Anti-sea Operation Knowledge Modeling of Aircraft Carrier Formation Based on Key Knowledge and Symbiotic Relationship of Conditions

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Abstract—Anti-sea operation of aircraft carrier formation involves a lot of operational knowledge. The correct use of this complex operational knowledge determines whether the carrier formation can carry out accurate mission planning for sea operations. Therefore, anti-sea operation knowledge modeling of aircraft carrier formation based on key knowledge and symbiotic relationship of conditions is carried out. Firstly, the existing knowledge ontology and key knowledge ontology were constructed according to the anti-sea operations knowledge of aircraft carrier formation. Then, a new type of conditional symbiotic knowledge relationship with intensity factor is constructed. Finally, the ontology mode layer of the knowledge graph of the anti-sea operation of carrier formation was modeled. An example analysis is carried out to prove that the ontology mode layer of anti-sea operation of aircraft carrier formation based on key knowledge and symbiotic relationship of conditions can effectively represent the process of aircraft carrier formation's sea operation, and then provide support for the knowledge graph driven decision support system.

Keywords-Anti-sea Operation; Aircraft Carrier knowledge graph; Knowledge Modeling

1. INTRODUCTION

Carrier formation is an important part of the modern navy, which is mainly composed of carriers, carrier-based aircraft, new types of destroyers and frigates, and nuclear submarines. It has strong comprehensive operation capability on high seas and can perform diverse tasks, among which anti-sea operation is one of the main operational tasks of carrier formation [1][2]. The anti-sea operation task of carrier formation mainly refers to the use of carrier-based aircraft and other core combat forces to attack enemy surface ships in a specific sea area [3], and annihilate enemy surface combat forces to achieve the operational goals of gaining sea control, implementing sea blockade and defending sea transportation lines [4]. The whole process of carrier formation's anti-sea operations involves massive knowledge, including force platforms, weapons and equipment, operational sea areas, and warlike operations [5]. Formation commanders need to use this knowledge to assist mission planning, but the huge amount, variety, and complex relationship of the above knowledge bring a heavy burden to the use of knowledge for formation commanders [6][7]. Traditional mission planning methods based on expert experience and tactical calculation cannot make efficient use of this complex knowledge, resulting in low efficiency of mission planning, long consumption of time, and low reliability of generated operational plans, which cannot adapt to current high-intensity maritime operations [8]. Therefore, it is urgent to build a new knowledge management method to improve the efficiency of task planning.

The knowledge graph is a new mode of massive knowledge management and service mode in the era of big data, which has an efficient knowledge retrieval ability and achieves high-quality information recommendations. Its technical advantages can well solve the knowledge use problem of carrier formation commanders [9][10][11]. By constructing the knowledge graph of anti-sea operations of carrier formation, the complex operational process is transformed into knowledge and the relationship between knowledge, to archive the rapid, efficient, and accurate push of relevant knowledge in the process of mission planning [12][13]. In the absence of expert knowledge, it can assist the commander to quickly formulate the anti-sea operation plan and ensure the reliability of the operation plan, to improve the overall operational effectiveness of the carrier formation and help the commander to gain the initiative in the war [14].

Accurate modeling of the knowledge graph ontology mode layer is the basis of constructing a knowledge graph [15][16]. It is difficult to construct the ontology mode layer of the knowledge graph of the anti-sea operation of carrier formation [17]. At present, most of the military domain knowledge graph constructed in the industry focuses on the fields of weapon and equipment retrieval, intelligence analysis, target recognition, and so on. There is no overall knowledge system formed around the operational domain, and there is no representation method for dynamic knowledge such as time and space existing in the operational domain. Based on the above problems, this paper firstly constructs part of the knowledge ontology according to the existing carrier formation combat knowledge and then constructs the key ontology of the combat action according to the decision-making scenario to accurately express the combat capabilities of the combat platform and weapons and equipment in a specific space and time, which effectively solves the problem that the traditional military knowledge graph is difficult to express spatio-temporal dynamic knowledge. Then, the complex relationship between the knowledge of the anti-sea operation of carrier formation is analyzed, and a new conditional symbiotic knowledge relationship is constructed

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to realize the relationship modeling between the knowledge of the anti-sea operation of carrier formation. Finally, the five-step method [18] was used to model the schema layer of the anti-sea operation knowledge graph ontology, and the anti-sea operation examples were used to verify the schema layer of the knowledge ontology.

