture, natural language processing (NLP), service matching.**

I. Introduction

THE integration of intelligence and automation technologies is transforming our lives, including the transportation sector [1]. With the development of next-generation communication technologies, the Internet of Things, big data, and artificial intelligence, these advancements are gradually being incorporated into Intelligent Transportation Systems [2]. The application of these technologies not only enhances the efficiency and responsiveness of transportation systems but also promotes the modernization of infrastructure and the improvement of service quality, simultaneously triggering a demand for higher levels of autonomous services [3]. In this context, scholars have proposed the concept of Autonomous Transportation Systems (ATS) [4, 5, 6, 7], which marks a shift from traditional passive management to more intelligent and autonomous service systems.

ATS operates on an autonomous logic system, enabling self-perception, self-learning, self-decision-making, and self-response, aiming to minimize human intervention and enhance the independent operation capability of transportation systems for efficient response to complex transportation demands [8]. Within this vision, a collaborative mechanism for an autonomous transportation scenario architecture is essential. With the introduction of Service-Oriented Architecture (SOA) [9, 10], ATS can be decomposed into a form based on services as fundamental components. The existence of the ATS cooperation mechanism is to self-organize the operation of each service component of the transportation system, providing autonomous services.

Existing transportation systems demonstrate internal module collaboration [11]. For example, Berlin's traffic control system integrates traffic flow analysis, traffic forecasting, and information dissemination modules, capable of predicting traffic volume and travel time, providing travelers with traffic information through a central network, and guiding the decision-making of the control center based on real-time traffic conditions [12]. Japan's Smartway vehicle networking system achieves high coordination between roads and vehicles, offering various traffic information, electronic toll collection, and internet connectivity services [13]. However, the existing forms of system collaboration only manifest in some system functions or services, unable to coordinate all modules of the transportation system for autonomous response to numerous random travel scenarios of users.

The theory and practice of Multi-Agent Systems (MAS) provide a reference framework for exploring the construction of collaborative mechanisms among internal modules of ATS. MAS involves multiple independent agents communicating, negotiating, and cooperating to accomplish tasks that single agents cannot complete independently [14]. This framework aligns with the essence of the collaborative process among ATS's internal modules to meet user needs. Under service-oriented architecture, ATS can be constructed as a system composed of multiple service components that cooperate to respond to complex transportation demands [5], similar to the cooperation among independent agents in MAS. Current

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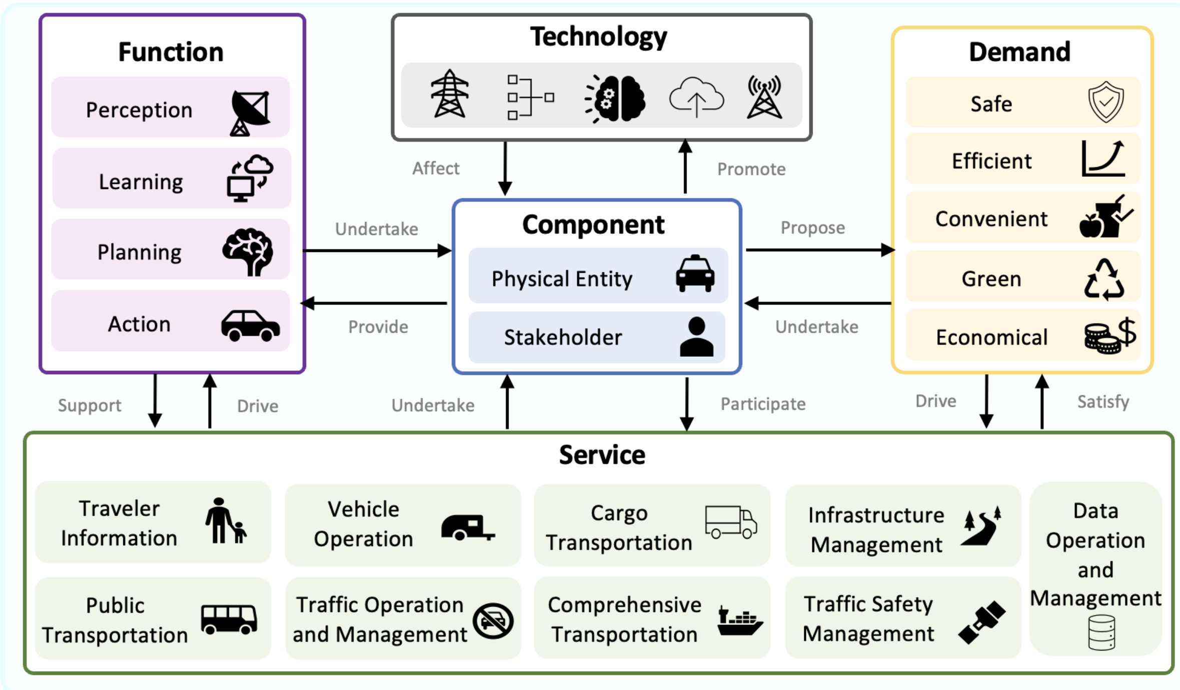

Fig. 1. The architecture of Autonomous Transportation System

research on MAS collaboration mechanisms falls into two categories: one explores methods and technologies from different fields, such as game theory [15], classical mechanics [16], and social sciences [17], to facilitate collaboration among agents. Although these methods perform well in specific environments, they lack flexibility or effectiveness when dealing with rapidly changing scenarios. The second category focuses on exploring collaboration mechanisms among multiple agents from the perspectives of system goals, intentions, and planning [18]. This includes contract net protocol [19], blackboard models [20], functionally accurate, cooperative (FA/C) models [21] and so on. Under this category, the system demonstrates effective task completion through task decomposition and collaboration under specific conditions. These advances provide guidance for building ATS collaboration architectures, showing that it is feasible to effectively complete tasks by decomposing complex tasks into subtasks and closely coordinating among system components.

