

Article

Enhancing Organizational Resilience in Emergency Management: A Cross-Organizational Intelligence System for Sustainable Response to Crisis

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Abstract: In today's urban environment, disasters are not isolated events but part of continuous, complex processes that threaten both sustainable urban development and effective emergency management. Traditional emergency management practices are hindered by departmental silos and fragmented information exchanges, which often lead to conflicting interests, unclear responsibilities, ineffective tools, and imprecise task divisions. In response, our study repositions emergency management within the broader context of sustainable urban development by emphasizing resource optimization, strengthened inter-agency coordination, and strategic decision support to achieve UN Sustainable Development Goal 11. Based on observations from 31 departments in Dongtai City, we identified key contradictions within the current activity system. Guided by activity theory, we designed the Cross-Organizational Emergency Intelligence System (COEIS), which synchronizes real-time data across agencies via a novel information exchange mechanism. Implementation in a real-world setting and evaluation using grounded theory demonstrated that the COEIS enhances collaborative efficiency and decision support capabilities, thereby improving inter-organizational resilience. This study makes both theoretical and practical contributions by integrating the DSRM, activity theory, and grounded theory, offering a replicable pathway for transforming fragmented crisis management infrastructures into sustainable and resilient networks aligned with urban development strategies.



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Keywords: sustainable urban development; emergency management; cross-organizational systems; intelligence systems; transboundary crises

1. Introduction

An emergency event is generally regarded as a disaster with significant losses caused by human activities or natural incidents. The event is not discrete and isolated but a part of a continuous and integrated process detrimental to organizations and stakeholders with conflicting needs and demands [1]. Managing an emergency is a process of dealing with a major event that is unpredictable and too problematic to be resolved by a single organization, threatening to harm the organization or the whole society [2]. Therefore, the management team must balance performing specific a priori roles with responding to unforeseen needs in this process and ensure that all relevant participants are able to make decisions and collaborate together by establishing collective procedures and rules [3]. From the perspective of sustainable development, the meaning of emergency management is further broadened and is no longer confined to short-term disaster response but rises to become an important component of the overall resilience and long-term sustainability of

cities. Specifically, optimizing resource allocation, strengthening sectoral synergies, and responding to disaster risks through behavioral adjustments [4] all help to promote cities' achievement of the United Nations Sustainable Development Goals (SDGs) in terms of ecological safety, environmental protection, and social coordination. This process not only enhances the ability of cities to cope with uncertainty and risk but also provides solid support for the realization of a green, inclusive, and sustainable urban governance model.

Organizational barriers and incomplete information exchange frequently hinder cross-organizational cooperation, rendering emergency management ineffective [5,6]. Integrating the exchange of information between organizations facilitates the optimal use of resources and decision-making processes. Since such action is much easier than breaking down political boundaries, taking early action is essential and strategically advantageous. In response to the challenges of complex emergencies and uncertainty, the Chinese government established the Ministry of Emergency Management on 22 March 2018, with the intention of promoting an overall upgrade of the emergency management system. However, the ministry did not integrate emergency handling at a higher level, not even at the city government level. Currently, emergency events are still assigned to different city government departments by categories (e.g., natural disaster, accident disaster, public health emergency, and social safety emergency) to take charge of the rescue and relief efforts. For example, the Emergency Management Bureau is responsible for disaster events such as earthquakes and landslides, the Water Affairs Bureau handles floods, and the Ecological Environment Bureau takes charge of pollution accidents. Yet, the departmental boundaries persist, rendering these agencies not closely integrated.

Previous studies have reported many information systems for emergencies in response to the occurrence of specific emergencies, such as earthquakes [7], floods [8], health emergencies [9], and pollution accidents [10]. However, there is a lack of a public information platform that provides a real-time method of exchanging and processing information between organizations, enabling borderless information flow and heterogeneous IT systems to operate collaboratively [11]. Thus, the critical question is how to build an integrated intelligence system that facilitates collaborative cross-organizational emergency management at the city level. Although prior studies have discussed the nine core components of integrated emergency management systems—organizational model, decision mechanism, situation awareness, information exchange, information management, system design, system prototype, testing, and user evaluation—aimed at managing cross-organizational rescue operations, these systems remain incomplete. For instance, Meng's [12] urban emergency management system based on IoT is characterized by the absence of information exchange, information management, and system prototype and testing modules. Li et al.'s [13] campus-wide crisis management system does not elaborate on the decision mechanism. Meanwhile, Zhang et al.'s [14] multi-industry, multi-hazard emergency command system lacks a formal user evaluation framework. Moreover, despite the complexity of crisis management systems discussed in the literature, no unified methodological framework has been systematically adopted in their development. This study addresses this gap by employing the design science research methodology (DSRM) to develop a Cross-Organizational Emergency Intelligence System (COEIS), with threefold objectives: (1) to investigate its structure design and operational mechanisms, (2) evaluate its functional effectiveness and limitations, and (3) provide actionable recommendations for replication in intelligent urban system implementations across other cities.