2. ONTOLOGY MODELING OF ANTI-SEA OPERATION KNOWLEDGE OF CARRIER FORMATION

There are two main methods for ontology modeling of anti-sea operation knowledge of carrier formation. One is to combine the existing military domain knowledge graph and the concept of anti-sea operation of aircraft carrier formation to carry out ontology modeling of existing operational knowledge. Secondly, considering the particularity that mission planning contains spatio-temporal dynamic knowledge, new key operational knowledge is constructed for ontology modeling.

2.1. Ontology modeling of existing operational knowledge

When it is necessary to construct a new domain knowledge graph ontology, the domain knowledge graph of the existing mature system can be fully referred to and the ontology can be reused, which can greatly improve the construction efficiency of the new domain knowledge graph ontology. At present, the existing knowledge ontology can be extracted in two ways. First, in the military field, there are many reusable ontology databases, such as the military equipment ontology database, in which the combat platform, weapon equipment, and other ontologies can be reused. Second, the knowledge ontology can be constructed according to the operational knowledge contained in the operational plans. These operational plans contain a series of operational knowledge used to describe the anti-sea operation of carrier formation, mainly including routes, sea areas, and so on. Based on the above two approaches, a series of knowledge such as combat platform, weapon and equipment, sea area, air route, and airspace can be extracted, and this knowledge can be classified into three ontology types: combat platform class ontology, weapon and equipment class ontology and activity space class ontology.

Combat platform class ontology, The combat platform class ontology includes the air and surface forces of both sides. Our combat platform is the main force to carry out the combat mission, while the enemy combat platform is the target that we want to fight and the combat force that may pose a threat to us. It mainly refers to various types of air and surface vehicles, including carrier, destroyer, frigate, fighter, EW(electronic warfare) aircraft, and AWACS(airborne warning and control system), whose ontology and description are shown in Table 1.

Table 1. Combat platform class ontology

ontology	description
carrier	A large surface ship with carrier-borne aircraft as its main weapon
destroyer (frigate)	A multipurpose surface ship capable of anti-aircraft, anti-submarine, sea-to-sea missions (destroyer basically the same as frigate except for tonnage)
fighter	A combat aircraft capable of striking surface targets
EW aircraft	A combat aircraft capable of electronic jamming or suppression
AWACS	A helicopter or fixed-wing aircraft with a large radar

Weapon and equipment class ontology, The weapon and equipment class ontology refers to the lethality equipment and detection equipment carried on the combat platforms of both sides, through which the combat platform can carry out detection and strike tasks, which is an important part of the combat, including radar, EW equipment, ship-to-air missile, ship-to-ship missile, air-to-ship missile, whose ontology and description are shown in Table 2.

Table 2. Weapon and equipment class ontology

ontology	description
radar	Equipment that uses radio methods to detect objects and determine their spatial position
EW equipment	Equipment capable of detecting and jamming radar and communications
ship-to-air missile	Missile weapons launched from surface ships against air targets
ship-to-ship missile （air-to-ship missile）	missile weapons launched from surface ships to attack surface targets (other types of anti-ship missiles are consistent with ship-to-ship missile attributes and are primarily launched from air platforms)

Activity space class ontology, The activity space class ontology refers to the operational sea area or air route that our combat platform relies on during the execution of missions and the area where enemy targets are active, including Target sea area, carrier activity area, warning airspace, EW airspace, Anti-sea ship route, Anti-sea aircraft route, Anti-sea The missile route, whose ontology and description are shown in Table 3.

