Parallel Emergency Management of Incidents by Integrating OODA and PREA Loops: The C2 Mechanism and Modes

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***Abstract*—Given the differences of command and control (C2) activities between the field command center and the emergency operations center (EOC), this article combined the edge C2 theory with the parallel C2 theory, and proposed a parallel incident C2 mode based on the observe–orient–decide–act (OODA) loop and planning–readiness–execution–assessment (PREA) loop. The aim is to build up a PREA loop-based parallel incident C2 mode and its related operating mechanism of edge empowerment and energy release in parallel incident C2 mode. The parallel incident C2 mode based on the PREA loop and OODA loop supports the co-existence and connection of the two roles of the incident C2 agent at the emergency scene. The two roles are the executive role of emergency response and operation and the command and organization role of the edge emergency system. This article initiates a deep integration of two different C2 process mechanisms in the emergency response and operation process, taking into account the local emergency scene and the global emergency system. Taken together, a key issue has been well addressed regarding the contradiction that the traditional emergency response cannot be reconciled in terms of rapidity and thoroughness.**

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***Index Terms*—Edge command and control (edge C2), incident C2, observe-orient-decide-act (OODA) loop, parallel command and control (parallel C2), planning-readiness-execution-assessment (PREA) loop.**

I. Introduction

IN THE process of emergency response and operation, there are completely different mechanisms related to command and control (C2) between the field command center and the emergency operations center (EOC). Although both the field command center and the EOC are responsible for emergency response and operation at an emergency scene, the subject of command usually follows a closed-loop process, that is, the observe-orient-decide-act (OODA) loop [1], [2] in order to respond quickly and efficiently. In the EOC, the commander and his team usually carry out emergency response and operation activities in an orderly manner according to the closed-loop process of planning-readiness-execution-assessment (PREA) loop. Why does this phenomenon exist?

In the field of C2, past studies point out that there is a scale correlation in the process mechanism of C2 [3], [4], [5]. To be specific, when the command subject encounters an incident or is assigned a task, its time, space and scale determine the process of its C2 activities. In the case of small scale, tight time, narrow space, and a small number of command objects, the process of C2 activities usually reflects the classic control theory, that is, OODA loop [6], [7], [8], [9], [10], [11], [12]. In military operations, it is reflected in tactical command; when there are large scale, enough time, wide space, and a large number of command subjects [13], [14], [15], the C2 activities reflect the process mechanism of C2 within a macro system, that is, the PREA loop. This case reflects systematic operations in military operations, including campaigns and strategic operations [16], [17], [18], [19].

The scale correlation regarding the process mechanism of C2 activities can better explain the difference between the activities of the field command center and the EOC. However, it cannot solve the limitations of the two kinds of C2 processes. The OODA loop emphasizes "rapidity" and focuses on the response and operation of emergencies. It is easy to ignore the relevance of incidents, and there is a risk of overflow. The C2 process often falls into the dilemma of local optimization; the PREA loop emphasizes both careful and prudent decision making. The response and operation of emergencies are

studied from the global and overall levels. Nonetheless, the PREA loop requires a longer period and a slower rhythm, which is contradictory to the fast response and operation of emergencies. How to resolve the conflict and contradiction between two different theories in the response and operation of emergencies?

This article attempts to combine the PREA loop theory with the classic OODA loop theory to establish an incident C2 mode and operation-related mechanism based on the PREA loop and OODA loop. The mode supports the rapid transformation and the connection of the C2 activities from field command center to EOC, and vice versa. Thus, it can adapt to the rapidly changing emergency environment, deal with emergencies and potential threats at an initial stage, eliminate those threats at a local level, and avoid further spread and expansion [20], [21], [22].

II. Related Works

A. Edge C2 Concept of Emergency and Its Response and Operation

An emergency is a type of unexpected incident with a security risk or potential risk at the same time. In the response and operation of emergencies, the ideal situation is to eliminate the risks at the very beginning. This requires the relevant subjects on the spot to be detected and the crisis to be handled as soon as possible. So that the crisis will not spread and expand, and there is no need for the EOC to intervene. As a result, the efficiency is improved.

In early 2020, when the Corona Virus Disease (COVID 2019) broke out in Wuhan, China, an interesting phenomenon emerged. Because the situation is very serious, the main difficulty for the medical staff that deals with the COVID 19 is a lack of lacked basic travel and living services. To address this problem, a courier, Wang Yong, quickly set up a volunteer service team by utilizing Internet to provide necessary conveniences for the operation of pandemic incidents. In this way, the demand of the travel and daily life of medical staff can be responded in time. Numerous researches are carried out on this phenomenon, Yang and Zhang [23] put forward the concept of edge command and control (edge C2), which is the action units (may be taxi drivers, pedestrians, ordinary citizens, etc.) located on the edge of the emergency system. When responding to emergencies, it can be instantly empowered or released to complete the changing of the role, such as changing from an edge action unit to a C2 unit or both. It can also release energy from a C2 unit to a combat action unit. After the conversion, the artificial intelligence technology can be used to quickly integrate the available edge resources, or quickly release the occupied resources. Then local reorganization can be realized, the emergencies can be handled effectively, and the time for the adjustment or transformation of the centralized C2 system can be reduced. In fact, the utilization of edge C2 is not limited to the process of edge activities, but also can be utilized in the collaborative process between the edge and the center. The center is the foundation and the goal, while the edge is the process. When the edge C2 process changes locally, a new centralized system needs to be formed accordingly.

Based to the pioneering research on the concept of edge C2, the concept of "center of gravity" is proposed to interpret the basic principles and features of "centralized" C2 [23], [24]. By defining the connotation of edge, edge operations and edge C2, and designing the process model and winning mechanism of edge C2, a new paradigm of edge C2 is established. The paradigm possesses the features of the whole process, including autonomous task discovery, autonomous resource search, autonomous decision making, and autonomous self-adjustment and change. The paradigm is not only the mechanism combination of the top-down mission command and the bottom-up incident command, but also the organic combination of other organizations and self-organizations.

Currently, the research of edge C2 is still in the initial stage, and most existing work remains on the conceptual level. Regarding to the concept and mechanism research, although the classical theoretical model (OODA loop) in the field of C2 is combined and used, there are still many challenges in carrying out empirical case studies. In summary, there is a lack of the in-depth research of the realization and the design of the corresponding mechanism.

B. Theoretical Models Related to the C2 Process Mechanism

In the field of C2, the classic theoretical models for the C2 process mechanism can be traced back to the Korean War in the 1950s. During the war, John Boyd, a U.S. Air Force fighter pilot, proposed a closed loop of OODA to analyze the process of air combat. It not only describes the general process of commanding confrontation, but also proposes the winning mechanism, namely, "quickness" and "intervention." Here, "quickness" refers to the comparative advantage of the running speed regarding one's own OODA loop, and "intervention" refers to the impact of each OODA loop on the opponent's OODA loop [26]. The OODA loop describes the general thinking and action process of both sides of the military command and confrontation in a concise and pretty form, and is a summary of the common sense of thinking and action of human war in the past few thousand years. This theory has been worshiped once it was put forward. It has been regarded as a classic model in the research of military theory and equipment construction, and was written into the combat doctrine of the armed forces in many countries. Besides in research area, the theory has also been used by front-line commanders in lots of applications.