However, due to the complexity of transportation systems, directly borrowing collaborative mechanisms from other systems cannot address the complex and variable traffic environment and user demands. Therefore, this study is based on the operational logic of ATS, aiming to construct a collaborative mechanism that guides the internal service modules of ATS to cooperate in responding to user demands from a system-wide coordination perspective. The methodology of this study is composed of three parts: 1) Elucidating the logic of traffic user demands from the perspective of traffic users' demand for transportation, revealing the traffic business logic rules they follow in traffic scenarios. 2) Designing a method for matching scenario information with ATS services. According to specific traffic scenario information, we use natural language processing technology to locate the service components needed by the system to respond to scenario demands. 3) Establishing collaboration among services. Combining the user demand logic from 1) and the services obtained in 2) needed to respond to user demands, we propose a service collaboration architecture in which services are orderly connected based on the principle of information flow triggering for specific scenarios. Finally, this paper demonstrates the feasibility of this collaboration architecture with the scenario of autonomous vehicles passing through intersections as an example.

The main contributions of this paper are as follows:

1) It fills the gap in system collaboration mechanisms for ATS. This study draws on the idea of multi-agent systems collaboration, focusing the collaboration mechanism of the transportation system on the cooperation and autonomous response of multiple service components in the face of scenarios, providing theoretical support for the next generation of transportation systems from a top-level architectural perspective.
2) This study realizes the collaboration of ATS components from three steps, suitable for autonomous response in random scenarios. First, by sorting out the logic of user demands, professional knowledge in the transportation field is introduced to help ATS understand external scenario information. Then, through natural language processing technology, the matching of system services with traffic scenario information is established, building the association between ATS internal and external information; finally, a collaboration architecture of ATS internal services is constructed from both the physical layer and the logic layer of traffic demand.

TABLE I
THE BASIC UNIT OF THE "PEDESTRIAN RECOGNITION" SERVICE

Basic unit	Starting point physical object	Information flow	Endpoint physical objects
1	Pedestrians	Pedestrian Characteristics Information	Vehicle Information Unit
2	Road Environment	Environmental Characteristics	Vehicle Information Unit
3	Vehicle Information Unit	Pedestrian Information	Vehicle Control Module

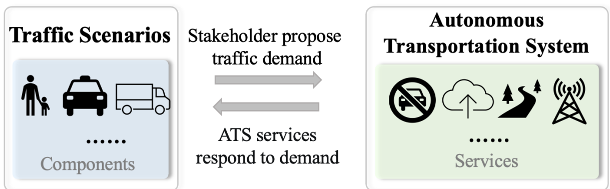

Fig. 2. ATS Collaboration Mechanism

II. BASIC THEORY OF ATS ARCHITECTUR

Before introducing the methodology of constructing the ATS collaboration mechanism, we introduce some basic theories of the ATS architecture.

A. ATS Architecture

Automated Transportation System can be viewed as an intelligent transportation solution designed to meet the mobility needs of people and goods efficiently. Analyzed by the service-oriented architecture method, the design of ATS can be unfolded around five key elements [22]. These elements together form the foundational framework of the system and broadly depict how ATS operates, as illustrated in Fig. 1. Within the ATS framework, components generate demands and participate in the service implementation process, serving as the physical basis for functionalities. Services play a pivotal role in fulfilling specific transportation needs and reflecting the overall capacity of the transportation system. These services are realized through a series of functionalities, which, from an information technology perspective, support the provision of services. Technological advancements directly facilitate the refreshment and optimization of functionalities, serving as a key driving force in the progress of ATS.

B. ATS Collaboration Mechanism

The ATS collaboration mechanism is a top-level architectural mechanism under the ATS architecture, ensuring orderly cooperation among various services to respond to user needs autonomously, as shown in Fig. 2. The existence and operation of the transportation system rely on the participation of various components and the collaborative response among different services. Therefore, we focus on the components and services within the ATS architecture, establishing their associations in random scenarios as our vision.

C. ATS Demand Scenarios

The core of ATS's daily operations is the demand raised by components and the system's service response to these demands. Thus, demand scenarios serve as the bridge connecting components and services. By describing the component information involved in scenarios, specific transportation scenes can be presented. The expression paradigm for ATS scenario information is as follows:

In the <scene >, the <service provider >should be capable of fulfilling the <demand >proposed by the <stakeholder >to achieve the <stakeholder's objectives >.