Table 3. Activity space class ontology

ontology	description
Target sea area	An area of the sea intended to strike enemy surface ships or a sealing-off area intended to deny entry to enemy surface ships
carrier activity area	The sea area where an aircraft carrier performs carrier-borne aircraft takeoff and landing operations
warning airspace	The flight space of AWACS performing radar detection missions to air or sea
EW airspace	Flight airspace of EW aircraft performing electronic jamming in fixed airspace
Anti-sea ship route	The navigation route of surface ships carrying out the task of attacking the sea
Anti-sea aircraft route	The flight path of fighter planes carrying out sea strike missions
Anti-sea missile route	The flight path of antiship missile carrying out sea strike missions

2.2. Ontology modeling of key knowledge

Key knowledge ontology is a kind of ontology that can support the application scenario of a knowledge graph effectively. The main role of an anti-sea operation knowledge graph of carrier formation is to retrieve and recommend combat operations. Meanwhile, from the perspective of combat science, combat platform, and weapon equipment must rely on their activity space in the process of combat to reflect their combat effectiveness. The relative location of activity space of combat platforms and weapon equipment is different, which will have a great impact on combat effectiveness. Warlike operation knowledge ontology can precisely combine the above three aspects and accurately reflect the combat effectiveness of combat platforms and weapons and equipment in different activity Spaces, which is a concept that the existing knowledge of combat platforms, weapons, equipment, and activity Spaces cannot express. Therefore, taking warlike operations as key knowledge, the ontology of key knowledge of warlike operations is constructed to describe the comprehensive situation of combat effectiveness of our combat platform located in its activity space. The combat effectiveness of warlike operations can be expressed through the relationship between various knowledge of warlike operations, as the basis for retrieval and recommendation of warlike operations, the ontology includes the following: target operation, carrier activity area operation, the operation against the sea, air early warning operation, EW operation and accompanying EW operation, whose ontology and description are shown in Table 4.

Table 4. Warlike operations class ontology

ontology	description
target operation	A comprehensive situation of enemy surface ships or groups of ships located in the strike area
carrier activity area operation	A comprehensive situation of the carrier located in the carrier activity area to guarantee the carrier-based aircraft takeoff and landing
operation against the sea	A comprehensive situation of our combat platforms and weaponry located in the path of naval vessels to carry out attacks on targets at sea
air early warning operation	A comprehensive situation of anti-air or anti-sea detection missions performed by the AWACS platform located over the warning airspace
EW operation	A comprehensive situation of electronic warfare platforms located in the EW airspace for electronic jamming missions.
accompanying EW operation	A comprehensive situation of electronic warfare platforms located in the anti-sea air route for electronic jamming missions.

3. MODELING OF ONTOLOGY RELATIONSHIP OF ANTI-SEA OPERATIION KNOWLEDGE OF CARRIER FORMATION

After the completion of ontology modeling, the relationship between ontologies needs to be modeled to complete the construction of the knowledge graph ontology pattern layer. The relationship is an important concept in the knowledge graph ontology pattern layer, and the relationship between knowledge can support knowledge recommendation and retrieval based on the knowledge graph effectively. As for the knowledge graph of carrier formation for anti-sea operations, the accurate construction of the relationship among the four ontological types of combat platform, weapons and equipment, activity space, and warlike operations is the key to realizing the recommendation of carrier formation for anti-sea operations knowledge, to effectively support the auxiliary decision-making.

3.1. Conditional symbiotic knowledge relationship with the addition of intensity factors

At present, most of the storage architectures of knowledge graphs are mainly ontological relationships based on the text description, which can effectively serve knowledge retrieval and question answering. In the anti-sea operation of carrier formation, the requirement of a knowledge graph is not only a search or question and answer but also includes the evaluation of combat effectiveness. For example, in the task planning process of searching and recommending suitable operations against the sea for a target operation, it is assumed that there are multiple operations against the sea ontology in the knowledge graph. These operations against the sea have different combat effectiveness for different target operations. If the knowledge graph which is only described by text relationship is used to describe the ontological relationship of different combat effectiveness, the operational effectiveness of operation against the sea cannot be quantified, the ontology recommendation cannot be realized effectively, and the auxiliary effect of mission planning is poor. In this paper, combat effectiveness relationship characteristics of anti-sea operation knowledge graph of carrier formation will be extracted, intensity factors will be added to its relationship attributes, and relationship intensity definition rules will be established, which can more accurately describe the association relationship of different strengths between ontologies, and improve the efficiency of knowledge graph assisted mission planning.

