Autonomous Transportation System collaboration mechanism based on Traffic semantics: an implementation in Automated Vehicles Crossing an Intersection Scenario

Jie Wang, Chen Xiong, and Ming Cai

***Abstract*—Autonomous Transportation System (ATS) can weaken the dependence on manual control and improve the autonomous capability of the transportation system through the logic of autonomous perception, autonomous learning, autonomous planning, and autonomous action (A-PLPA). As transportation systems need to face numerous realistic scenarios while residents expect faster demand response, a set of ATS collaborative mechanisms is required to guide ATS self-organized operation and provide autonomous services with low human intervention. Therefore, we propose the collaboration mechanism of ATS scenario architecture based on the existing architecture of ATS. In this work, we first classify the service logic of traffic users' demand so that the system can understand the scenario better. Secondly, ATS services are matched with the scenario information based on natural language processing (NLP) to respond to the demand of the scenario, with an accuracy rate of 93% in a typical traffic scenario. Then, we construct the physical connection of the service based on the principle of information flow triggering, and revise and simplify the physical connection based on the demand business logic of the scenario. Finally, a random scenario is also given to verify the rationality of the cooperation architecture. This study is a vital exploration of the ATS collaboration mechanism, and this successful attempt can also be applied to other transportation scenarios.**

***Index Terms*—Autonomous Transportation System (ATS); Demand business logic (DBL); Cooperation mechanism; Text similarity; Traffic scenario**

I. Introduction

INTELLIGENT Transportation System (ITS) is a product of modern technology and transportation integration, first proposed by the United States in the 1960s. It is developed with modern high technology and is a critical technical means to manage urban traffic congestion and improve environmental pollution [1]. However, with the further integration of cloud computing, big data, artificial intelligence, mobile Internet, and other technologies in the field of transportation, innovations in transportation technologies such as autonomous driving and connected vehicles have brought about improvements in the performance of the transportation system and qualitative changes in services [2], making the involvement of people in the transportation system is gradually weakening [3]. At the same time, with the continuous development of urban transportation, residents want a faster response to transportation needs and the future transportation system needs to face a large number of different realistic scenarios, such as vehicle-road cooperation and Mobility as a Service (MaaS). In response to the demand of residents for convenient travel, the self-organized operation and autonomous service capability of the transportation system are rapidly increasing [4]. In this context, Autonomous Transportation System (ATS) that can proactively provide services to users and operate autonomously for decision-makers is emerging.

ATS operates in a new way as the auto organization and autonomous serving, whose operating mechanism obeys the logic of autonomous perception, autonomous learning, autonomous planning, and autonomous action (A-PLPA), aims to enhance the autonomous ability of transportation system by means of reducing human intervention [5], which is manifested in four aspects including the active response to transportation requirements, automatic operation of vehicles, active control of infrastructure and active adaptation to the external environment. It can enhance the autonomy of the transportation system without relying on manual control [6] while improving the safety and efficiency of the transportation system [7], [8].

ATS is the next generation of ITS, and the system architecture should be studied first for better system construction [9]. The collaboration mechanism of the autonomous traffic scenario architecture is an integral part of the ATS system framework. As shown in Fig. 1, the collaborative mechanism guides ATS to autonomously complete the understanding of external traffic scenarios, including the behavior of people, vehicles and goods, and then find all services that can meet user needs, such as public transportation service, traffic operations and management, integrated transportation service and so on, and finally respond to user needs in collaboration among services. It guides the elements within the ATS to actively adapt to the external environment in random scenarios, provides a rule-based model reference for the autonomous operation of the ATS, and ensures coordinated and orderly cooperation among the system components.

Many scholars have studied the collaboration mechanism of the system. In big data systems, Bohn *et al*. [10] have

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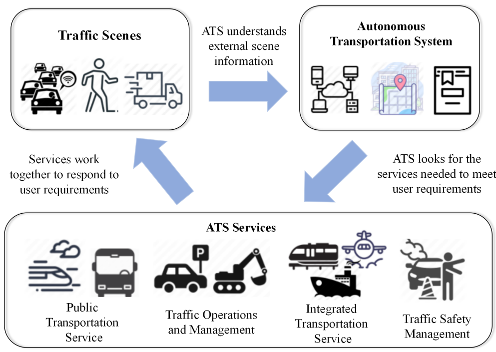