D. Physical Architecture of ATS Services

The ATS architecture includes functional, logical, and physical architectures [8]. The functional architecture consists of various functions required to complete services and the relationships between these functions. The logical architecture constructs a relational view of the system's functionality implementation, information exchange, and data flow among functional modules. The physical architecture describes the overall composition elements of the system, mapping the functional and logical architectures' implementation logic to the real world, constituted by various traffic entities and the information flow interactions between them. ATS services, encompassing various transportation system functionalities, must ensure that each element can map to traffic entities and that the information flow between elements corresponds to the real world. Therefore, the orderly connection of ATS services at the physical architecture level is foundational for the collaborative response of ATS services to user demands. In ATS, the physical architecture of each service includes physical objects and the information flow between these objects, with the basic unit fundamentally represented as:

<Starting physical object >- <Information flow >- <Ending physical object >

Table I shows the physical architecture of the "Pedestrian Recognition" service, composed of four physical objects and three basic units. Herein, pedestrians and the road environment transmit pedestrian characteristics and environmental information to the vehicle information unit, which internally recognizes pedestrians and then passes the information to the vehicle control module.

III. METHODOLOGY OF ESTABLISHING ATS COLLABORATION MECHANISM

We propose a method for developing an ATS collaboration mechanism that can respond to user needs in random scenarios, as shown in Fig. 3, divided into three steps. Initially, we organize the logic behind users' transportation demands, revealing the traffic business logic followed within scenarios from the perspective of transportation users making demands. Subsequently, we devise a method for matching scenario information with ATS services. Employing natural language

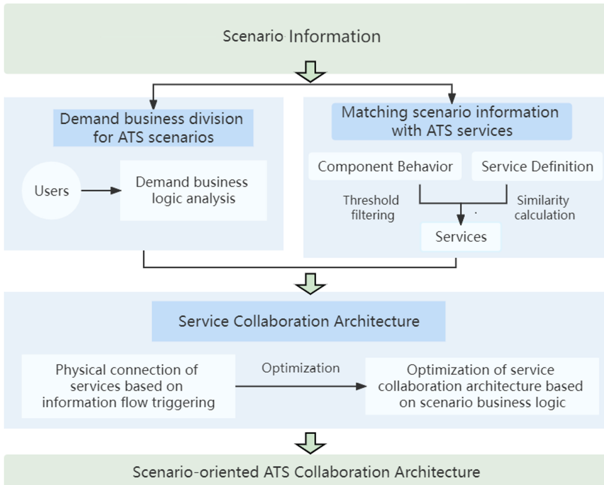

Fig. 3. Technical route for building the ATS collaboration mechanism

processing, we calculate the text similarity between component behaviors and service functionalities within the scenario, filtering the necessary services to respond to scenario demands. Finally, we establish a collaborative architecture among services. Service interconnections are established based on the principle of information flow triggering. On this foundation, we simplify the physical connections according to the logic of user needs within the scenario, ultimately obtaining a scenario-oriented service collaboration architecture.

A. Demand business logic division

The primary task of transportation systems is to complete the transportation of people and goods. In most traffic scenarios, users propose their transportation needs, and administrators and service providers ensure the normal operation of the transportation system and timely response to users' demands through various management tools, system rules, and maintenance. Depending on the mode of travel, transportation demands can be categorized into self-driving, walking, taxi and ride-hailing, and public transportation. Besides human travel, the transportation of goods also constitutes an essential part of the transportation system. Therefore, in ATS, "transportation users" are classified into four categories based on the type of transportation service used:

Pedestrian: Individuals who travel from their origin to their destination without using any form of transportation vehicle.

Passengers: Individuals who use different modes of transportation to move from their origin to their destination.

Drivers: Transportation drivers, including car drivers, bus drivers, and taxi drivers.

Logistics and Transportation Service Users: Organizations or individuals who utilize logistics and transportation services to move goods from the origin to the destination.

We employ a process-oriented construction method to detail the transportation demands articulated by each type of user in specific scenarios. As illustrated in Fig. 4, users are subdivided into "Pedestrians", "Passengers", "Drivers", and "Logistics Transportation Service Providers" based on "whether transporting goods", "whether using a transportation vehicle", and "whether driving," with each type of traffic user having different demand business logics in traffic scenarios. Based on the activity theory, Zhou *et al*. [23] divided the ATS demand into three stages: before, during, and after the activity. Therefore, according to the above classification, the business logic of traffic users is summarized as follows:

1) Before the trip, pedestrians access traffic and travel information; during the trip, pedestrians use route navigation services to complete their journey.
2) Before the trip, passengers choosing public transportation gather information on public transport and rely on its operation and scheduling to ensure their journey, while passengers opting for taxi travel need to complete taxi or online ride-hailing bookings.
3) Before the trip, autonomous vehicles require access to road traffic information; during the trip, autonomous vehicles conduct road environment detection, followed by the identification of obstacles and pedestrians, subsequently making driving behavior decisions and ultimately responding to and executing safe driving measures; post-trip, information about parking lots, gas stations, etc., is needed.
   Before the trip, drivers of non-autonomous vehicles gather road traffic information; during the trip, they acquire real-time information on vehicles and traffic lights; post-trip, they seek out parking lots, gas stations, etc.
4) Logistics and service providers' transportation needs are divided into three stages. Before transportation, they focus on managing goods, commercial vehicles, and driver information. During transportation, they require real-time monitoring and testing of cargo and commercial vehicles' real-time information, scheduling, and route optimization. After transportation, further information updates are needed.