While extensive applications of the classic theoretical OODA loop are carried out in the military field, the defects of the OODA loop in practical application are recognized, especially in the applications in command center. The main defects include: 1) the description of the general process of C2, which include but not limited to operational planning activities, operational assessment activities, and operational evaluation activities, is incomplete; 2) the rapid response of OODA loop to the observed situation is a passive thinking, and is unsuitable for active planning and deployment; and 3) though the advantages and disadvantages of fighter tactical confrontation can be explained, many classic battles, such as the Battle of Midway, cannot be explained. Moreover, there

is a regularity to these defects, that is, the higher the level of C2 activities, the more problems will be exposed in the OODA loop. To conquer these defects, many researches are conducted to improve the traditional OODA loop, and numerous achievements have been accomplished, such as C-OODA, D-OODA, E-OODA, M-OODA, etc. [9], [10], [11], [12], [16], [17], [18]. These improvements mainly focus on the "decision making" of the OODA loop, and the main idea is to extend the decision-making phase by increasing activities, such as operation plan generation, plan evaluation, and plan optimization. Unfortunately, these activities affect the running speed of the OODA loop, and the improved versions of the OODA loop are not in accord with the winning mechanism of "fast" and "intervention," which are the original purpose John Boyd in proposing OODA loop.

Completely different from the above-mentioned improvement ideas of OODA loops, Yang and Zhang [19] proposed the scale correlation of the C2 process mechanism. They paid more attentions to the differences between the macro-system and the micro-system in C2 discipline, just like what we do in many other areas, such as physics, economics, military science, etc. Though the classical theory OODA loop originates from the confrontation of fighters, it is also suitable for tactical command confrontation. Considering that the C2 activities of the combat system on the macro scale have completely different C2 process mechanisms, researchers propose a C2 process mechanism of macro combat system, which is known as the PREA loop, namely, "PREA" [16], [17], [18]. The four phases correspond to the deductive situations based on historical statistical data, the forward situation based on forecast, the real-time situation based on sensor data fusion, and the historical situation based on the assessment process, respectively. Four decision-making methods are designed for four-time windows, and they are careful decision making based on intention, prudent decision making based on plan, rapid decision making based on rules, and conversion decision making based on effects, respectively. There are three types of conversion methods for operational assessment. The first method is the conversion from assessment feedback to plan adjustment, which only occurs when the plan execution effect is as expected. The second method is the conversion from assessment feedback to deployment plan adjustment. This method occurs on the condition that the implementation effect of the plan does not meet expectations, but the expected mission objectives can be achieved by changing the deployment plan, which include force deployment, action plan, and related operational elements, such as time and space. The third method is the conversion from assessment feedback to planning, which is conditional on changing the deployment plan to adapt to the current situation. The process contains the replanning and the changing of the combat mission or determination, which includes combat intentions, combat objectives, and related combat requirements.

The winning mechanism of C2 confrontation on the macro scale is reflected in the stability of the operation of the macro combat system and the continuity of evolution. Any change or adjustment of the system means a "U"-shaped change process in which the overall effectiveness first declines and then recovers. Therefore, the constant is the maintenance of the overall effectiveness. The continuity means that the macro-operational system maintains the evolution of the system when it must be adjusted and changed. The continuity of the process ensures that the efficiency change of "U"-shaped process is smooth and transitional, and there is no "cliff-type" decline of the efficiency. Finally, the "rapidity" and "intervention" of the OODA loop are not applicable to the entire process of the macro combat system confrontation, it is applicable only in the "execution" phase of the PREA loop.

C. Parallel Command and Control

The concept of parallel command and control (parallel C2) is proposed based on a new understanding of the nature of C2. The war activities of human society are typical complex system behaviors. Wang et al. [27] believed that the essence of C2 in the military field is to converse the uncertainty, diversity, and complexity (UDC) faced by complex systems of war into agility, focus, and convergence (AFC) for specific tasks and missions. The conversion from UDC to AFC requires instant C2, but how to realize such conversion remains unresolved [28], [29]. Wang [30], [31], [32] believed that the conversion from UDC to AFC faced by modern warfare cannot be effectively realize by relying solely on the resources of physical space. Cyberspace and its "virtual" resources must be introduced to complete the conversion from UDC to AFC through the parallel thinking of the interactions between the virtuality and the reality [33], [34]. Therefore, combined with ACP theory and CPSS concept, the "paradigm" of C2 5.0 [35], [36], [37], [38] is proposed, which is composed of the C2 system, theory, methodology, and technology oriented to parallelization technology.

C2 5.0 can be summarized as one idea, two supports, three themes, and four integrations. One idea is the parallel idea of the interaction between the virtuality and the reality, which is the core idea of parallel C2. Two key supports are ACP theory and CPSS infrastructure. ACP theory is the combination of Artificial Societies, Computational Experiments, and Parallel Execution. CPSS infrastructure is the synthesis of three worlds, i.e., physical world, psychological world, and artificial world. CPSS is a cross-domain system, "P" mainly corresponds to the physical world that is composed of materials in natural or physical domains, "S" mainly corresponds to psychological world in real social, cognitive, or psychological domains. "C" mainly corresponds to the artificial world in actual information, knowledge, or artificial domains. The three thematic tasks are intelligent force or intelligent organization, intelligent command or intelligent management, and social intelligence or social analysis. The four integrations are personnel, information, equipment, and missions. They form agility with in-depth knowledge by focusing on experimental analysis, and finally implement closed-loop, feedback, and precise convergence.

In the paradigm of C2 5.0, ACP theory not only includes the concept of digital twins, but also establishes a complete closed-loop process from physics to description, from description to prediction, and from prediction to guidance [37].

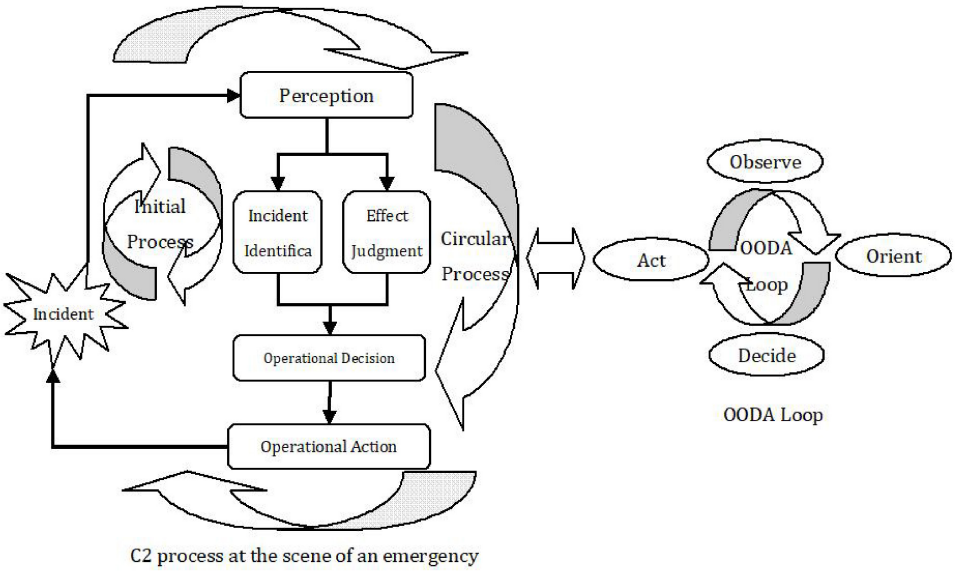

Fig. 1. C2 activities and essence analysis at the emergency scene.

The conversion from UDC to AFC has been refined into different state conversions. The process is known as digital quadruplets [39], [40], [41].

Based on the theory of digital quadruplets, Yang and Yan [17] and Yang and Zhang [18] found that in the research on the C2 process mechanism of C2, there is a perfect consistency between the model of PREA in C2 process mechanism on the macro-scale and the state transition process established by the digital quadruplets of the combat system. First, operational planning is the establishment of the "prediction" digital body. Second, deployment preparation is the establishment of the "guidance" digital body of the combat system. Third, operational execution is the establishment of the "physical" digital body of the combat system. Finally, operational assessment is the establishment of the "descriptive" digital body of the combat system. The PREA loop is a process that describes the C2 activities of the macro combat system, while the digital quadruplets establish four states of this process. Obviously, the two theories achieve a perfect combination while possess their own emphasis.