Fig. 1. Operation of the ATS Collaboration Mechanism

mapped computational procedures to corresponding data nodes according to corresponding rules through location consistency mapping and metadata mapping to achieve collaboration between computation and data, enabling the system to effectively face big data processing. In multi-domain optical networks, a multi-controller collaboration framework based on software-defined transport networks is proposed to describe the optical network architecture and provide inter-domain routing resources [11], providing the basis for multi-controllers to collaborate. Tootoonchian *et al*. [12] presented a logically centralized control consisting of many distributed controllers that minimize the response time of the control plane by local decisions of each controller. In wireless sensing networks, Younis *et al*. [13] used genetic algorithms to solve the problem of parallel computing, robot collaboration, and task assignment of cluster head nodes of sensor networks to accomplish collaborative data processing of multiple nodes. Boukerche *et al*. [14] suggested a collaborative mechanism for on-demand distribution, dividing the network into multiple Wireless actors and sensor networks subnetworks and generating demand-dependent optimal routes according to certain routing algorithms to provide better Quality of service solutions. Gungor *et al*. [15] gave a localized network busy-idle estimation mechanism to reasonably control the number of sensor nodes injecting network packets for efficient and energy-saving purposes. In the field of distributed artificial intelligence, Zhan *et al*. [16] proposed a theoretical model predictive control framework to analyze and implement sampled data consensus for multi-intelligent body network systems. Hoshen *et al*. [17] presented the VAIN algorithm to dynamically construct communication routes using an attention mechanism to predict the relationship between artificial intelligence and then communicate based on the relationship. Lesser *et al*. [18] uses partial global planning to coordinate the collaboration between subjects to prevent conflicts among agents. However, none of these collaborative mechanisms from other systems can be directly applied to the transportation system, which is a giant system with complexity. On the one hand, the collaborative mechanisms of other systems lack the understanding of the traffic system, which is the logical basis on which the ATS needs to operate. On the other hand, the collaboration mechanisms of ATS need to be adapted to large-scale stochastic scenarios, which cannot be satisfied by the collaborative mechanisms of other systems.

ATS is a more autonomous transportation system based on ITS, and the collaboration mechanism of ATS needs to adapt to the ever-changing traffic scenarios and different user needs and to organically combine all elements in the transportation system, which is less studied at present. Considering that the ATS architecture is the key to guiding the construction of ATS, we build a set of scenario architecture collaboration mechanism applicable to ATS from the operation logic of ATS. First, the ATS understands the scenario information outside the system based on the demand business logic (DBL) of the user subjects we sorted out. Second, the association of information inside and outside the system is established by similarity calculation based on natural language processing (NLP). Then, we build an internal collaboration mechanism based on the information flow passing of physical objects and DBL. Finally, we validate the effectiveness of the proposed approach to build an ATS collaboration architecture for stochastic scenarios in a typical traffic scenario.

The main contributions of this paper are as follows:

1) In the division of scenario demand business, a set of demand user logic is constructed to sort out the laws followed by different traffic users within the scenario, which is adaptable to most scenarios.
2) Using NLP for text similarity calculation in matching scenario information with ATS services reduces the system's reliance on subjective experience, and the method achieves an accuracy of 93%.
3) We build a collaborative architecture of services based on the physical connection and the business logic of transportation scenarios, achieving a simplification rate of 40.9% while ensuring the complete delivery of information flow.

II. BASIC THEORY OF ATS ARCHITECTUR

The existence and operation of the traffic system depend on the participation of components in traffic links and the association between elements. In different traffic scenarios, the participating components and their behaviors are different, and they can be categorized into two categories: those that drive the formation of the traffic system and those that maintain the existence of the traffic system. Among them, the components that drive the construction of the traffic system are the initiators of the demand of the traffic system. In contrast, the components that maintain the existence of the traffic system are the guarantors of the operation of the traffic system, providing various functions and services to the initiators of the demand. By describing the information of the components involved in the scenario, a specific traffic scenario can be presented, and the description of the ATS scenario information is defined as follows:

Component name: The constituent entities of the transportation system involved in the scenario.

Component behavior: The requirements or services that the component entities make or participate in the scenario.

In order to be able to correspond to the ATS scenario information, the description of the ATS services is defined as follows:

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

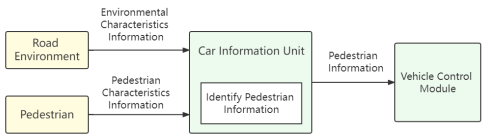


Fig. 2. Physical architecture of the "Pedestrian Recognition" service

Service object: corresponding to the component that proposes the demand in the scenario.

Service provider: corresponding to the component that provides the service in the scenario.

Service function: A specific function provided by the service component for the traffic user.

Physical architectures of services: includes physical objects and information flow between physical objects. The basic unit is "physical object at the starting point - information flow - physical object at the end point", which ensures the integrity of the functional implementation within the service and is the basis for realizing the ATS services to meet the needs of users. Fig. 2 shows the physical architecture of the "Pedestrian Recognition" service, which consists of four physical objects. There are three basic units, shown in Table 1. Among them, Pedestrian and Road Environment transmit pedestrian characteristics and road characteristics information to Vehicle Information Unit, which identifies pedestrians internally and then transmits the information to Vehicle Control Module.