B. Scenario-Service Matching

In this subsection, we match user behaviors in scenarios with ATS services to establish associations between internal and external information in the ATS system. In ATS, scenario information and services are primarily defined through textual descriptions of their content and scope. Establishing a mapping between them involves measuring the similarity between the two texts. The text similarity will be higher if there are more common attributes between the two texts being compared; otherwise, the greater the differences, the lower the text similarity [24]. The matching method is as follows:

1) Scenario information consists of several components, namely stakeholders in the ATS scenario paradigm. For each component, its name is preliminarily matched with the names of service objects and service providers of all services in ATS.
2) Based on the first step, calculate the similarity between the component's behavior description and the function description of the preliminarily filtered services. Set a

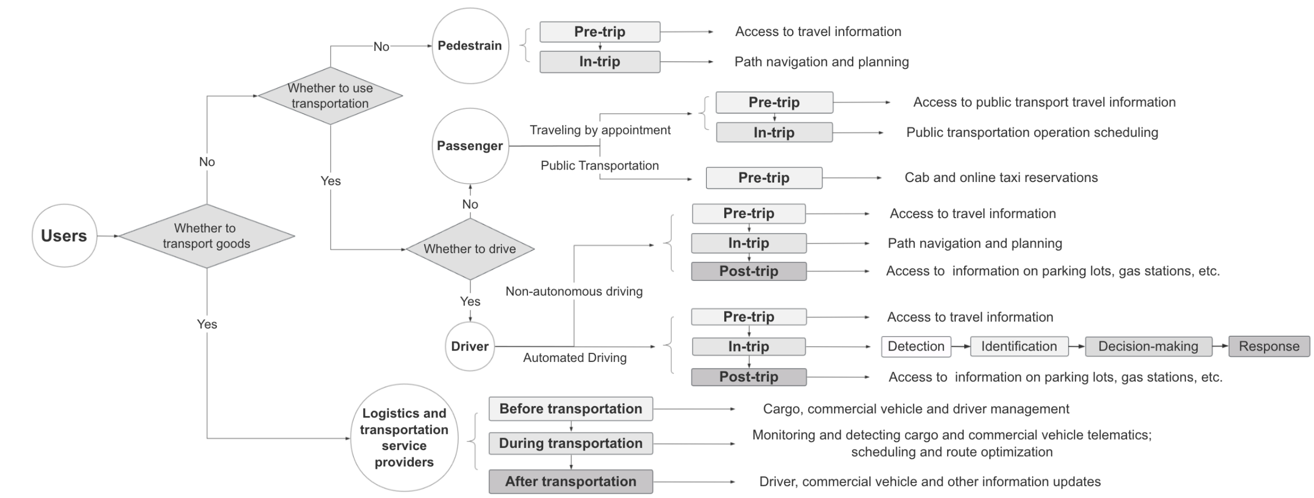

Fig. 4. Demand business logic of traffic users in ATS

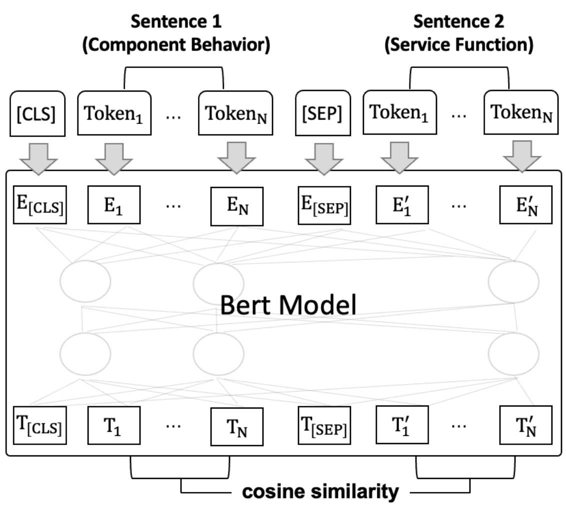

Fig. 5. Text similarity calculation process using Bert model

threshold for filtering to obtain all the services required by the components in that scenario.

3) Repeat the above two steps until all components in the scenario are matched with corresponding services.

In this study, we use the Bert model, based on natural language processing principles, for calculating text similarity. The Bert model was released by Google in October 2018 and pre-trained on a large-scale corpus [25]. It achieves high accuracy in various text-matching scenarios, such as text matching for Chinese disease Q&A [26], automatic text classification [27], and effectiveness evaluation of text generation [28]. Fig. 5 shows the text similarity calculation process using the Bert model, where sentence start and end markers $[CLS]$ and $[SEP]$ are used to separate different sentences: component behavior and service functions. The input sentences are encoded by multiple Transformer encoders in the middle layer of the Bert model to obtain separate output vectors for component demand and service function, expressed as $(T_1, T_2, ..., T_N)$. We use the cosine similarity algorithm to calculate the distance between the output vectors to determine the text similarity between two text pairs. Cosine similarity measures the similarity of vectors through the angle between two vectors [29]. For two vectors A, B in space: $A = (A_1, A_2, \ldots, A_n), B = (B_1, B_2, \ldots, B_n)$, their cosine similarity is expressed as:

$$cos(A, B) = \frac{\sum_{i=1}^{n} A_i \times B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \times \sqrt{\sum_{i=1}^{n} B_i^2}} \tag{1}$$

The smaller the angle, the more aligned the direction of the two vectors, and the closer the cosine value is to 1, indicating higher text similarity; otherwise, if the cosine value is close to 0, the text similarity is low.