III. Analysis of Incident C2 Process Mechanism

The incident C2 process of response and operation has different processing activities in terms of command agencies. The main difference is reflected in two types of command agencies: one is the field command center, which is responsible for on-scene operation of emergencies and the other is the EOC. There are essential differences between the two types of command agencies in the C2 process.

The field command is usually carried out by the first person who arrives at the scene and has the highest title, or other legal personnel. The main C2 activities include the following five aspects.

The first is to perceive and process the incident, and obtain the comprehensive situation of the incident scene.

The second is the identification and judgment of the incident, that is, to determine the type of the incident. In the initial operation of the incident, the identification and judgment of the incident need to be carried out. When the incident is transferred to the cyclic operation, there is no need to identify the incident, but transfer to the assessment of the effect of the incident operation.

The third is the decision making on the selection of incident operation methods. When it is judged that the operation of incident is within the scope of its authority and can be handled on the spot, the relevant methods to handle the incident can be decided.

The fourth is to implement the action of incident operation, that is, to take corresponding actions according to the decision made in the third step.

The fifth is to observe the effect of methods. When the effect meets the expectation, it can be transferred to the next cycle of operation or end the incident operation process. When the effect does not meet the expectation, it needs to continue to enter the operation cycle.

The process of C2 activities regarding on-scene emergency response and operation can be summarized into four main procedures, namely, observation, judgment, decision making, and action, which is consistent with the classic theory of the OODA loop. Moreover, the basic principles and requirements of on-scene emergency response and operation are to be fast and effective to prevent the spread and expansion of incidents, which is also in accord with the essence of the OODA loop.

The C2 activity process of on-scene emergency response and operation and its essential analysis are shown in Fig. 1.

When an emergency involves multiple areas or departments, and there is a possibility of unstoppable spread or expansion, the command subject (including the command agency or commander) on the spot needs to put forward relevant requirements in a timely manner. The most critical requirement is to escalate the incident operation rights and authority, requests the EOC to conduct overall planning and coordination of emergency

response and operation. When the response and operation of incident is escalated, the command subject is not only the on-scene command, but also the overall planning and coordination activities of the EOC. It includes the following eight aspects.

The first is the initial consultation on the incident operation. After the on-scene command and relevant departments submit the briefing, the EOC needs to organize the initial consultation on the incident to make up the determination and premobilization decision.

The second is the determination or adjustment of the target of the incident operation. When entering the incident operation for the first time, the target is usually determined in the form of consultation. When entering the cycle of the incident operation, the adjustment of the target is determined in the form of consultation.

The third is the strategic negotiation of incident operation. The strategic negotiation takes the command center that is in charge of the incident operation as the main body, and uses the overall coordination of incident as a method to determine the long-term planning of incident operation, that is, the strategic plan.

The fourth is the tactical consultation of incident operation. The tactical consultation focuses on short-term methods and strategies for incident operation. The command center in charge of the incident operation is the main body, and jointly determines tactical strategies with the tactical executive body of incident operation.

The fifth is to make action plan and ready for coordination of incident operation. The emergency action plan is usually formulated by the planning team of EOC. After making up the plan, it is necessary to coordinate the relevant parties for plan implementation and formulate a collaborative plan.

The sixth is the implementation of the emergency action plan. When it is transferred to the implementation stage of the emergency action plan, the action subject will execute the plan. The EOC will monitor its implementation, and timely intervene according to the situation, so as to control the whole implementation process.

The seventh is the assessment of the implementation of the emergency action plan. The assessment is organized by the EOC, focusing on evaluating its practical effect and comparing it with the expected effect.

The eighth is the conversion of emergency treatment. The conversion of emergency treatment is determined after the assessment, and its main body is the EOC. The basis of conversion is the effect of assessment. There are many possibilities for the selection and decision making of conversion. When meeting the expected effect, the incident operation can be ended; When the expectation is not achieved, it needs to be transferred to the next cycle of operation.

In the EOC, the above incident C2 activity process of response and operation can be described as a periodic cycle of incident triggering and operation. This process is also known as "P" model, as shown in Fig. 2. After the incident is triggered, the "P" model is transferred to the "preliminary consultation," which is the key link of the periodic cycle of incident operation. The "preliminary consultation" marks the milestone point from the passive response to the active response and operation of the incident.

The "P" model establishes the main C2 activities of the EOC for emergency response and operation. Its periodic operation cycle only outlines the general process. In fact, in the process of periodic operation, there are also differences in details, which are reflected in the specific links pointed by the cyclic feedback. In the loop of the "P" model, the feedback has three directions.

First, when the assessment of plan implementation meets the expectation, the cyclic feedback still points to the implementation of the emergency action plan, and the actions are continuously implemented and monitored.

Second, when the effect of plan execution is unexpected, the overall emergency situation changes still in line with the expected target direction, and a new emergency action plan can be reformulated through the allocation and deployment of emergency resources, the cyclic feedback points to the deployment preparation link of the operation, which is the preparation for the tactical strategy consultation.

Third, when the effect of plan execution is unexpected, the overall emergency situation does not meet the expected target direction, and the overall emergency situation cannot be turned to the desired target situation through the allocation and deployment of emergency resources, the cyclic feedback points to the strategic consultation of emergency response and operation.

Therefore, when the "P" model further refines the feedback activities of the emergency response cycle, the C2 activities of the emergency incident in the EOC can be described as five phases and three types of feedback. The five phases are the perception and initial operation of emergencies, the formulation of an action plans for operation emergencies, the preparation for the implementation of the action plans, the monitoring of execution of the action plans, and the assessment and conversion of the implementation effects of the action plans.

The three types of feedback are execution effect assessment $\rightarrow$ plan execution monitoring, execution effect assessment $\rightarrow$ planning and execution preparation, and execution effect assessment $\rightarrow$ formulation of action plan. This process takes the form of a "β" (as shown in Fig. 2), which can also be referred to as the "β" model.

After the "β" model is transferred to a continuous cycle, its C2 activities are mainly reflected in four phases and three types of feedback, which is exactly the embodiment of the macro-scale C2 process. There is equivalence between the "P" model and the macro-scale C2 activity process mechanism model, that is, the PREA loop.

The equivalence between the "P" model, the "β" model, and the PREA loop is shown in Fig. 2.

IV. Parallel Incident C2 Mode Based on PREA Loop and OODA Loop

There are two different process mechanisms for C2 activities of the field command center and the EOC in incident operation. In the EOC, the C2 activity process is guided by the PREA loop; at an emergency scene, the C2 activity is guided by the OODA loop. The two types of activities work together at different scales. When there are multiple incidents