The traditional knowledge graph is mainly composed of knowledge nodes and connected edges, namely "entity-relation-entity" triplet semantic relation. At present, it is difficult to describe the relationship between anti-sea operation knowledge of carrier formation in this knowledge graph composed of ordinary flat triples. For example, again taking the operation against the sea entity recommendation as an example, strike forces start from the carrier activity area to carry out strikes on maritime targets, the operation against the sea entity recommendation should refer to its relationship with the corresponding carrier activity area operation and the relationship with the target operation. The two relations are co-activated. Therefore, this paper improved the original triplet semantic relation knowledge graph and proposed a conditional symbiosis relationship, namely "entity-

relationship-entity-relationship-entity", which could effectively express the mutual relationship between the three knowledge nodes, and make the effectiveness expression of various combat operations more accurate.

3.2. Construction of relationship between anti-sea operation knowledge of carrier formation

In the following process of relationship construction, text description relationships, relationships including intensity factors, and conditional symbiosis relationships of different combat knowledge domains will be listed respectively according to different relational requirements among various combat knowledge ontologies. As shown in Table 5 and Table 6.

Table 5. Ontology relation and literal description

Relation	Description
Destroyer(Rigate, Carrier) - Target operation	Enemy surface ship is inscape of target operation
Target sea area - Target operation	Target sea area is inscape of target operation
Destroyer(Frigate, Carrier) - Target operation	Enemy surface ship is inscape of target operation
Radar - Target operation	Radar is inscape of target operation
ship-to-air missile - Target operation	Ship-to-air missile is inscape of target operation
Destroyer(Frigate, Carrier) – Radar	Destroyer(Frigate, Carrier) carry Radar
Destroyer(Frigate, Carrier) - Ship-to-air missile	Destroyer(Frigate, Carrier) carry Ship-to-air missile
Carrier - Fighter	Carrier carry Fighter
Fighter - Air-to-ship missile	Fighter carry Air-to-ship missile
Carrier - Carrier activity area operation	Carrier is inscape of Carrier activity area operation
Carrier activity area - Carrier activity area operation	Carrier activity area is inscape of Carrier activity area operation
Carrier - Carrier activity area	Carrier is located into Carrier activity area
Carrier – Fighter(EW aircraft)	Carrier area Fighter(EW aircraft)
Destroyer(Frigate) - Operation against the sea	Destroyer(Frigate) is inscape of Operation against the sea
Fighter - Operation against the sea	Fighter is inscape of Operation against the sea
Ship-to-ship missile(Air-to-ship missile) - Operation against the sea	Ship-to-ship missile(Air-to-ship missile) is inscape of Operation against the sea
Anti-sea ship route - Operation against the sea	Anti-sea ship route is inscape of Operation against the sea
Anti-sea aircraft route - Operation against the sea	Anti-sea aircraft route is inscape of Operation against the sea
Anti-sea missile route - Operation against the sea	Anti-sea missile route is inscape of Operation against the sea
Destroyer(Frigate) - Ship-to-ship missile	Destroyer(Frigate) carry Ship-to-ship missile
Fighter - Air-to-ship missile	Fighter carry Air-to-ship missile
Anti-sea ship route(Anti-sea aircraft route) - Anti-sea missile route	Anti-sea ship route(Anti-sea aircraft route) end-joining Anti-sea missile route
Destroyer(Frigate) - Anti-sea ship route	Destroyer(Frigate) is located on Anti-sea ship route
Fighter - Anti-sea aircraft route	Fighter is located on Anti-sea aircraft route
Ship-to-ship missile(Air-to-ship missile) - Anti-sea missile route	Ship-to-ship missile(Air-to-ship missile) is located on Anti-sea missile route
AWACS - Air early warning operation	AWACS is inscape of Air early warning operation
Warning airspace - Air early warning operation	Warning airspace is inscape of Air early warning operation
Radar - Air early warning operation	Radar is inscape of Air early warning operation
AWACS - Radar	AWACS carry Radar
AWACS - Warning airspace	AWACS is located on Warning airspace
EW aircraft - EW operation	EW aircraft is inscape of EW operation
EW airspace - EW operation	EW airspace is inscape of EW operation
EW equipment - EW operation	EW equipment is inscape of EW operation
EW aircraft - EW airspace	EW aircraft is located on EW airspace
EW aircraft - EW equipment	EW aircraft carry EW equipment
EW aircraft - Accompanying EW operation	EW aircraft is inscape of Accompanying EW operation
EW equipment - Accompanying EW operation	EW equipment is inscape of Accompanying EW operation
EW aircraft - Anti-sea aircraft route	EW aircraft is located on Anti-sea aircraft route