The remainder of this paper is organized as follows. Section 2 reviews the literature related to emergency management. Section 3 introduces the theoretical background of activity theory and the design science research methodology (DSRM). Section 4 discusses a case study on the development of the COEIS using a mixed-method approach based

on the DSRM and activity theory, implemented in a real organizational setting, with its performance evaluated using grounded theory. Sections 5 and 6 present the discussion and conclusions.

2. Literature Review

2.1. *The Challenge of Risk Uncertainty*

The nature of risk is unpredictable and dynamic. A great deal of uncertainty exists in any crisis. There are complex, non-linear, and unpredictable relationships between response plans and critical incident disposition outcomes [15]. Since the future is not a repetitive past [16], there is no generalized theory that explains the causes and management of critical incidents. Traditional emergency decision-making falls into the trap of applying historical events and scenarios without taking responsibility for the outcome. This has been demonstrated in many cases, such as the dilemma in the 2010 Icelandic ash cloud crisis—the biggest challenge is something completely new [17]. When crisis phenomena are beyond the scope of application of domain models and pre-existing human perceptions of the world, analyzing based only on bounded data and developing intelligence systems using a single domain model are not suitable for the complexities of novel and cross-border crises [11].

Girasole and Cannatella [18] point out that the concept of risk has become increasingly complex, where physical, social, economic, and environmental factors increase the sensitivity of hazard impacts and the difficulty of recovering from a disaster. There may be potential relationships between different types of disasters, such as fires and floods [19]. Even a single type of disaster can have multifaceted consequences, e.g., a nuclear power plant accident may simultaneously cause damage to public health, environmental pollution, and economic consequences. Uncertainty determines the level of information processing in an organization [20]. When oriented to deterministic tasks, the availability of fixed intelligence channels and static information is strong. However, when in a highly uncertain situation, contingency plans are ineffective due to the fact that the information and analyses embedded in the plans may become outdated and the interactions between hazards are not taken into account [21].

2.2. *Cross-Organizational Collaborative Emergency Intelligence*

The large-scale emergency response process extends beyond a specific organization and often involves the efforts of multiple agencies, such as police, fire departments, medical teams, and the military [22]. The presentation of quantitative and semi-quantitative emergency response information greatly influences stakeholders' ability to make well-informed decisions [23]. By analyzing a database of emergencies in Quito, Ecuador, Corral-De-Witt et al. [24] found that several emergencies have significant interrelationships, which in turn lead certain responding agencies to collaborate. Lee et al. [25] noted the importance of ICT systems for recognizing and resolving disaster situations in mass crashes due to the involvement of multiple teams. In Mexico, as many as 23 participants are classified as co-responsible for hydrometeorological disaster events, making collaboration between organizations a key element of disaster operations [26]. Savoia et al. [27] demonstrated the utility of cross-sectoral partnerships and exercises in enhancing decision-making capabilities and coordination among organizations.

The emergency response to the 1999 Marmara earthquake in Turkey [28], the 2005 emergency response to hurricane Katrina [29], and the COVID-19 global pandemic of 2020 [30] illustrate that relying on a single domain of intelligence systems can easily lead to failure in the dynamic scenarios of extreme disasters. Emergency management involves multiple cross-organizational responders who need to share digital tracking of mission-

critical information, but the lack of structured mechanisms for information sharing results in difficult inter-organizational collaboration [31]. Technology and the adoption of technology management capabilities are important determinants of inter-organizational relationships, so there is a need to develop common data standards and interoperable platforms and applications that enable participants to collect, process, and share data from different sources [32].

2.3. Information Technology in Emergency Management

GIS has been extensively used to optimize emergency shelter layouts [33], develop emergency evacuation plans [34] and rescue strategies [35], map vulnerable areas [36], assess health impacts of public health events [37], and evaluate urban storm flooding risks [38] and building fire hazards [39]. Emerging technologies like big data analytics, IoT, machine learning, and AI are increasingly integrated into disaster prevention and emergency response research [40,41] to enhance operational agility and improve decision-making quality [42].

Freeman et al. [43] suggested that ICT and big data tools should be more broadly tested, with attention to the characterization of intended users and implementation challenges to deepen understanding of their utility in disaster contexts. The U.S. National Water Center employed the FloodHippo prototype system for flood emergency response [44]. Brazil integrated multi-source data through the FDWithoutFire system to enhance user awareness of fire risks [45]. South Africa's KwaZulu-Natal province centralized four main access points via an information portal to collect and distribute management information during extreme weather events [46]. Poland implemented an integrated database-supported IT system to manage flood risks and mitigate losses from natural, technological, and synergistic hazards [47].