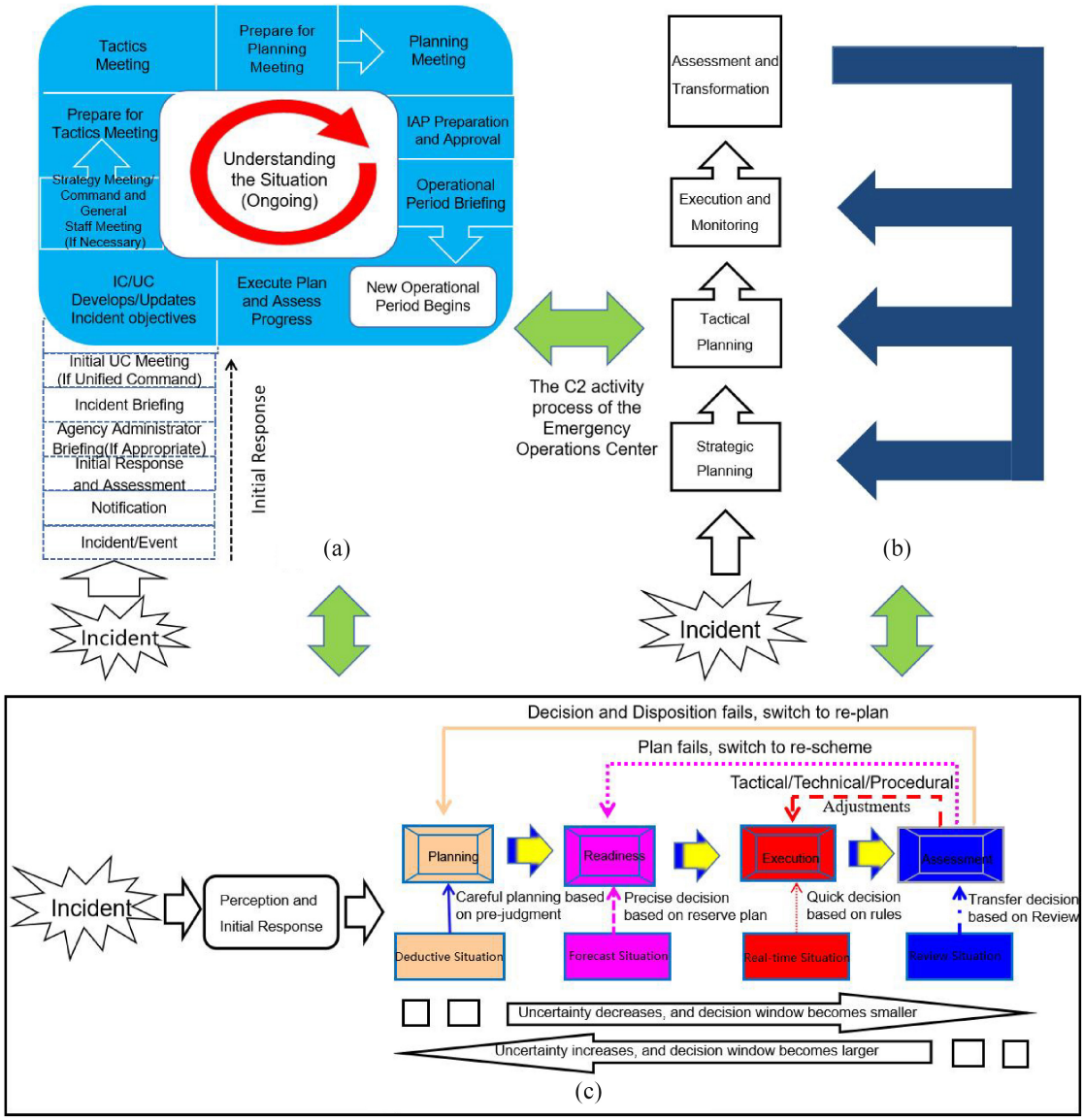

Fig. 2. C2 activities and mechanism analysis of EOC in emergency operations and response. (a) "p" model. (b) β model. (c) Macro-scale C2 process—PREA.

or multiple action groups in the same incident, the C2 activities need to establish multiple processes, that is, there are multiple PREA loops running at the same time. Under the guidance of the macro-coordinated PREA loop, each PREA loop has its own cycle and rhythm. Meanwhile, each PREA loop contains multiple on-scene OODA loops. The multi-PREA loop and its multiscale operation process are shown in Fig. 3.

The orderly deployment of multiple PREA loops requires a command team, a command system, and the related technical support. These necessary conditions are difficult to meet at the scene of an emergency, but the emergency scene needs the central C2 mode to provide timely guidance and support. The OODA loop of the on-scene C2 needs to be synchronized with the central PREA loop in an appropriate time in order to achieve efficient operation of emergencies.

Can the PREA loop of the EOC and the OODA loop of the on-scene command be integrated to achieve efficient coordination between the emergency scene and the EOC? Parallel C2 provides the conditions for the design of this mode.

On the one hand, the concept of digital quadruplets (physics, description, prediction, and guidance) established by the parallel theory provides conditions for the operation of the PREA loop in parallel space. The activities of the PREA loop in the four phases of planning, preparation, execution, and assessment are essentially an embodiment of the parallel theory in military C2. The essence of planning activities is to establish future goals based on predictions. The preparation activities are based on predictions to establish guidance for the actual battlefield situation. The execution activities are the interaction of actual physical implementation. The assessment is the judgment based on a correct description of the real physical world. Therefore, the digital quadruplets of the parallel theory are another form of the PREA loop, and it can also be understood that the digital quadruplets of the parallel theory are four states mapped from the real battlefield to the parallel space

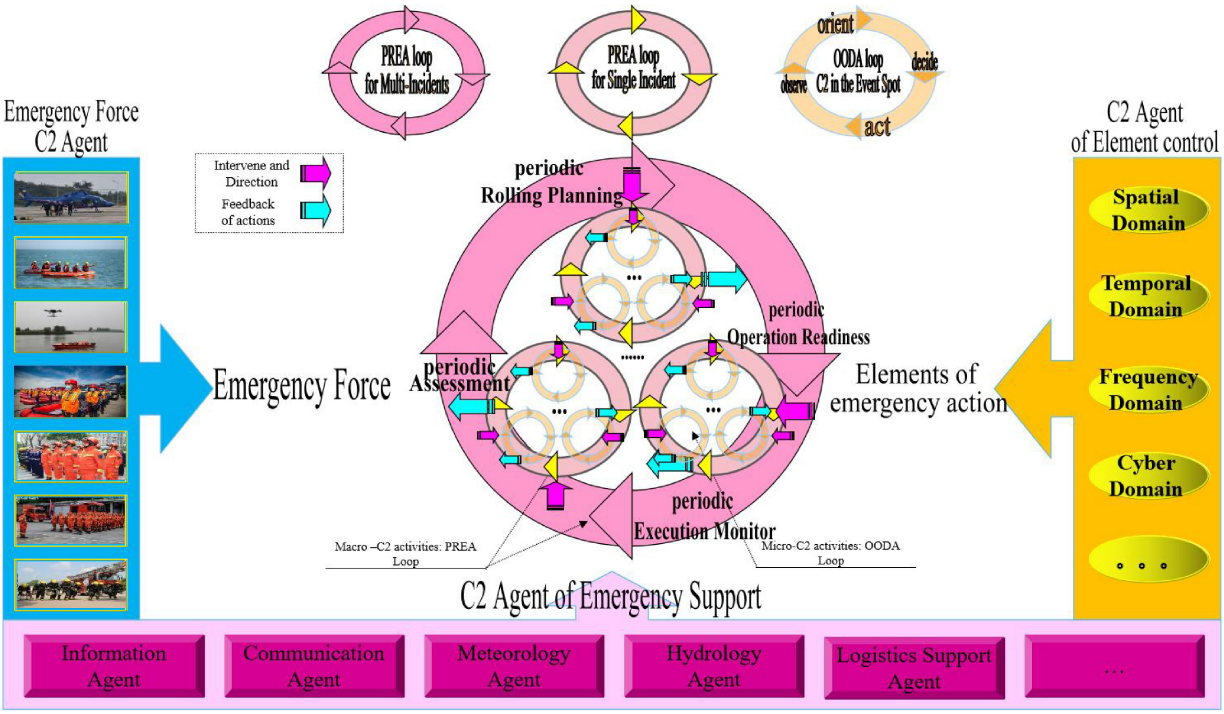

Fig. 3. Multi-incident C2 process—the schematic of multiscale coordination of multiple PREA loop.

battlefield, and the PREA loop is the continuous conversion process of the four states.