III. METHOD OF ESTABLISHING COLLABORATION MECHANISM

The collaboration mechanism of the autonomous traffic scenario architecture, an essential part of the ATS architecture framework, is indispensable. Therefore, based on the existing ATS system framework, we propose a method to build an ATS collaboration mechanism that can be applied to various random scenarios.

We sort out the DBL of user subjects and reveal the traffic business logic laws they would follow in the scenario from the perspective of traffic users making traffic demands. Second, we design the method of matching scenario information with ATS services. Based on NLP, we use the text similarity algorithm to calculate the matching degree between the component behaviors and the service functions in the scenario and filter the service components required by the system to respond to the scenario demand. Finally, the collaboration architecture between the service components is established. The physical connection between services is established based on the information flow triggering principle. On this basis, the physical connection architecture is modified and optimized based on the business logic of the scenario, and the scenario-oriented service collaboration architecture is finally obtained.

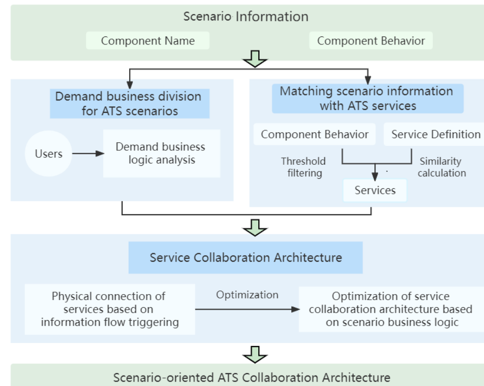


Fig. 3. Technical route for building the ATS collaboration mechanism

The technical route is shown in Fig. 3, and we will present this method in three parts: Demand business division, Scenario-Service Matching, and Service Collaboration.

A. *Demand business division*

Depending on the mode of travel, transportation demand can be classified as travel by car, by foot, by cab and online car, and by public transportation. In addition to human travel, the transportation of goods is also an essential part of the transportation system. Therefore, in the ATS, "transportation users" are divided into four categories according to the type of transportation services used:

Pedestrian: a person who completes the movement from the place of departure to the destination without using any means of transportation;

Passenger: a person who moves from the place of departure to the destination using different modes of transportation;

Driver: drivers of transportation, including car drivers, bus drivers, cab drivers;

Logistics and transportation service User: an organization or a person who moves goods from the place of departure to the place of destination using logistics and transportation services.

We use a process-oriented construction method to refine the transportation requirements proposed by each type of user in a specific scenario. As shown in Fig. 4, "Users" are subdivided into "pedestrians", "passengers", "drivers", and "logistics and transportation service providers" according to "whether to transport goods", "whether to use transportation", and "whether to drive", in which the four types of traffic users have different DBL in traffic scenarios.

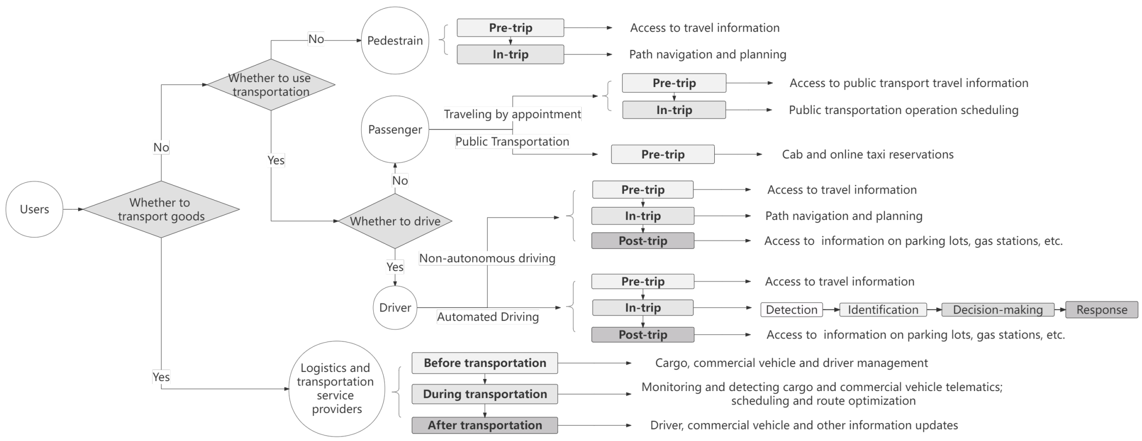


Fig. 4. Demand business logic of the users in ATS

The demand business of pedestrians is divided into pre-trip and in-trip. They get traffic and travel information before the trip and use route navigation services during the trip to help them complete the traffic and travel.

The business logic of passengers who choose to travel by public transportation is similar to that of pedestrians. They obtain information about public transportation before traveling and rely on the operation and scheduling of public transportation to ensure their travel during the trip. Passengers who choose to travel by cab need to complete the reservation of cabs and online cabs before traveling.