C. Services Collaboration Architecture Construction

The ATS service response to user demands is neither parallel nor sequential nor random but collaboratively orchestrated following a specific logic. We consider the collaboration architecture from both physical and traffic logic perspectives. From the physical logic perspective, the demands arise in the real-world context, necessitating the establishment of appropriate connections between services to ensure the interaction of corresponding traffic entities within the service collaboration framework. From the traffic logic perspective, user demands in traffic scenarios progress through different stages according to the underlying demand business logic. Consequently, ATS services cooperate to align with this demand logic on the basis of ensuring physical connectivity.

1) Physical Layer

Service Definition: Each service, S_k, is defined as a triplet $(O_{S_k}, I_{S_k}, D_{S_k})$, where $O_{S_k}(i)$ represents the starting physical object of the ith basic unit, $I_{S_k}(i)$ denotes the information flow, and $D_{S_k}(i)$ signifies the ending physical object. For service S_k, i ranges from 1 to m_{S_k}, where m_{S_k} is the number of basic units.

Connection Condition: A connection pointing from S_1 to S_2 can be established if there exists i $(1 \leq i \leq m_{s_1})$ such that the ending physical object of S_1, $D_{S_1}(i)$, matches one of

TABLE II
PHYSICAL ARCHITECTURE OF THE TWO SERVICES

Vehicle-to-Roadside Unit Communication			
No.	Starting Physical Object	Information Flow	Ending Physical Object
1	Driver	Driver Input	Vehicle-Human Interaction Device
2	Onboard Control Module	Vehicle Status	Onboard Information Unit
3	Vehicle-Human Interaction Device	Driver Commands	Onboard Information Unit
4	Roadside Communication Device	Roadside Unit Information	Onboard Information Unit
5	Onboard Information Unit	Onboard Unit Information	Roadside Communication Device
6	Traffic Information Center	Traffic Status Information	Roadside Communication Device
7	Traffic Information Center	Traffic Management Information	Roadside Communication Device
Collaborative Driving between Vehicles and Signals			
No.	Starting Physical Object	Information Flow	Ending Physical Object
1	Traffic Policy and Regulation Department	Traffic Regulation Information	Traffic Information Center
2	Traffic Information Center	Broadcast Traffic Regulation Information	Traffic Information Publishing System
3	Traffic Information Publishing System	Traffic Regulation Information Update	Onboard Information Unit
4	Onboard Information Unit	Driving Scheme	Onboard Control Module
5	Onboard Information Unit	Vehicle Position Information	Other Vehicles
6	Other Vehicles	Vehicle Feature Information, Vehicle Position Information	Onboard Information Unit
7	Road Environment	Environmental Feature Information, Traffic Light Information, Signage Information	Onboard Information Unit
8	Vehicle Control Module	Vehicle Status	Onboard Information Unit

the starting physical objects of S_2, $O_{S_2}(j)$ $(1 \leq j \leq m_{s_2})$, i.e., $D_{S_1}(i) = O_{S_2}(j)$.

Information Flow as a Bridge: Upon meeting the connection condition, the information flow $I_{S_1}(i)$ acts as a bridge between S_1 and S_2, facilitating the physical connection between the two services.

Example: Taking the services "Vehicle-to-Roadside Unit Communication" and "Collaborative Driving between Vehicles and Signals" as examples, we demonstrate the construction of the service's physical connections (the physical architecture of the two services is shown in Table II). It can be observed that the endpoint physical objects "Onboard Information Unit" of the basic units 2, 3, and 4 of the "Vehicle-to-Roadside Unit Communication" service correspond to the starting physical objects of the basic units 4 and 5 of the "Collaborative Driving between Vehicles and Signals" service, thereby establishing a sequential relationship based on the trigger of the information flow. Therefore, at the physical architectural level, the "Vehicle-to-Roadside Unit Communication" service can establish a connection to the "Collaborative Driving between Vehicles and Signals" service.

2) Traffic logic layer

In this step, we utilize the user demand business logic inducted above to simplify the physical connection architecture of the services. Zhou *et al*. [23] categorizes and summarizes the ATS services, which correspond to different demands within the demand business logic. (details are seen in Appendix I in the Supplementary Materials). Since the demand business logic is not considered in constructing the service's physical connections initially, these established physical connections and demand businesses have four possible relationships, which we sequentially define as sequential connection, reverse connection, internal connection, and jumping connection.

Symbol Definitions:

$C(S_a, S_b)$: Represents the physical connection pointing from service S_a to service S_b.

B_j: Denotes the jth demand business.

$R(S_a, B_x)$: Indicates that service S_a is categorized under demand business B_x.

$O(B_x, B_y)$: Signifies that demand business B_x occurs before demand business B_y.