Table 6. Includes strength factors and symbiotic relationship of conditions

Relation	Description	Intensity Factor
Carrier activity area operation - Target operation	Carrier activity area operation direct at target operation	Target threat width: According to our combat aircraft plus the air-to-ship missile range or the ship to ship missile range is the inside diameter, The tactical ellipse with the center point of our carrier activity area and the center point of Target sea area as the center of the circle gives the threat width of 0 km, 50 km, 100 km, 150 km and 200 km away from the target, respectively. the greater the threat width, the greater the flexibility of operation against the sea
		Width of target threat: Depending on the enemy combat aircraft plus the range of the air-to-ship missile or the range of the ship-to-ship missile,

		The tactical ellipse with the center of our carrier activity area and the center of Target sea area as the center of the circle gives the threat width of 0 km, 50 km, 100 km, 150 km and 200 km from our carrier activity area, respectively. The wider the threat, the greater the threat to us
Carrier activity area operation - Operation against the sea - Target operation	Operation against is target of carrier activity area operation	Missile penetration probability: The higher the penetration probability of the missile used, the better the strike effect
		Maximum penetration missile quantity: The higher the maximum penetration missile quantity, the better the strike effect
		Impact degree: The amount of ammunition in the action against different enemy formations can cause damage, affect the operational effectiveness of different enemy formations
	Carrier activity area operation initiate operation against the sea	Force utilization ratio: the ratio of the number of fighters included in the carrier activity area operation to the number used in the operation against the sea. The higher the ratio, the better the force surplus
Carrier activity area operation - Air early warning operation - Target operation	Air early warning operation support carrier activity area operation	Detection probability: The probability that radar detects the target at sea
	Air early warning operation scout target operation	
Carrier activity area operation - EW operation- Target operation	EW operation support carrier activity area operation	Jamming effect: Attenuation effect of the detection range and target discovery probability of the enemy maritime air target radar detection equipment
	EW operation disturb target operation	
Accompanying EW operation - Operation against the sea - Target operation	accompanying EW operation disturb target operation	Jamming effect: Attenuation effect of the detection range of the enemy maritime target radar detection equipment and target discovery probability
	accompanying EW operation support operation against the sea	

4. Ontology Mode Layer Modeling of Aircraft Carrier Formation Knowledge Graph in Anti-sea Operation

Ontology mode layer modeling of aircraft carrier formation knowledge graph in anti-sea operation, which can clearly describe the knowledge structure and accurately express each knowledge element and the relationship between knowledge, is conducive to the filling and application of knowledge entity. This paper adopts the five-step ontology construction method to model the ontology pattern layer.

- Determine ontology scope: Ontology mode layer modeling of aircraft carrier formation knowledge graph in anti-sea operation is directed at the related knowledge of carrier formation in anti-sea operation.
- Acquired knowledge definition: The definition of knowledge of carrier formation in anti-sea operation has been given in knowledge ontology modeling.
- Define concept classes and attributes: Knowledge is divided into existing knowledge and key knowledge and further subdivided into 4 types of 17 knowledge ontologies.
- Ontology instance creation: Build instance by taking attacking a naval formation in a certain sea area for example.
- Ontology validation and analysis: Based on Protégé, the ontology classes and relationships are modeled, and the operational plan example is used for analysis and verification to ensure the correctness of the ontology schema layer.

The constructed ontology is shown in Figure 1. The concepts of knowledge ontology mainly include four categories: combat platform knowledge, weapons and equipment knowledge, activity space knowledge, and combat operations knowledge. This knowledge is linked through conditional symbiosis relation based on strength factors.