The transportation requirements of logistics and transportation service providers are divided into three stages. Before transportation, they focus on the management of cargo, commercial vehicles, and driver information. During transportation, they need to perform real-time monitoring and testing of freight and commercial vehicle real-time information, scheduling, and route optimization. After transportation, further updating of information is needed.

The self-driving driver needs to obtain road traffic information before the trip. During the trip, the self-driving vehicle first carries out road environment detection and obstacle and pedestrian recognition, then completes the driving behavior decision, and finally responds and completes safe driving. After the trip, it needs to obtain a parking lot, gas station, and other

B. Scenario-Service Matching

In ATS, scenario information and service components are mainly defined by textual descriptions of their content and scope. Establishing their respective mapping relationship is involved in similarity measurement between two texts. Therefore, we use NLP to match the services. The process of matching traffic scenario information with ATS services is shown in Fig. 5:

1) Scenario information consists of several different components. For each component, the component name is first corresponded to all service objects and service providers to filter the services that meet the requirements.

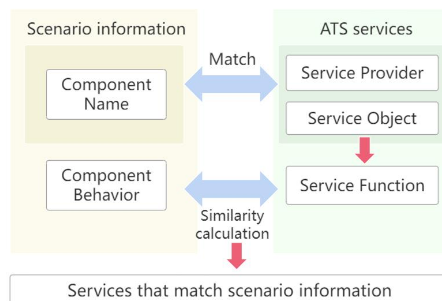


Fig. 5. The process of matching traffic scenario information with ATS services

2) Calculate the similarity between the component's behavior and the service function, and filter by setting certain thresholds to obtain all the services required by the component in the scenario.
3) Repeat the above two steps until all components in the scenario are matched to the corresponding service

For two texts to be compared, the text similarity will be higher if they have more attributes in common with each other and lower if there is no correlation between them, that is, the more differences there are [19]. In the study, we use the Bert model for text similarity calculation. Bert model was released by google in October 2018, which is an unsupervised learning method that can be divided into pre-training and fine-tuning phases [20]. Since it is pre-trained on a large-scale corpus, the Bert model has a high accuracy rate. Many NLP tasks based on it have achieved good results so far, such as text matching of Chinese disease QA [21], automatic text classification [22], and evaluation of the effectiveness of text generation[23].

We use the Bert model to output the sentence vectors of component behavior and service function and then calculate their similarity. Inputting component behavior and service function as sentence 1 and sentence 2, which are represented as $E_1, E_2, ..., E_N$. The output vector $T_1, T_2, ..., T_N$, which is the vectorized representation of the text, is obtained by multiple Transformer encoders in the middle layer, as shown in Fig. 6.

Text similarity is usually expressed as a decimal in the interval of $[0, 1]$, the closer to 1, the more similar the two

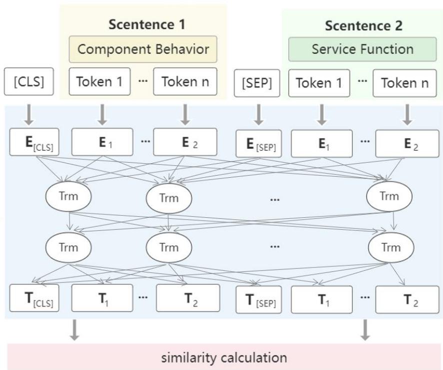


Fig. 6. Embedding input process of the Bert model

texts are, and the closer to 0, the less common points between the texts. We use the cosine similarity algorithm to calculate the degree of similarity between two text pairs.

Cosine similarity measures the vector similarity by the angle between two vectors [24]. The smaller the angle, the more the directions of the two vectors match, and the closer the cosine value is to 1, the higher the text similarity. 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:

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

C. Service Collaboration

In the process of ATS responding to user needs, the services mobilized by the system do not occur in parallel or serially, much less in a haphazard manner, but collaborate according to specific rules and logic to jointly accomplish the transportation needs to be proposed by the user subject in the scenario. Since user requirements are proposed in the real world, and ATS needs to be scenario-oriented to meet user traffic requirements, the collaboration of services should not only consider the physical integrity, but also the correctness and simplicity of business logic.

Therefore, the collaboration architecture of the service is built in two parts:

1) **Building physical connections among services:**

Definition1: For any service of physical architecture S, $S = (O_S, I_S, D_S)$, where $O_S(i), I_S(i), D_S(i)$ respectively represent the starting physical object, information flow and end physical object of the $i\text{-}th$ basic unit in the physical architecture of the service. (1≤i≤m$_S$, m_S is the number of basic units)

Considering the information flow of the start physical object of the former service is the bridge between the two services, the method of physical connection of services based on information flow triggering is shown in algorithm 1.