3. Theoretical Background

3.1. Activity Theory

Activity theory was introduced by L.S. Vygotsky in the 1920s and evolved through three generations of research. The first generation created the triangular model with the subject, object, and mediating artifact [48]. The second generation adapted the work of Leont'ev [49] and proposed the notion of collective activity [50]. Finally, the third generation introduced the community, rules and norms, and division of labor as three key elements of an activity system, emphasizing the interactivity between multiple activity systems based on a greater focus on organization and society [51]. The third-generation activity theory and its related conceptual tools help understand the interaction between an information system (IS) and its organization, which is the focus of this study. The structure of a human activity system introduced by Engeström [52] is shown in Figure 1.

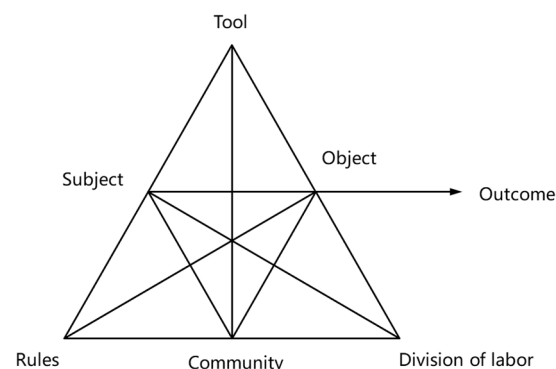


Figure 1. The structure of a human activity system.

According to this theory, an activity is a purposeful, mediated, contextual dialectic relationship between subject and object. The object is the problem, situation, or focus that anchors the activity. The activity system consists of six basic elements: “Tool-Object-Subject-Rules-Community-Division of Labor”. A subject is an agent (a person or a collective) that acts upon the object. The activity is mediated by tools and affected by community members, the rules associated with the activity, and the division of labor related to the activity. An activity system also distinguishes the outcome of an activity, both intended and unintended, from its object or purpose [53].

Activity theory offers a socio-technical perspective to investigate human activities in specific situations. In IS research, technical tools and organizational contexts are integrated into activity systems. The concepts in the activity theory have been used to understand IS intervention, IS use, and IS-driven management changes [54]. Thus, activity theory can enhance understanding and offer significant insights into ISs, providing an alternative (but not necessarily opposing or discordant) perspective to positivistic, interpretive, and critical approaches [50].

Contradictions are an important concept of activity theory. The term “contradiction” indicates “a misfit within elements, between them, between different activities, or between different developmental phases of a single activity” [55]. They are “historically accumulating structural tensions within and between activity systems” [56]. They expose dynamics, inefficiencies, disturbances, and opportunities for changes and actions, and precipitate the development of an activity system [57]. This study intends to develop an optimal information system by analyzing the incoherence of the elements of the activity system, revealing contradictions and seeking structures and mechanisms to resolve them.

3.2. The Design Science Research Methodology (DSRM)

Applying interpretive research methods to solving problems encountered in research and practice often fails because the resulting research output is still mostly explanatory. Therefore, developing an activity system involves both interpretive and scientific processes. Earlier, in the 1990s, Nunamaker et al. [58] integrated the system development methodology into the research process by proposing a multi-methodological approach that would include theory building, systems development, experimentation, and observations. In addition, Walls et al. [59] defined IS design theory as a class of research that would stand equal to traditional social science-based theory building and testing. These two works provide a conceptual and paradigmatic basis for design science research. Furthermore, Peffers et al. [60] propose a design science research methodology (DSRM) identifying a research framework of six iterative steps.

Following Peffers et al.’s [60] six-stage framework, this study operationalizes the DSRM:

- (1) Problem identification and motivation: Through activity theory-based root analysis of organizational contradictions in China’s emergency governance system, we identify interoperability gaps in information practices across agencies.
- (2) Definition of objectives for a solution: Establishing system requirements via “14th Five-Year Emergency Management Plan” and cross-organizational coordination of conflicts.
- (3) Design and development: Constructing system architecture based on activity theory’s contradictions, ensuring iterative alignment with sustainable governance principles.
- (4) Demonstration: Piloting the system in real cross-departmental disaster scenarios to validate system function.
- (5) Evaluation: Qualitative evaluation using grounded theory for the effectiveness of system implementation.
- (6) Communication: Utilizing the full text for communication in order to disseminate the resulting knowledge.

According to the constructivism and holistic view of information behavior, the term “information practice” refers to the actions to identify, create, seek, manage, use, and share information, following a set of socially, culturally, and historically constructed and materially mediated rules [61]. Fidel [62] emphasized that the research of human information interaction should go beyond the traditional cognitive stance to the study of human information behavior and give full consideration to the interactions between humans and their environment. Thus, there is a need for conceptual tools to describe and elucidate the mechanics of how human–technology interactions are unfolding in information practices, setting standards of social conduct, and regulating social processes [63]. As a result, this study integrates activity theory and activity-oriented methods into the DSRM and applies them to uncover more fully the interconnections and potential of the different trajectories of the elements that make up information practices in terms of problem identification and motivation, and to develop the COEIS to normativize information practices in a city government.