Connection Types:

- **Sequential Connection:** If $C(S_a, S_b)$ exists, with $R(S_a, B_x)$, $R(S_b, B_y)$, and $O(B_x, B_y)$, then the connection from S_a to S_b is defined as a sequential connection. That is,

$$C(S_a, S_b) \wedge R(S_a, B_x) \wedge R(S_b, B_y) \wedge O(B_x, B_y) \Rightarrow C_{\text{Sequential}}(S_a, S_b) \quad (2)$$

- **Internal Connection:** If $C(S_a, S_b)$ exists, with both $R(S_a, B_x)$ and $R(S_b, B_x)$, then the connection from S_a to S_b is defined as an internal connection. That is,

$$C(S_a, S_b) \wedge R(S_a, B_x) \wedge R(S_b, B_x) \Rightarrow C_{\text{Internal}}(S_a, S_b) \quad (3)$$

Both sequential and internal connections align with the logic of demand business, ensuring continuity in the information flow.

- **Reverse Connection:** If $C(S_a, S_b)$ exists, with $R(S_a, B_x)$, $R(S_b, B_y)$, but the sequence of services contradicts the sequence of business logic, i.e., $O(B_y, B_x)$, then the connection from S_a to S_b is defined as a reverse connection. Reverse connections conflict with demand business logic, leading to logical conflicts and necessitate deletion. That is,

$$C(S_a, S_b) \wedge R(S_a, B_x) \wedge R(S_b, B_y) \wedge O(B_y, B_x) \Rightarrow C_{\text{Reverse}}(S_a, S_b) \Rightarrow Delete \quad (4)$$

- **Jump Connection:** If $C(S_a, S_b)$ exists, with $R(S_a, B_x)$, $R(S_b, B_y)$, but B_x and B_y are not adjacent, i.e., there exists a demand business B_k such that $O(B_x, B_k)$ and $O(B_k, B_y)$, then the connection from S_a to S_b is defined as a jump connection. That is,

$$C(S_a, S_b) \land R(S_a, B_x) \land R(S_b, B_y) \land O(B_x, B_k) \land O(B_k, B_y) \Rightarrow C_{\text{Jump}}(S_a, S_b) \quad (5)$$

Jump connections might introduce redundancy, as the information flow from the preceding service may not immediately activate the subsequent service, necessitating extra storage space for information. To decide whether to retend or delete jump connections, we introduce the concept of an intermediary service.

- **Intermediary Service:** If a service S_m has physical connections with both S_a and S_b, and its corresponding demand business B_m is between the corresponding demand businesses, B_x and B_y of services S_a and S_b, then S_m acts as an intermediary service. This intermediary service can bridge information from S_a to S_b, rendering the direct physical connection between S_a and S_b redundant and eligible for deletion. That is,

$$C(S_a, S_m) \land C(S_m, S_b) \land R(S_a, B_x) \land R(S_b, B_y) \land R(S_m, B_m) \land O(B_x, B_m) \land O(B_m, B_y) \Rightarrow Delete \quad C_{\text{Jump}}(S_a, S_b) \quad (6)$$

IV. CASE STUDY

In order to verify the feasibility of the proposed ATS collaboration mechanism in Chapter III, a typical scenario, Autonomous Vehicles Crossing an Intersection (AVI), is used as an example for experimental analysis. First, we match the scenario information with ATS services by calculating the text similarity. Then, we build the collaboration architecture of the services.

A. Scenario Description

ATS architecture researchers summarized the standardized description of the "Autonomous Vehicle Crossing an Intersection" scenario and selected corresponding services by analyzing the scenario requirements [30]. We normalize the scenario information to a combination of multiple component names and component behaviors, as shown in Table III.

B. Matching scenario with ATS services

Utilizing the scenario-service matching methodology described in Chapter III, we calculate the similarity between the behaviors of each component in AVI scenario and the service functions in the ATS service set corresponding to the component name. To evaluate the algorithm's performance, we adopt two commonly used performance metrics in matching algorithms or classification tasks, accuracy (ACC) and F1 score [31], representing the model's correctness and overall performance, respectively. The calculation of ACC is:

$$ACC = \frac{TP + TN}{TP + FP + FN + TN} \quad (7)$$

where:

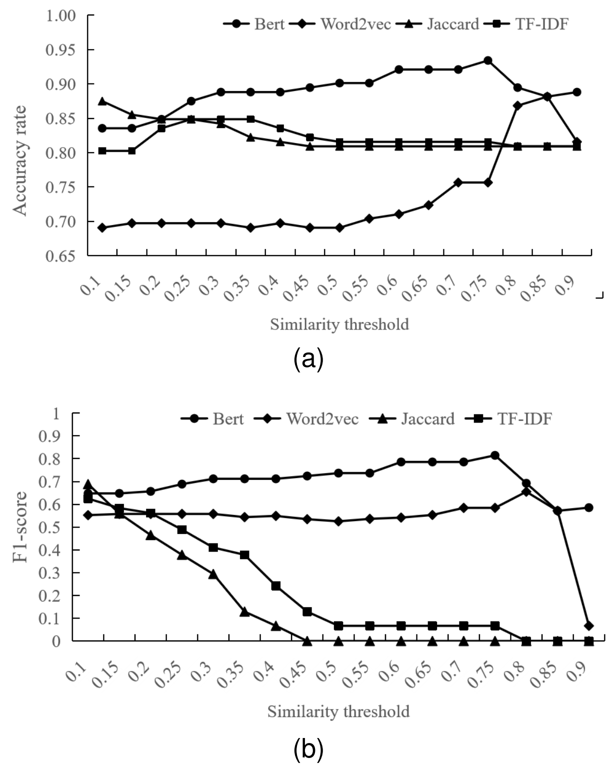

Fig. 6. Evaluation of service matching results. (a) ACC. (b) F1 score.