Algorithm 1 Physical connection of services matched to scenario

TRAIN($\mathbf{S_1}, \mathbf{S_2}, ..., \mathbf{S_N}$)
  for $n = 1, 2, ..., N$
    for $k = n + 1, n + 2, ..., N$
      for $i = 1, 2, ..., m_{S_n}$
        for $j = 1, 2, ..., m_{S_k}$
          if $D_{S_n}(i) == O_{S_k}(j)$ **then**
            service S_n connects to service S_k : $O_{S_n}(i) - I_{S_n}(i) - O_{S_k}(j)$
          else if $O_{S_n}(i) == D_{S_k}(j)$ **then**
            service S_k connects to service S_n : $O_{S_k}(i) - I_{S_k}(i) - O_{S_n}(j)$
          else if
            S_n and S_k are not connected
          end if
        end for
      end for
    end for
  end for
  return Physical connection relationships between services

2) **Correction and optimization of physical connection of services based on DBL:** According to the correspondence between demand business and ATS services, we can correspond the services matching the scenario information to each demand business of the scenario. There are four possible relationships between the physical connection between services and the scenario business logic, as shown in Fig. 7, which are defined as a sequential connection, inverse connection, internal connection, and jump connection.

Sequential connection: The physical connection relationship of services in sequential connections is consistent with the order of occurrence of the demand business, ensuring the accuracy of service collaborations.

Internal connection: reflect the order of occurrence of multiple services in completing a demand business, and there is no conflict with the business logic.

Inverse connection: The physical connection between services in an inverse connection is contrary to the DBL of the scenario.

Jump connection: The connection relationships of the services in a jump connection are not adjacent to each other in the order of occurrence of the demanded services, although they are consistent, and there is a possibility of redundancy. In this case, the information flow sent by the former service will not be enabled by the latter service for the time being, and the system needs to allocate additional storage space for information storage. However, to ensure the delivery of information flow at the physical level, the system still needs the connection. Nevertheless, suppose there is an intermediate service in the architecture that is physically connected to both of them, and the demanded business of the intermediate service occurs between them, as shown in Fig. 8. At this point, the intermediate service can take over the information of the

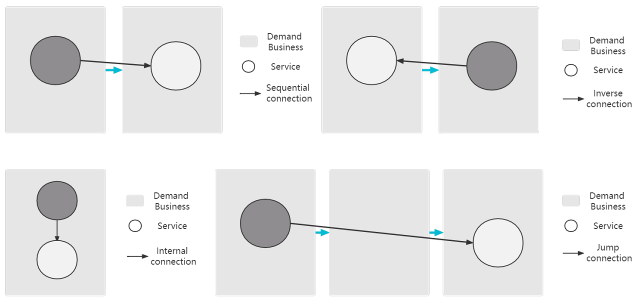


Fig. 7. Diagram of sequential connection, internal connection, inverse connection and jump connection

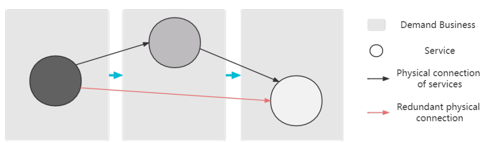


Fig. 8. Diagram of a physical connection with redundancy

former service and pass it to the latter service, and this jump connection is redundant.

The above analysis shows ATS should follow as much as possible the occurrence rule of the users' demand business in the scenario when providing services to minimize the temporary storage of information flow in the system during system operation. Therefore, we apply the DBL to correct and improve the physical connection between services, which can be divided into two main steps.

a) **Find and remove all inverse connections in the physical connectivity architecture of the service.:**

Definition2: The physical connectivity architecture of the services is represented as a directed graph $G = (v, e)$, where the vertex v represents each service and the edge $e_{i,j}$ represents the connectivity between service v_i and service v_j with weight $w_{i,j}$. To simplify the directed graph network G, we consider all connections between services equally important and let the weight of all edges be 1.

Definition3: The DBL of the user in the scenario is represented as a directed graph $G^{'} = (V, E)$, where the vertex V represents each demand business and the edge $E_{i,j}$ indicates that the demand business V_j occurs immediately after V_i in the scenario demand. If there is no edge $E_{i,j}$, the demand business V_i and V_j do not occur adjacent to each other.

Definition4: A vertex v_i is said to be connected to v_j if all edges on the path from vertex v_i to vertex v_j are congruent, and the path is called the connected path from v_i to v_j.

$Step1$: For vertex v_i of directed graph G, find its corresponding demand service E_i in directed graph $G^{'}$. if there is no corresponding demand service, skip the vertex and go to Step3.

$Step2$: Analyze all the rays emitted by v_i. Take $e_{i,j}$ as an example, find the demand service E_j corresponding to v_j in the directed graph $G^{'}$. If there is a connected path from E_j to E_i in the directed graph $G^{'}$, the physical connection $e_{i,j}$ between the service v_i and the service v_j is the inverse connection. If v_j does not correspond to any demanded service, the ray is skipped. Continue traversing the other rays.