On the other hand, the parallel C2 theory not only provides the PREA loop operating support for the operation of the emergency center C2 activities at the emergency scene, that is, digital quadruplets, the parallel C2 theory also provides a cloud-based parallel C2 operation mode so as to project the "central command" (such as the EOC) into the parallel space. So, the generation and conversion activities of the three states, namely, "description," "prediction," and "guidance" are implemented on the "cloud," guided by the theory of the PREA loop in the "cloud." These make it possible to implement parallel planning, parallel guidance, and parallel assessment activities on the cloud. The parallel C2 on the cloud maps the activities of the command center onto the physical world. The mapping content includes three aspects: The first is the role mapping. The role of the command center, no matter commanders, staff officers or other management and support personnel, is established, with the corresponding "agent" on the cloud. The second is the activity mapping. The activities of the command center, no matter planning, preparation, monitoring, or assessment, are synchronized with the cloud C2. The third is the mode and mechanism mapping. The operation mode and mechanism of the command center are synchronized in the cloud C2 center.

This ensures that the battlefield with "brain" of the cloud C2 can always be consistent with the "brain" of the real battlefield. After the artificial intelligence technology is embedded, the cloud C2 not only have the synchronous mapping function of the real battlefield command center, but also serves as the real command center. Besides, it also provides enhanced functions, such as relevant knowledge, advice, assistance in planning, monitoring and assessment, for the real command center. When the real command center is damaged or the communication is restricted, the cloud C2 center can take over or make up the damaged functions.

The EOC transfers to "cloud C2" through parallel C2 technical support, and then from "cloud" to "end," through "cloud C2" to support the C2 unit at the emergency scene from the action and execution function to the organization and command function. After proposing the request of upgrading the incident operation level, the C2 units at the emergency scene can obtain the authorization of command, guidance, guarantee, and other related technical support from "cloud C2." It no longer needs the command team, command system, and related guarantee and technical support in the real world. The aim of "cloud C2" is to establish parallel C2 on the cloud for the EOC in the physical world, and at the same time, establish cloud-to-end guidance for C2 activities at the emergency scene. The cloud parallel C2 is not only the projection of the EOC in the physical world, but also synchronously establishes the virtual role and overall operation mechanism of each functional subject of the EOC. At the same time, the cloud C2 also has the functions of describing the physical world, predicting the evolution, and guiding the behavior of the evolution process.

Using the C2 cloud, we can integrate the two different C2 processes of the EOC and the command on the spot, to achieve efficient coordination between the PREA loop of EOC and the OODA loop of the command on the spot. The establishment of a parallel incident C2 mode is shown in Fig. 4.

The "C2 cloud" with parallel intelligence can empower any emergency on-scene C2 unit, and at the same time, any emergency on-scene C2 unit can apply for empowerment or energy release from the "cloud C2." Once authorized, a mode change

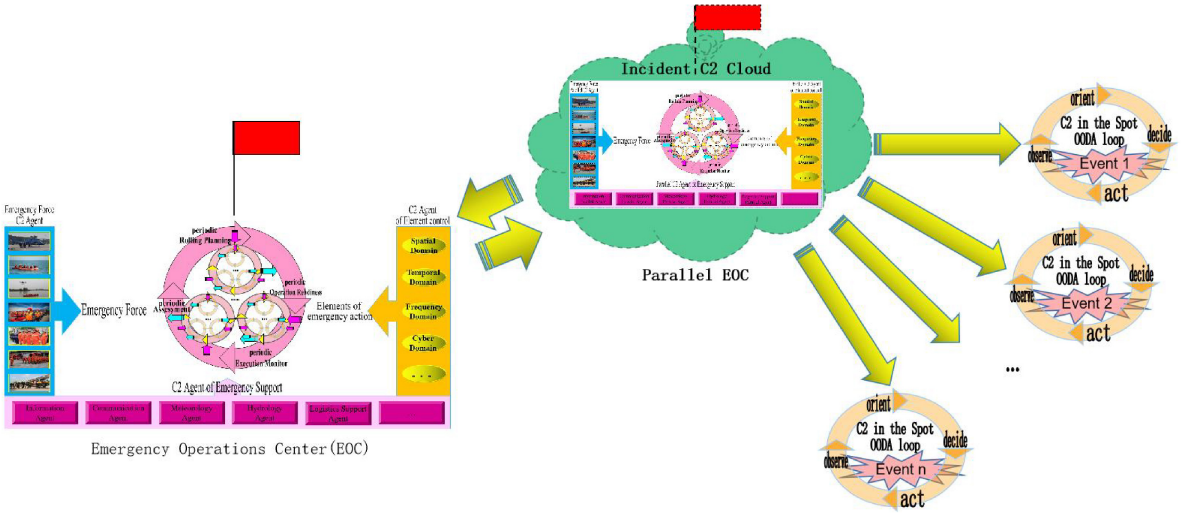

Fig. 4. Parallel incident C2 mode based on PREA loop and OODA loop.

can be conducted to perform a new function, or to execute an operation, or to organize and direct an operation, or both.

In the cloud C2, each role of the EOC has a corresponding "Agent." A behavior synchronization mechanism, a learning mechanism, and a coordination mechanism are established between the physical role and the cloud virtual "Agent." There are three aspects of interaction between the cloud virtual agent and the EOC role: the first is the interaction of cloud synchronization. When the physical role has made the decision-making behavior, the cloud virtual agent will make the synchronous behavior; the second is to interact with the virtual roles in the cloud to make predictions and guide decisions when the physical roles are dealing with the problems; and the third is that the cloud virtual agent learns the decision making and behavioral preferences of the physical role during the interaction, and gives relevant suggestions according to the preference.

V. Operation Mechanism of Parallel Incident C2 Mode Based on PREA Loop and OODA Loop

The parallel incident C2 mode based on the PREA loop and OODA loop establishes a "bridge" and "link" between the EOC and the C2 unit at the emergency scene, which provides conditions for efficient operation of incidents. The C2 unit at the emergency scene can switch roles quickly as needed. When the incident is within the controllable scope, it will run its OODA loop to quickly handle the incident with the role of execution; when the incident spreads and expands beyond the controllable scope, it needs to be upgraded and processed. The on-scene C2 unit needs to apply for authorization or support. With the support of cloud C2, the local "system" of the emergency scene, namely, the edge emergency system is reorganized or restructured. This mode of operation is reflected in the "empowerment" of cloud C2; when emergencies are effectively controlled, the on-scene C2 unit needs to sever relevant resources to ensure that the occupied resources can be timely returned to the unified scheduling of cloud C2 so as to provide conditions for the operation of other incidents. This operation mode is reflected in the "energy release" of cloud C2.

A. Empowerment Mechanism and Operation Mode of C2 Unit at the Emergency Scene

The C2 unit at the emergency scene is the main body of incident operation. When the incident spreads or expands beyond the capacity of the C2 unit at the emergency scene, it needs to apply to the cloud parallel C2 main body for operation permission and resources. At the same time, its operation is transformed from the executive role to the organization and command role of local resources. This process can be divided into five steps: 1) incident triggering; 2) on-scene C2 agent empowerment application; 3) center empowerment assessment; 4) on-scene C2 unit empowerment and edge emergency system construction; and 5) the operation of cloud parallel incident C2 mode.