- TP (True Positives): The number of samples correctly identified as positive.
- TN (True Negatives): The number of samples correctly identified as negative.
- FP (False Positives): The number of samples incorrectly identified as positive (actually negative samples).
- FN (False Negatives): The number of samples incorrectly identified as negative (actually positive samples).

The F1 score is the harmonic mean of precision and recall, where precision is the proportion of actual positive samples among the samples predicted as positive, and recall is the proportion of actual positive samples that the model correctly predicted. This metric balances the identification of all relevant services (high recall) and the selection of only relevant services (high precision).

$$F1_{score} = \frac{2 \times TP}{2 \times TP + FN + FP} \quad (8)$$

To explore the performance of the Bert model in matching scenario information with services, we compare the Bert model with other similarity calculation models such as Word2vec [32], Jaccard [33], and TF-IDF [34], employing different service filtering thresholds to compute matching accuracy. The experimental results are depicted in Fig. 6.

The results indicate a superior service matching accuracy using the Bert model compared to the other three methods. At lower thresholds, the service matching accuracy of the Bert model, Word2vec, and TF-IDF is relatively similar. However, as the threshold increases beyond 0.4, the accuracy of the Bert model continuously improves, peaking at 93% when the threshold is set to 0.75, which is 18%, 13%, and 11% higher

TABLE III
COMPONENTS OF AVI SCENARIO

Scenario Description		
Private carriers	When entering an intersection, autonomous vehicles drive into the lane according to the destination judgment, interact and communicate with the traffic signal, and start the departure according to the signal command before the stop line; communicate with other vehicles and roadside equipment to automatically adjust the speed to ensure driving safety; realize real-time sensing of environmental information and detection of targets through sensors during driving; detect road environment, other vehicles, obstacles on the ground that may affect vehicle passability and safety, pedestrians and various traffic signs	
Traffic managers	Use appropriate strategies to control traffic flow at intersections	
Vehicle manufacturers	Testing whether autonomous vehicles have the basic performance to support the realization of driverlessness	
On-board facility manufacturer operator	Design, operation, evaluation and improvement of supporting facilities for autonomous vehicles	
Transportation product service provider	Provide information on vehicles and routes at intersections to autonomous vehicles through communication products and mapping products	
Traffic infrastructure maintainers	Maintenance of road surface at intersections, maintenance of roadside equipment and maintenance of road traffic signs	
Traffic facilities manager	Responsible for the detection of communication facilities and networks at intersections	
Traffic infrastructure condition monitor	Monitoring the status of intersection road pavement, intersection roadside equipment and intersection road traffic signs	
Emergency manager	Emergency vehicle deployment to provide rescue services in the event of an accident at an intersection	
Services		
Service Object	**Vehicle Operation Service Domain:**	
	Vehicle vision perception	Sensor intelligent perception
	Road environment recognition	Obstacle and vehicle recognition
	Pedestrian recognition	Adaptive cruise
	Collision management	Transmission control system
	Driving system control	Steering system control
	Braking system control	Vehicle and signal light cooperative driving
	Unmanned vehicle whole vehicle performance testing	Unmanned vehicle scenario testing
	Communication between vehicle units	Communication between vehicle units and roadside units
	Communication between vehicle units and network	Communication between vehicle units and pedestrian devices
Service Provider	**Traffic Operation and Management Service Domain:**	
	Traffic flow monitoring	Vehicle monitoring
	Urban surface traffic management	
	Infrastructure management Service Domain:	
	Roadside equipment maintenance	Road surface maintenance
	Traffic signage maintenance	
	Traffic safety management Service Domain:	
	Traffic accident monitoring	Emergency vehicle management
	Traffic accident response	Social security event emergency evacuation response
	Social security event evacuation route release	

than that of Word2vec, Jaccard, and TF-IDF, respectively. These results suggest that a similarity threshold 0.75 effectively retains the necessary services for the scenario while filtering out unnecessary ones. Moreover, the Bert model also outperforms the other three methods regarding the F1 score. As shown in Fig. 6(b), with the increase in threshold, the service matching performance based on Jaccard and TF-IDF deteriorates, whereas the Bert model demonstrates superior performance, improving by 23% compared to Word2vec at a threshold of 0.75. The experimental findings demonstrate that the similarity calculation method based on the Bert model enhances the matching results between traffic scenario demand and ATS services significantly.

C. Services Collaboration Architecture

In the experiment, we take some of the services required for the AVI scenarios as examples: *Vehicle visual perception, Sensor intelligent perception, Obstacle and vehicle recognition, Collision management, Collaborative driving between vehicles and signals, Drive system control and Brake system control*. The collaboration process among these services is analyzed to demonstrate the efficacy of the proposed service collaboration architecture construction method. (For the physical architecture of these services, see Appendix II in Supplementary Materials.)