$Step3$: If all vertices have been traversed, the algorithm ends; otherwise, go to Step1 to continue traversing other vertices.

Based on the above algorithm, all the inverse connections can be found, and they are removed from the physical connection architecture of the service to obtain the updated directed graph G.

b) **Find jump connections in the physical connectivity architecture and determine if they are redundant:**

Definition5: For a vertex v_p of a directed graph G, when there exists only edge $e_{p,j}$ but not edge $e_{i,p}$, v_p is the start node, and all start nodes form the set K ; for a vertex v_q, when there exists only edge $e_{i,q}$ but not edge $e_{q,j}$, v_q is the end node. The remaining vertices are called intermediate nodes.

Definition6: In a directed graph G, the path consisting of all edges that pass from vertex v_i to vertex v_j is called a road, and the road with the greatest sum of weights of each edge is called the longest road. Since each edge in G has the same weight, it can be considered that the path from vertex v_i to vertex v_j that passes through the largest number of edges is the longest. Further, the path that passes through the maximum number of vertices is the longest.

Definition7: The maximum weight that can be added to each edge without affecting each longest path in the directed graph is called the total maneuver resource of the edge, denoted as $T(i, j)$, and i and j are the two vertices of the edge. It can be proved that the edge in the directed graph with total motor resources of 0 is on the longest path.

In physically connected architecture G, the longest path between any two service vertices is the path that passes through the largest number of vertices among all their connected paths, and all edges on the longest path are indispensable because they ensure that information flow between services can be carried out at the physical level. Apart from that, other edges are potentially redundant because the information flow between them can be passed with the help of other services. The existence of these physical connections needs to be further judged according to the DBL. They should be deleted from the physical connection architecture of the services when and only when they are jump connections to get a more concise and efficient collaboration architecture. Otherwise, they should be retained.

Therefore, we design the longest path algorithm to search for redundant physical connections of jump connections.

$Step1 : a = 1$

$Step2$: Number all the vertices connected to the starting point $K(a)$. Number the starting point $K(a)$ as 1, remove all the directed edges from the starting point $K(a)$ and find the new starting point. If there is only one new starting point, number it as "numbered vertex + 1". If there are more than one new starting point, number it as "numbered vertex + 1 ", "numbered vertex +2", ..., and so on, until the last endpoint connected with the starting point $K(a)$ to complete the numbering, recorded as n.

$Step3$: Compute the longest right-of-way value W_e from the start point $K(a)$ to each numbered vertex by:

$$W_e\left(1\right)=0 \tag{2}$$

$$W_e\left(j\right)=\max\left\{W_e\left(j\right)+w_{i,j}|j=2,3,...,n\right\} \tag{3}$$

where i is the node pointing to j.

$Step4$: Calculate the total mobile resources $T(i,j)$ for each side by:

$$T\left(i,j\right)=W_e\left(j\right)-W_e\left(i\right)-w_{i,j}\left(j=n,n-1,...,2\right) \tag{4}$$

If the total motorized resource $T(i,j)\neq 0$, the physical connection between the two services corresponding to vertex i and vertex j may be redundant.

$Step5$: Determine whether all edges with $T(i,j)\neq 0$ are genuinely redundant. The method of determination is:

Find the demand business corresponding to service i and service j, denoted as V_f, V_g, respectively. If there is no edge $E_{f,g}$ in the directed graph $G^{'}$, the edge $e_{i,j}$ is redundant and deleted from the directed graph G. If either service i or service j has a party that does not belong to the demanded business that has been divided, both edges $e_{i,j}$ are to be retained.

$Step6$: If all the starting points have been traversed, the algorithm ends. Otherwise, let $a=a+1$, go to Step2, and continue the execution.

A simplified and modified service collaboration architecture is obtained based on the above algorithm.

IV. CASE STUDY

In order to verify the feasibility of the proposed ATS scenario collaboration mechanism in Chapter 3, a typical scenario, Automated Vehicles Crossing An Intersection (AVI), is used as an example for experimental analysis. First, we match the scenario information with ATS service by calculating the text similarity. Then, we build the collaboration architecture of the services.

A. scenario Description

The scenario information is normalized to a combination of multiple component names and component behaviors in order to facilitate matching, as described in Chapter 2, as shown in Table 2.

Based on the scenario information, the services involved are identified at the ATS service domain level to provide a reference standard for the subsequent validation of the experimental results. First, consider the service domains involved in the scenario:

1) From the service object perspective, the scenario involves the vehicle operation service domain;
2) From the service provider perspective, it involves the traffic infrastructure management, traffic operation management, and traffic safety management service domains.

Second, consider the finer granularity of services within each service domain.