The first step is to trigger the incident. Incident triggering means that the C2 unit at the emergency scene encounters the spread or expansion of the emergency incident, which exceeds its ability to operate. After the emergency incident is perceived and identified, for the operation of emergencies, the C2 unit at the emergency scene cannot handle them independently, or cannot handle them effectively under the framework of the current edge emergency system. In order to effectively operate the emergency incidents, the corresponding emergency on-scene C2 unit puts forward the demand of empowerment to the central C2 (central parallel C2) after assessing the incident. There are two conditions that must be met for triggering the demand of empowerment: the first condition is an unexpected emergency, and the need for emergency operation will only occur when an emergency occurs. Therefore, an emergency is a necessary condition for triggering the demand; the second condition is the evolution of emergencies, so that its operation is not within the capability or authority of the on-scene C2 unit or the edge emergency system. The on-scene C2 unit or the edge emergency system cannot work under the framework of the current macro system. To effectively handle emergencies, the edge emergency system must be rebuilt or reorganized, resulting in the need for edge empowerment. The needs for edge empowerment are proposed by the C2

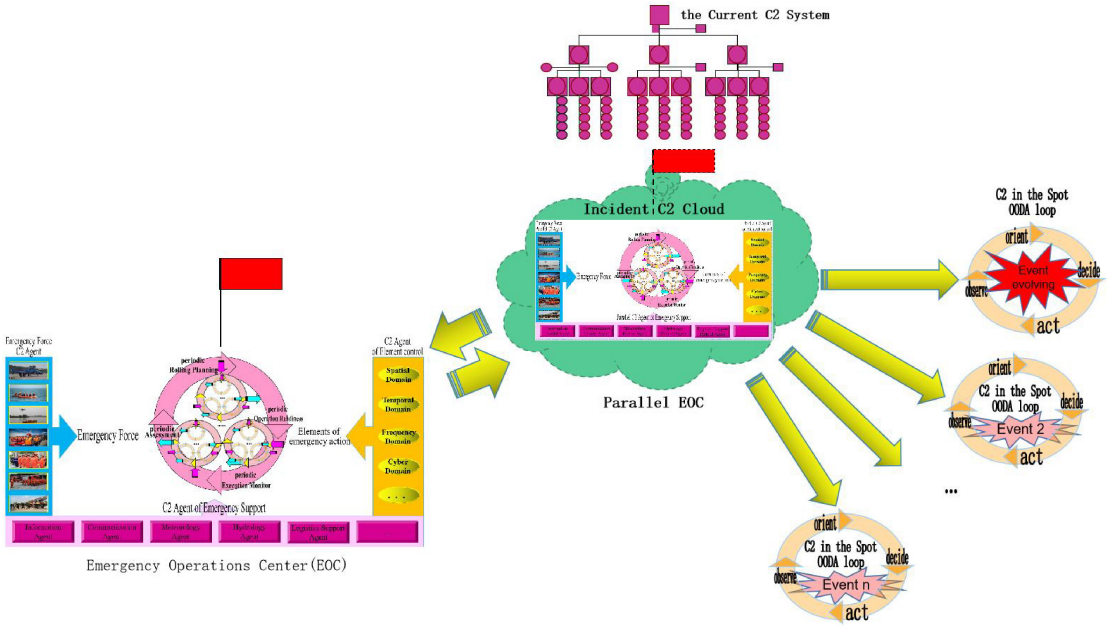

Fig. 5. Incident evolution triggers on-scene C2 agent to apply for empowerment.

unit at the emergency scene on the basis of full assessment and planning. The purpose is to effectively handle emergencies. The needs include resources, C2 permission, support and coordination, other guarantees, etc. The content of its needs is different according to different types of emergencies.

The triggering process of the need for empowerment of the C2 unit at the emergency scene is presented in Fig. 5.

The second step is to apply for on-scene C2 agent empowerment. Since the on-scene C2 agent is usually far away from the C2 center and does not have the conditions for real-time interaction with the EOC, the empowerment application usually occurs between the on-scene C2 agent and the cloud center of parallel C2. With the support of the central cloud parallel C2, the demand for on-scene C2 agent empowerment can be directly uploaded to the cloud parallel C2, and the cloud parallel C2 is synchronized with the C2 center. The need for on-scene C2 agent empowerment originates from the on-scene operation of emergencies. When the on-scene C2 agent cannot effectively handle emergencies, the need for on-scene C2 agent empowerment is generated and applied thereafter. Whether it is the limitations of the on-scene C2 agent or the edge emergency system in operating emergencies, the empowerment requirements are all predesigned for the reconstruction or reconstruction of the edge emergency system. The goal is to handle emergencies effectively through reorganizing or reconstruct local resources or systems, and propose relevant empowerment requirements based on predesign, including resources, permissions, and techniques and guarantees. The spread or expansion of emergencies is often accompanied by multiple incidents, involving multiple on-scene C2 agents or edge emergency systems. Different on-scene C2 agents or edge emergency systems may simultaneously perceive and identify emergencies. The empowerment applications may occur in multiple on-scene C2 agents or edge emergency systems. Therefore, these applications may conflict with each other. It is the function of the C2 center to resolve the conflict of empowerment application.

The empowerment application process of the on-scene C2 agent is shown in Fig. 6.

The third step is the empowerment assessment by the center. Any application for empowerment of the C2 subject for on-scene incident operation may have an impact on the overall situation. The impact includes two aspects: on the one hand, the impact of the structural relationship, which may be the configuration relationship of emergency resources, the coordination relationships of the incident C2 units, or the C2 relationships between C2 nodes. All changes in these relationships will have an impact on the overall effectiveness of the emergency system and structure; on the other hand, it is the impact of the overall emergency action. The fixed action plan will have an impact on the action effect when the edge emergency system needs to be adjusted. In order to achieve the expected effect, the action process needs to be adjusted. The adjustment may be a change in deployment and determination. It could also be an adjustment of the plan, or an adjustment of the tactics/techniques/operational procedures, etc. The on-scene C2 unit empowerment application triggers parallel C2 of the center to assess the evolution of the global system. The main purpose of the evolution of the global system is to adapt to the adjustment of the edge emergency system and achieve the expected goals and effects with a better global system. The evolutionary assessment of the global system often requires a central parallel C2 to collaborate with a real-world C2 center. Similar to the adjustment of the edge emergency system, the main content of the global system evolution is the reconstruction of the global system process and the reorganization of the structure, as well as the matching analysis of the restructuring structure and the reconstruction process. The evaluation focuses on the performance, including the changing process of static efficiency and dynamic evolution efficiency. Static efficiency refers to the measure of the degree of matching between the adjusted structure and process. The dynamic evolution efficiency is the efficiency changes of the transformation process from the current system to the evolved system.