Taking the operational plan of an anti-sea operation as an example verify the effectiveness of the knowledge graph schema layer. The correspondence between the knowledge instance in this instance and the knowledge graph ontology pattern layer is as follows(Examples of knowledge in the plan are in parentheses):

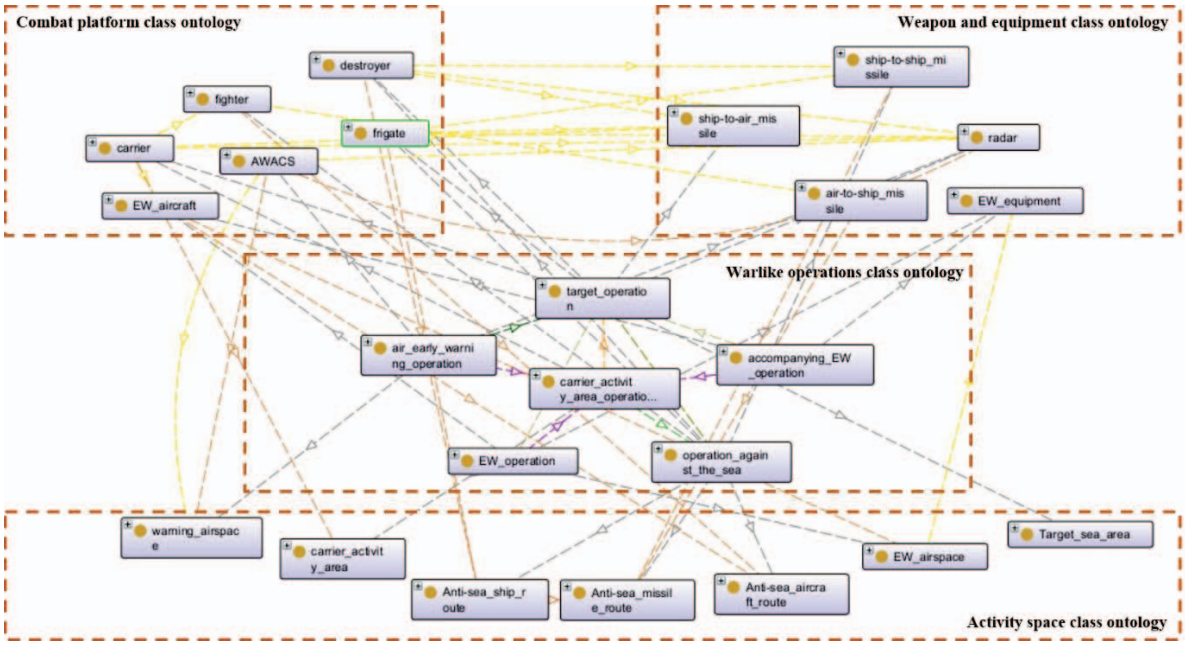


Figure 1. The anti-sea operation knowledge graph ontology pattern layer of carrier formation

- **Combat platform class knowledge:** Our aircraft carrier(type X), destroyer(3 type Z), fighter(2 type E), AWACS(1 type L). enemy destroyer(2 type S).
- **Weapon and equipment class knowledge:** Our ship-to-ship missile (2 type G), our air-to-ship missile (2 type H).
- **Activity space class knowledge:** Carrier activity area (A sea area), target sea area (S sea area), warning airspace (B airspace), anti-sea missile route (A1-A4), anti-sea aircraft route (B1, B2).
- **Warlike operations class knowledge:** Target operation Taifeng (enemy destroyer type S located in Target sea area S); carrier activity area operation Fangfe (our carrier type X located in carrier activity area A); operation against the sea Poland (our fighter located in B1, B2 Anti-sea aircraft route and our missile located in A1-A4 anti-sea missile route to carry out attacks on targets at sea); air early warning operation Yingyan (our type L AWACS located over the warning airspace B).