In the carrier operation service domain, automated vehicles on the road need to realize the perception of the surrounding environment and road conditions through onboard sensors to achieve target detection and identification of surrounding vehicles, pedestrians, and obstacles to ensure driving safety. At the same time, they need to communicate with surrounding vehicles and roadside equipment to make correct driving decisions and maintain a safe distance from the vehicle in front. In an emergency, timely avoidance and collision management are needed. In addition, automated vehicles need to complete vehicle safety testing before hitting the road.

From the perspective of service providers, the road traffic infrastructure management service domain involves roadside equipment maintenance, road surface maintenance, and traffic signage maintenance services to ensure the maintenance and management of infrastructure at intersections.

In the traffic management and control service domain, the safe and efficient passage of automated vehicles at intersections requires the coordination of traffic flow at intersections based on real-time detection of vehicle information and the adoption of appropriate control strategies, including traffic flow monitoring, vehicle monitoring, and urban surface traffic management services.

In the traffic safety management service domain, common emergency events of automated vehicles through intersections include damage to the onboard equipment of automated vehicles, poor physical and mental conditions of passengers in the vehicles, and traffic accidents at intersections. In the face of these emergencies, it is necessary to obtain real-time information such as the status of the incident and the geographic location of the occurrence, reasonably deploy emergency vehicles, provide emergency rescue services for the injured, and at the same time, release the incident information to the surrounding vehicles and do a good job in diverting the traffic flow on the nearby road, to quickly and properly handle the emergency while ensuring the safe and smooth passage of the rest of the traffic.

B. Matching AVI scenario with ATS services

Using the Scenario-Service Matching method described in Chapter 3, we calculate the similarity between the behavior of each component within the AVI scenario and the content of the service corresponding to that component name in the ATS service set and get matching services by setting a reasonable threshold filter. In order to evaluate the superiority of model effects under different parameter conditions, we defined two judgment criteria: accuracy (ACC) and F1_score (F1), representing the model's correctness and overall performance, respectively.

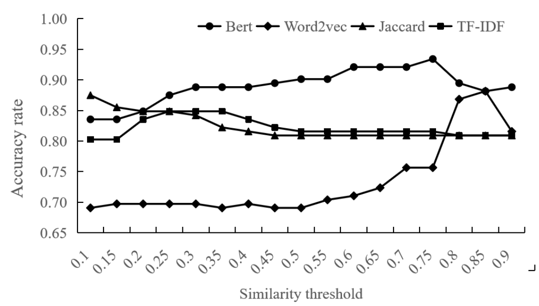
$$ACC=\frac{TP+TN}{TP+FP+FN+TN} \tag{5}$$

Among them, TP and FP respectively represent which data are judged to be positive and, in fact, a positive and negative sample. FN and TN respectively represent which data are judged to be negative and, in fact, a positive and negative sample [25].

$$F1\_score=\frac{2*TP+FN+FP}{2*TP} \tag{6}$$

TABLE II
COMPONENTS OF AVI SCENARIO

Component Name	Component Behavior
Private carriers	When entering an intersection, automated 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 automated 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 automated vehicles
Transportation product service provider	Provide information on vehicles and routes at intersections to automated 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



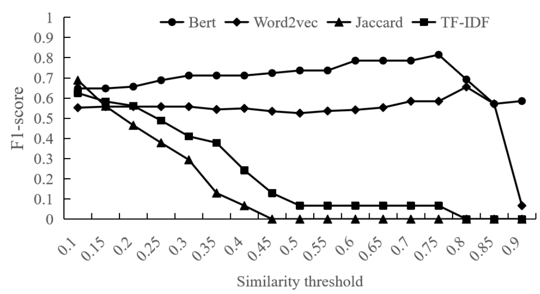


Fig. 9. Evaluation of service matching results. (a) Case I. (b) Case II.

To explore the performance of scenario information and service matching using the Bert model, we compare it with other similarity calculation models: Word2vec [26], Jaccard [27], and TF-IDF [28], and set different thresholds for service filtering to calculate the accuracy of matching. The experimental results are shown in Fig. 9.

As can be seen from the figure, service matching using the Bert model is significantly better than the other three methods in terms of model accuracy. When the threshold is small, the accuracy of service matching using the Bert model, Word2vec, and TF-IDF is relatively close. However, when the threshold value is higher than 0.4, the Bert model's accuracy rate increases continuously and reaches a peak of 93% when the threshold value is equal to 0.75, which is 0.18, 0.13, and 0.11 higher than word2vec, Jaccard, and TF-IDF, respectively. It shows that the threshold of 0.75 can retain as many corresponding services as needed by AVI while filtering out some incorrect services.

Also, the Bert model outperforms the other three methods in the F1-score metric, which measures the overall level of the model. F1-score is the summed average of Precision and Recall, combining the results of Precision and Recall [29]. F1-Score takes values from 0 to 1, with 1 representing the best output of the model and 0 representing the worst. As seen in Fig. 9(b), with the increase of the threshold value, the relevant services cannot be matched using Jaccard and TF-IDF, while the service matching effect based on the Bert model performs well and reaches the best at the threshold value equal to 0.75, which is 0.23 improvement over Word2vec. The experimental results show that the similarity calculation method based on the Bert model can improve the traffic scenario demand and the matching effect of ATS services.