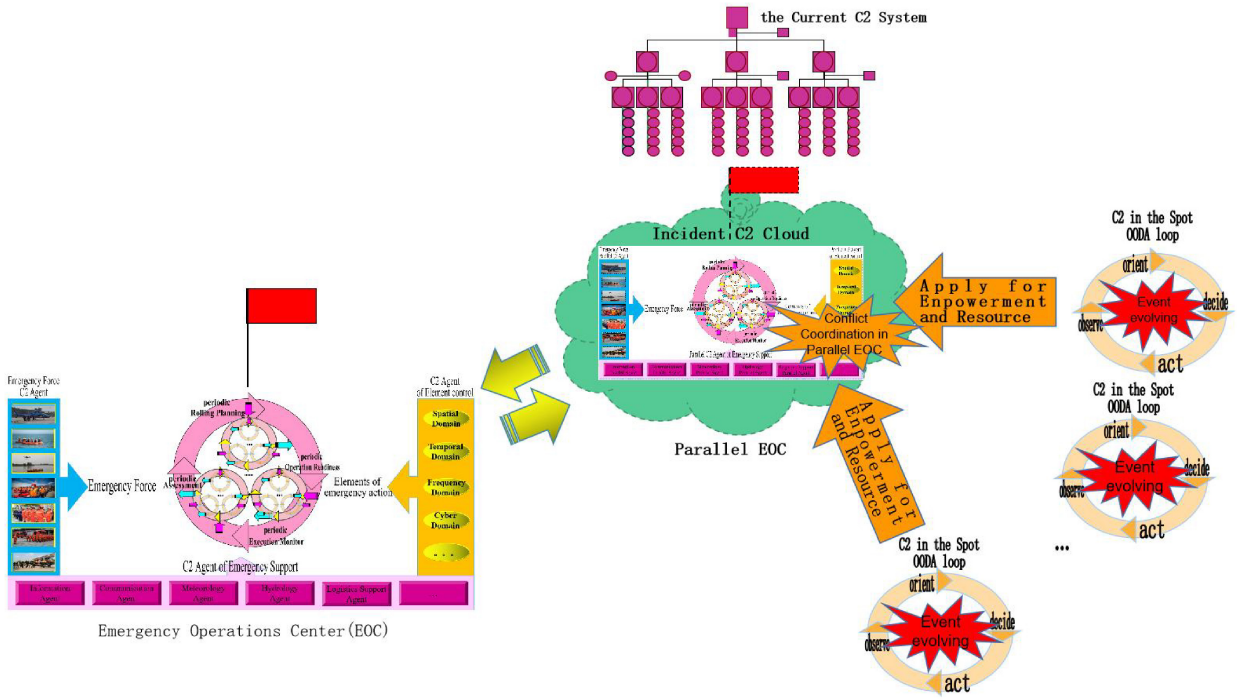

Fig. 6. On-scene C2 agent empowerment application for multiple incidents.

The evolution (reconstruction/reorganization) and assessment process of the global system adapting to edge empowerment is showed in Fig. 7.

Step 4 is the construction of on-scene C2 unit empowerment and edge emergency system. After the parallel C2 center completes the conflict coordination of the edge empowerment application and the reorganization or reconstruction plan of the overall system, the C2 warfare unit and the edge emergency system at the scene of the incident operation can be empowered. According to the empowerment application of the on-scene C2 warfare unit and the edge emergency system, the empowerment may include the allocation of combat resources, the issuance of mission objectives and related combat requirements, etc. After the on-scene C2 warfare unit is empowered, it can build up or reconstruct the edge emergency system, and organize the available edge combat units, and establish an effective organizational system for incident operation, including the structural relationship of edge units and the process of incident operation.

The fifth step is to run in the cloud parallel incident C2 mode. When the construction or reconstruction of the edge emergency system is completed, the edge emergency system is transferred to an operation mode that is suitable for the system C2 process. This mode is the planning–preparation–execution–assessment, a closed loop known as PREA loop. Its operation requires command team, command system, and related guarantee and technical support, but the edge combat unit and edge emergency system do not have these supports. Therefore, the PREA loop of edge command needs the support of "parallel C2 center," and the edge is parallel to the "cloud parallel C2" both in reality and virtuality. A command team is formed by including the relevant virtual roles (such as subdomain command roles, staff roles, support roles, etc.) of the "parallel central C2 in the cloud," together with the real roles of the C2 warfare unit and the edge emergency system at the incident operation scene. The command team formed by both real and virtual roles plays the main role in the operation of the command mode of the edge emergency system. Similarly, the use of relevant command methods, in the command mode of the edge emergency system, needs to download related system support from the cloud parallel C2 center, including combat planning tools and combat monitoring tools, combat assessment tools, etc. Different roles operate different tools and means to implement the C2 activities of the edge emergency system.

The synchronization between the on-scene C2 warfare unit and the cloud "C2 center" is shown in Fig. 8.

The edge incident C2 with the PREA loop as the main process is carried out around its design, construction, evolution, and assessment. The edge emergency system is the same as the macro combat system. Its structure is formed by the resource allocation, coordination, and C2 relationship between the on-scene C2 agents. At the same time, the incident processing procedure is established by the perception and identification of the incident, and the two together forms the edge emergency system.

B. Energy Release Mechanism and Operation Mode of C2 Unit in the Emergency Scene

The energy release of the on-scene C2 unit in the incident operation is the transformation of the main function of the C2 unit from the organization and command of the edge emergency system to the action execution. When the energy is released, the C2 relationship is terminated between the combat units related to the edge emergency system, and the relevant resources in the edge emergency system are released, returning to the original system, or participating in the construction of a new edge emergency system as needed.

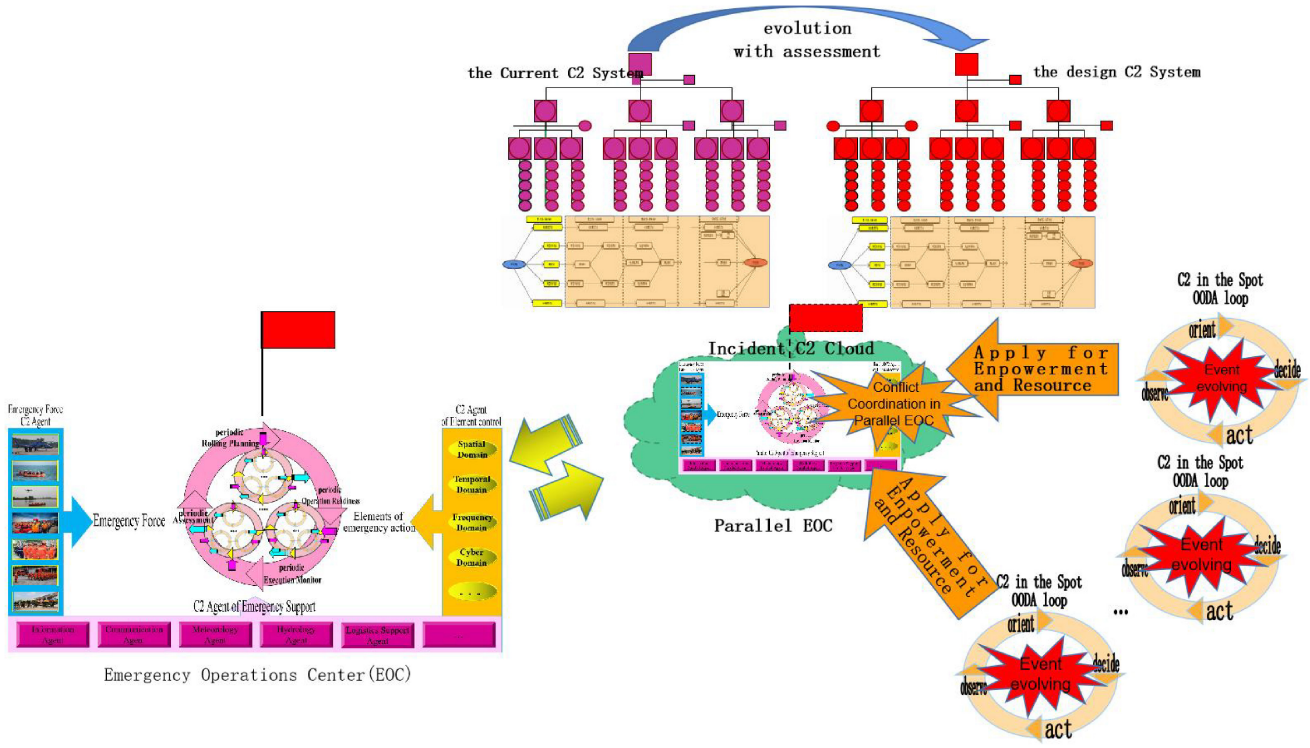

Fig. 7. Evolution (reconstruction/reorganization) and evaluation of the global system adaptation and edge empowerment influenced by incidents.