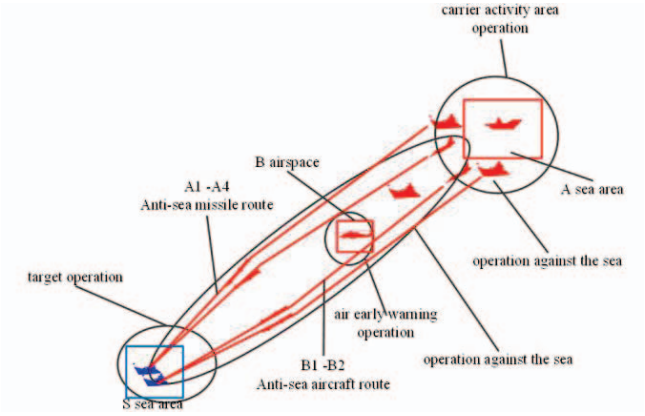


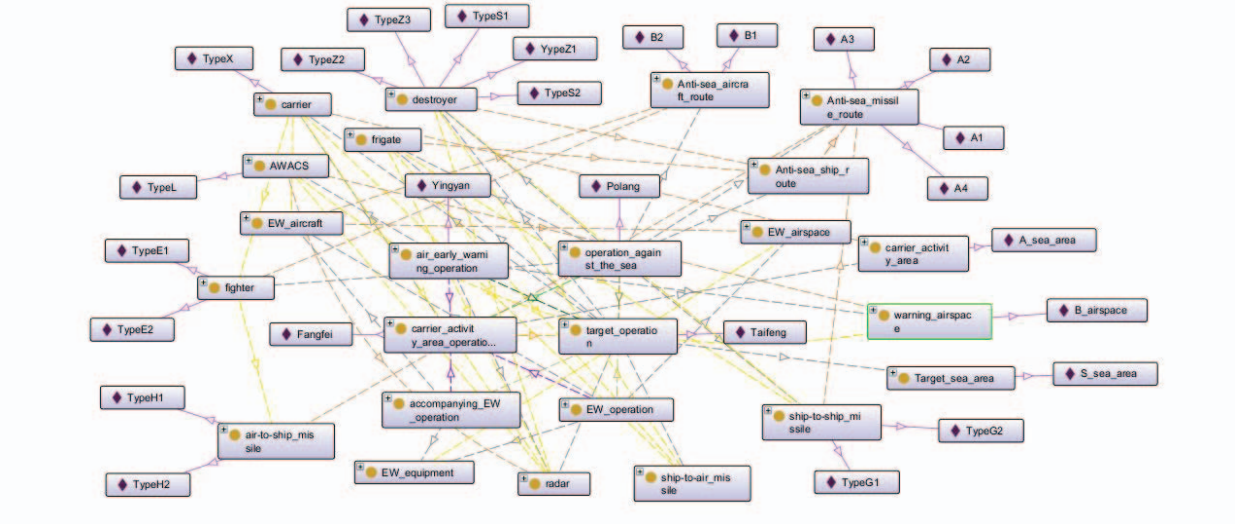
Figure 2. Battle plan of a naval formation in a certain sea area against a certain country

The operational plan diagram and the instance construction results are shown in Figure 2 and Figure 3, respectively.

The knowledge graph driven decision support system based on the above knowledge graph schema layer can provide effective support for task planning. The first is to make the elements of the anti-sea operations of the carrier formation knowledgeable, and support the command crew to quickly and efficiently query the relevant operational information they want to master through knowledge retrieval. Second, the relationship based on intensity factors can effectively express the effectiveness of operational actions, and rank operational actions by comparing intensity factors, and recommend operational actions with better operational effects to command crew. Third, it can deepen and display the deep operational knowledge contained in the operation, clearly display the troop and weaponry conditions in the operation, and assist the command crew to select the operation with the best cost ratio.

5. CONCLUSION

This paper comprehensively analyzes the relevant knowledge of aircraft carrier formation in anti-sea operation, adequately uses the existing ontology classes of combat platform, activity space, and weapon equipment knowledge, innovatively constructs the ontology class of key knowledge of combat operations, used the knowledge graph conditional symbiosis relationship based on intensity factor to model the relationship between knowledge, finally completed the modeling of the ontology mode layer of the knowledge graph of sea operations by carrier formation. The ontology pattern



Picture 3. Knowledge of naval strike in a certain sea area against a certain country's naval fleet

layer of the knowledge graph can effectively overcome the problem of considering the spatiotemporal dynamics of the knowledge graph in the military domain, clearly and unequivocally states the knowledge contained in operations and the key elements recommended for operations, can effectively assist the decision-making of aircraft carrier formation in anti-sea operation. Based on the above work, further research can be carried out as follows:

- By using the intelligent knowledge graph filling method, the knowledge instances in the existing combat tasks are filled into the knowledge graph of aircraft carrier formation in anti-sea operation, and the large-scale knowledge graph of aircraft carrier formation in anti-sea operation based on the ontology mode layer will be constructed.
- Based on the knowledge graph, the intelligent task planning system of aircraft carrier formation is constructed, to realize the efficient retrieval and recommendation of operational knowledge, and help commanders seize the initiative in anti-sea operation.

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