Initially, based on the principle of information flow triggering and the physical architecture information of each service, physical connections between services are established, as illustrated in Fig. 7. Building upon this, following the demand business division logic summarized in Chapter III, the AVI scenario can be divided into four continuous demand processes: detection, identification, decision-making, and response. According to Appendix I, each service corresponds to its respective demand business. Therefore, we classify the physical connections between services established in the previous step as Sequential, Internal, Inverse, and Jump connections. Furthermore, all reverse connections not conforming to the demand business logic are eliminated, resulting in a preliminary simplified service collaboration architecture. Finally, by identifying intermediary services and removing redundant jump connections, the collaboration relationships between business components are further optimized.

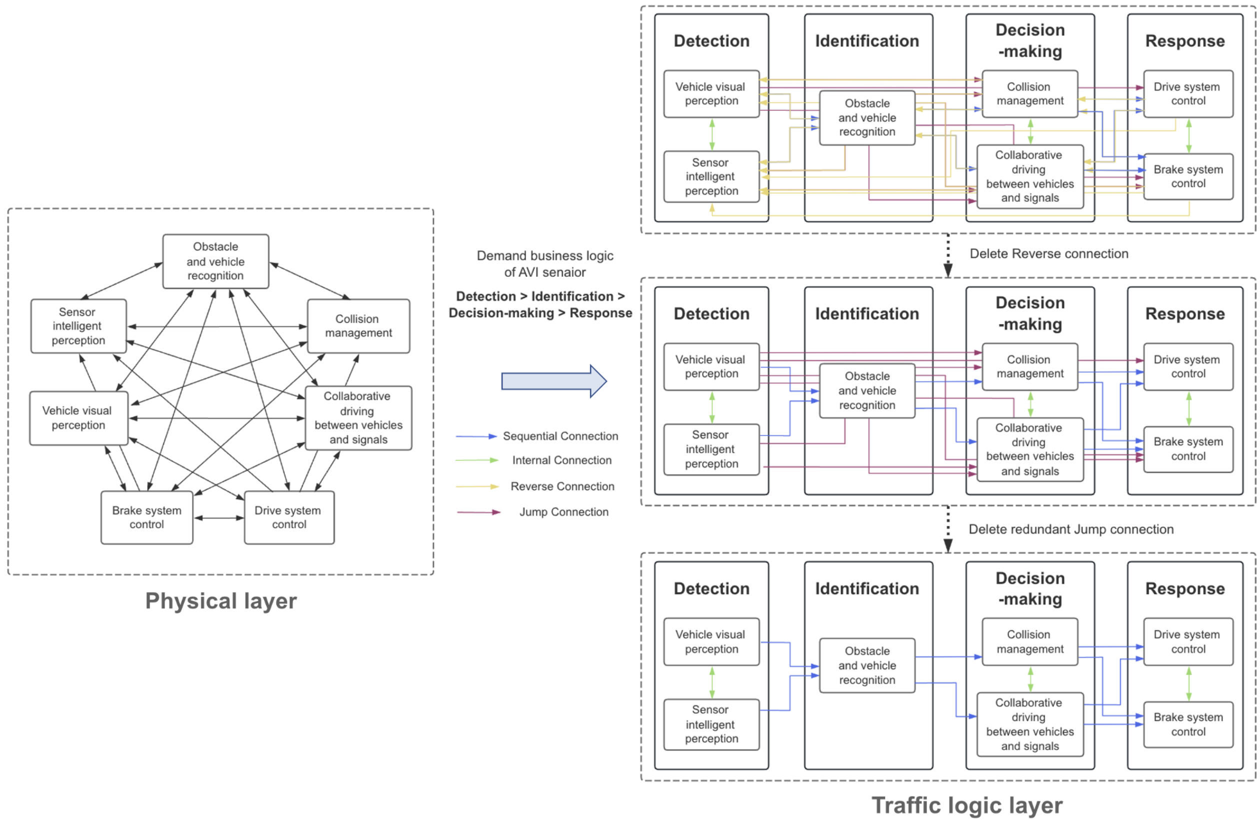

Fig. 7. ATS service collaboration architecture construction

V. Open Issues

The proposed ATS scenario collaborative architecture marks an initial effort towards the ATS collaboration mechanism. However, it involves the operation of the whole system, which is a complicated and detailed work with a broad scope and many considerations. Considering that in the real world, each physical unit has specific performance parameters, the results of collaboration can be further explored in terms of system performance and traffic efficiency. In the future, further effort is required to construct a specialized dataset of autonomous transportation systems to fine-tune the Bert pre-training model, improving the accuracy of service matching.

VI. Conclusion

In this study, we introduce a method for developing a collaborative mechanism for Autonomous Transportation System scenario architecture, encompassing the understanding of external scenarios, the correlation of information inside and outside the system, and the collaboration among internal system components. Specifically, we delineate the demand business logic of traffic users from their perspective, categorizing the demand services of various traffic participants. Subsequently, we match scenario information with ATS services by calculating the similarity between component behaviors within the scenario and service functions. Furthermore, we propose a method for designing a service collaboration architecture based on the principles of information flow triggers and scenario demand business logic. Finally, the construction of an ATS collaboration architecture is demonstrated through a typical demand scenario of autonomous vehicles crossing an intersection. Experimental results show that our proposed method can match ATS services according to scenario demands with a 93% accuracy rate and validate the feasibility of constructing service physical connections based on information flow and simplifying physical connections based on business demand logic.

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