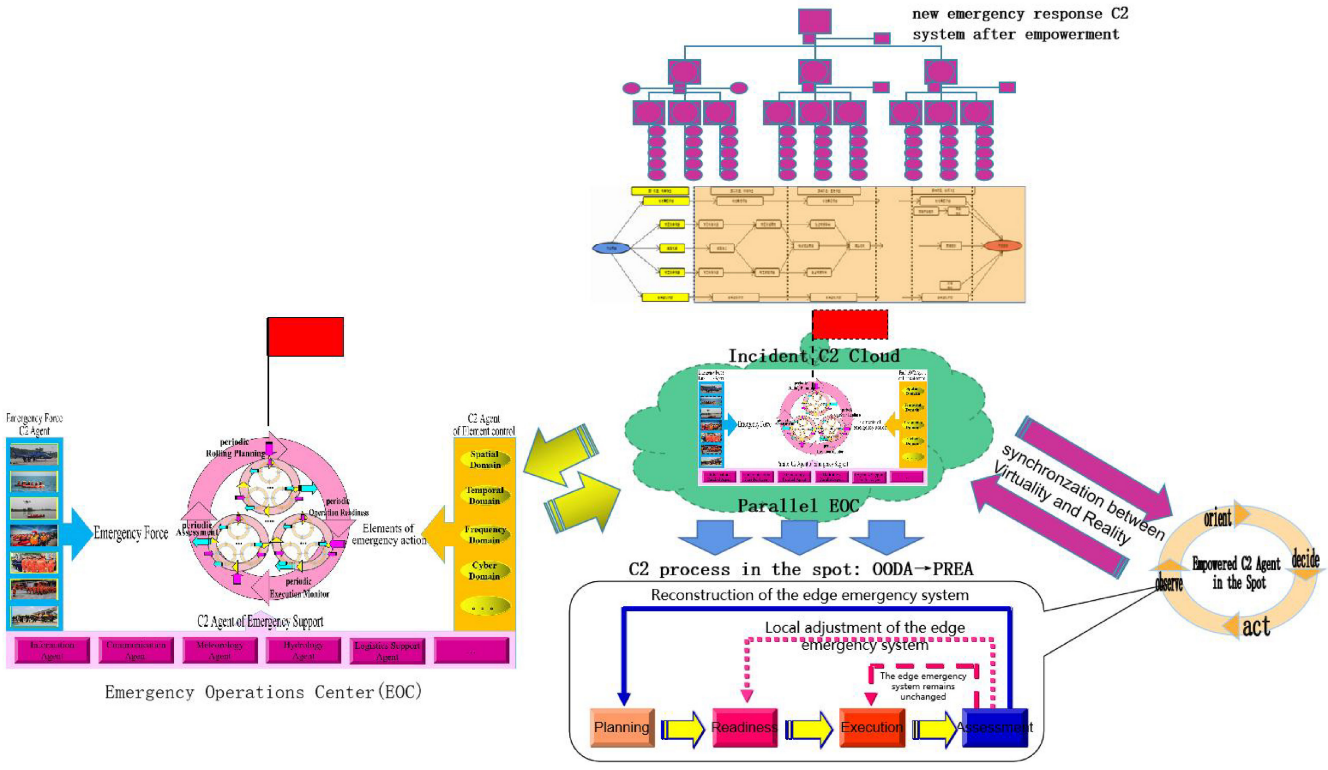

Fig. 8. Operation of cloud parallel incident C2 mode.

The energy release process of the on-scene C2 unit in the incident operation is the reverse process of edge empowerment. The energy release process is usually completed after the incident processing. The C2 unit at the incident site applies to the "cloud C2 center." The cloud C2 center will assess the incident operation result and the energy release behavior of the on-scene C2 unit. After receiving the assessment feedback from the C2 center, the on-scene C2 unit releases the resources of the edge emergency system and deconstructs the edge emergency system. After completing the deconstruction, the function of the on-scene C2 unit in incident operation switches from C2 to action, that is, from the

operating mode of the PREA loop to the operating mode of the OODA loop.

The energy release of the incident C2 unit at the incident scene is a deconstruction of the edge emergency system. Like the macro combat system, the edge emergency system is also composed of structure and incident operation procedures. After the incident operation procedures are correctly executed and the "assessment" of the edge PREA loop achieves the intended purpose, the incident C2 unit at the incident site releases the relevant resources of the edge emergency system, and removes its structural relationships. The relevant combat units of the edge emergency system reenter the current system.

Similar to the empowerment of the incident C2 unit at the incident scene, its process of energy release includes three aspects: first, the release of resources, that is, the related resources occupied by the edge emergency system are removed from the structural relationship with other members within the system, and they no longer play a role in the system; second, the authority handover of the edge C2 authority, the authority handover of the edge C2 node and the "central parallel c2," and the relevant C2 authority of the edge emergency system returning to the "central parallel c2"; and third, the switching of the role and operation mode of the edge C2. Its function is transferred from the organizational command of the edge emergency system to the execution of its own actions, and the operation mode is switched from the PREA loop to the OODA loop.

After the release of energy at the edge, the structural relationship of the edge emergency system is dissolved, the related emergency units, and resources need to be reorganized and integrated into the current overall system. Therefore, the central parallel C2 requires an evolution assessment of the current emergency system. The assessment is focusing on the efficiency changes in the reorganization or reconstruction of the global emergency system after the deconstruction of the edge emergency system.

When the structural relationship of the edge emergency system is dissolved, the equal peer-to-peer connection and collaboration relationship between each combat unit is thus restored. There is no longer the relationship between commanding and being commanded, controlling and being controlled, and supporting and being supported. The edge C2 node no longer performs the organizational command function of the edge emergency system, and its C2 process operation mode is converted from the PREA loop to the OODA loop. During the conversion, the operation mode of the central parallel C2 no longer establishes the synchronization with the C2 process operation mode, but operates in a relatively independent OODA loop.

VI. Conclusion and Discussion

In the response and operation of emergencies, quickness and carefulness are an eternal contradiction. The traditional solution to this contradiction is to establish two levels of C2 system: 1) the field command center and 2) the EOC. On-scene C2 activities are mainly based on quick response and operation. The focus of EOC is thoroughness. As limited by the differences in the operating process mechanism, the two-level commanding subjects are difficult to achieve efficient coordination.

In view of the efficient coordination requirements of two-level command subjects in emergencies, combined with the concepts of edge C2 and parallel C2, this article proposed a parallel incident C2 mode based on PREA loop and OODA loop, which supports the co-existence of two roles of C2 at the incident scene. The two roles are the executive role of emergency response and operation and the command role of the edge emergency system. The purpose is to integrate the two roles in the process of C2 activities, and operate the emergencies and potential threats on the spot as soon as possible, especially when emergencies evolve rapidly. This can avoid the further spread and expansion of emergencies and potential threats, so as to maintain the continuity and stability of the global system operation, and enhance its adaptability.

The realization of the concept of parallel incident C2 mode based on PREA loop and OODA loop not only involves the establishment of modes and mechanisms, but also requires the support of relevant key technologies and supporting infrastructure. In terms of infrastructure, it is necessary to build a "C2 cloud" to cover edge incident C2 activities. At the same time, it is also necessary to establish a security barrier for cloud C2, which is one of the foundations for the implementation of the edge C2 concept. In addition, the implementation of the parallel incident C2 mode based on the PREA loop and OODA loop also requires the relevant humanitarian environment. This is the trust and authorization of the cloud C2 center to the edge incident C2. Only on the premise of trust can the edge incident C2 be authorized. Otherwise, the edge incident C2 will be out of the question. How to address the edge C2 infrastructure and humanitarian support? This is the main direction of future research in the related field.

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