The Scenario-Service Method enables ATS to understand the information of AVI, accurately match all service domains corresponding to the scenario, and find most of the services needed to satisfy the user's demand, which is a crucial step toward realizing the system's autonomous response to the scenario demand.

C. Collaboration Architecture Building

In this experiment, we take some of the services required for the AVI scenario as examples and analyze the collaboration process between the services. The services involved include:

- Vehicle vision perception
- Sensor intelligence perception
- Obstacle and vehicle recognition
- Collision management
- Cooperative driving between vehicles and signals
- Driving system control
- Braking system control
- Communication between vehicle units
- Communication between vehicle units and roadside units

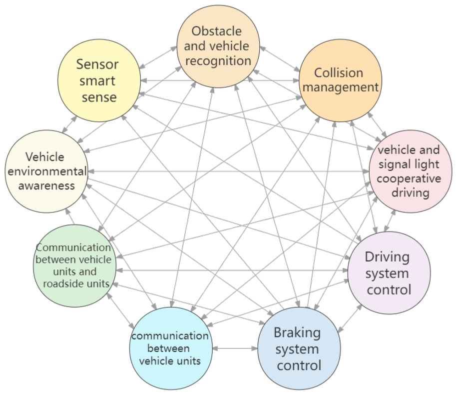


Fig. 10. Physical connectivity architecture for services

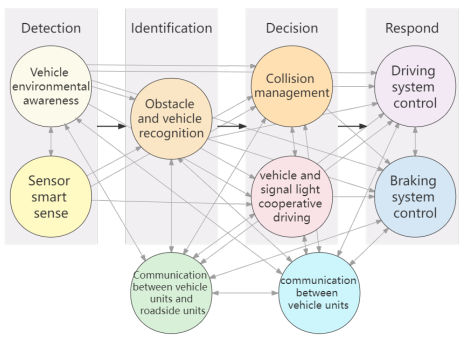


Fig. 11. Service collaboration architecture after removing inverse connections

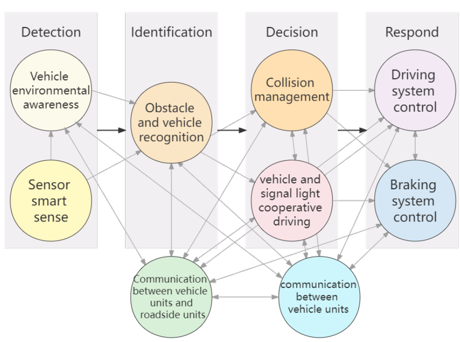


Fig. 12. Ultimate Service Collaboration Architecture

First, based on the principle of information flow triggering, the physical connection between services is established based on the physical architecture information of each service, as shown in Fig. 10. On this basis, the physical connection architecture of the services is revised and optimized based on the DBL of the scenario.

According to the demand business division logic summarized in Chapter 3, the AVI scenario can be divided into four serial requirement processes: detection, identification, decision, and response. After that, each of these nine services corresponds to the respective demand business. Further, the initial simplified service collaboration architecture is obtained by eliminating all the inverse connections that do not conform to DBL based on the algorithm proposed above, as shown in Fig. 11. Finally, the longest path algorithm is used to determine the existence of redundant jump connections and further optimize the collaboration relationship of service components, as shown in Fig. 12.

The service connection correction rate based on AVI scenario DBL reaches 40.9%, optimizing the service components' collaboration architecture with a 100% guarantee of the integrity of information flow simultaneously. As can be seen, the algorithm proposed above ensures both the connection and information flow of the physical objects of the services in the real world and the correctness of the scenario demand logic at the traffic level, which to a certain extent reduces the information storage space required for the system operation and makes ATS more accurate and efficient in responding to the users' needs.

V. Open Issue

The collaboration mechanism of ATS scenario architecture proposed is the first step to exploring the collaboration mechanism of ATS. 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.

VI. Conclusion

In this article, we propose an approach to building a collaborative mechanism for ATS scenario architecture, including the understanding of scenarios outside the system, the association of information inside and outside the system, and the collaboration of components inside the system. Specifically, we sort out the DBL of user subjects from the perspective of traffic users, dividing the demand business of each type of traffic user. Next, we match scenario information with ATS services by calculating the matching degree between service functions and component behaviors within the scenario, achieving an accuracy rate of 93% in a typical traffic scenario. Then, a method is designed to build a collaborative architecture of services based on the principle of information flow triggering and DBL of scenarios. Finally, the feasibility and effectiveness of the method are verified and achieve an optimization rate of 40.9% while ensuring the integrity of information flow delivery.

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