4. The DSRM Process—A Case Study

Dongtai City, located in the coastal region of eastern China, faces recurrent extreme weather events (droughts, floods, windstorms) due to its maritime climate. Its abundant river systems and agricultural infrastructure amplify flood risks, evidenced by 66 historical floods (1768–2021) and severe incidents in 1991/2015. In 2018, under the central government’s emergency management system reform, Dongtai established its Emergency Management Bureau. This bureau is responsible for formulating comprehensive emergency plans and guidelines, directing interdepartmental responses to emergencies, advancing emergency plan systems and drills, and coordinating emergency force deployment and material reserves. However, due to emerging cross-border crises, emergency management still requires joint participation from relevant departments: for instance, the Emergency Management Bureau collaborates with the Natural Resources and Planning Bureau, Housing and Urban-Rural Development Bureau, Forestry Bureau, and Seismological Bureau for natural disaster prevention; coordinates with the Development and Reform Commission, Housing and Urban-Rural Development Bureau, and Grain and Material Reserves Bureau for emergency material storage; and works with water management and meteorological departments under the Municipal Flood Control and Drought Relief Headquarters to organize flood management operations.

In 2021, the central government emphasized further advancement of emergency management informatization. Dongtai’s municipal government explicitly proposed in its “14th Five-Year Emergency Management Plan” to “improve interdepartmental, regional, and cross-regional coordination mechanisms and optimize the mobilization of emergency forces and material reserves”. Consequently, cross-organizational coordination of emergency intelligence has become a critical challenge. The municipal government aims to adopt advanced technologies to eliminate information flow bottlenecks, strengthen interdepartmental collaboration, enhance emergency management performance, and achieve long-term urban sustainability.

Under this context, this study selects Dongtai City in Jiangsu Province as a case to investigate how integrating interdepartmental information systems and decision support through activity theory and design science research methodology (DSRM) can promote sustainable urban emergency management. The development process of Dongtai’s COEIS is elucidated below.

4.1. Step 1: Problem Definition

Guided by activity theory, this study conceptualizes cross-organizational collaboration as a dual activity system configuration for exchanging decision information in interconnected emergency governance. Drawing from Engeström's [52] framework, the two activity systems are explicitly defined as follows:

- (1) The decision-making department activity system
 - Subject: Staff members executing emergency decisions;
 - Object: information calling;
 - Tools: official phone, official document;
 - Rules: one-for-one information call, information call according to an emergency plan;
 - Community: leader of the decision-making department;
 - Division of labor: staff is responsible for decision-making collecting information, leader guides and assists the staff.
- (2) The coordinating department activity system
 - Subject: staff members providing operational data;
 - Object: information called;
 - Tools: existing information systems, official phone, official documents;
 - Rules: one-for-one information provision, information provision according to an emergency plan;
 - Community: leader of the coordinating department;
 - Division of labor: staff is responsible for providing information, leader guides and assists the staff.

This study used the participant observation method to track the cross-organizational collaboration among the 31 departments involved in the city's emergency management processes for three months, from August to October 2022. During the investigation, we recorded the discussions with various departments on emergency information coordination. These discussions are summarized in excerpt form to document the contradictions within and between the activity systems.

The constellation of contradictions in the two activity systems of Dongtai City is schematically depicted in Figure 2. In both the decision-making and coordinating departments, contradictions emerge between the object of obtaining decision-supporting information and the elements implemented in both systems (i.e., the one-for-one rule, established tools, and the division of labor). The major contradictions are described below.

1. Benefit against responsibility. The greatest benefit of the decision-making department is the comprehensive acquisition of information because it influences the implementation effect of the decision. Failure to obtain complete, accurate, and real-time information may cause misjudgments of problems and situations. Conversely, the best benefit of the coordinating department is to protect its data and behavior records under the premise of solving the problem, so as not to breach confidentiality requirements or be held accountable afterward.
2. Ineffectiveness of the tools. There is no integrated information system to support cross-departmental information calls. Therefore, the calls depend on intermediary tools such as decentralized ISs, official telephones, official documents, and face-to-face communication, rendering timeliness not satisfied and data validity not verified.
3. Fuzzy division of labor. Although the staff is responsible for collecting and providing information, whether the information can be shared is the discretion of the department leaders, resulting in evasion, delay, and overstepping. Frequently, a community

member cannot determine what information is necessary for emergency decision-making, and there is no clear division of responsibilities.

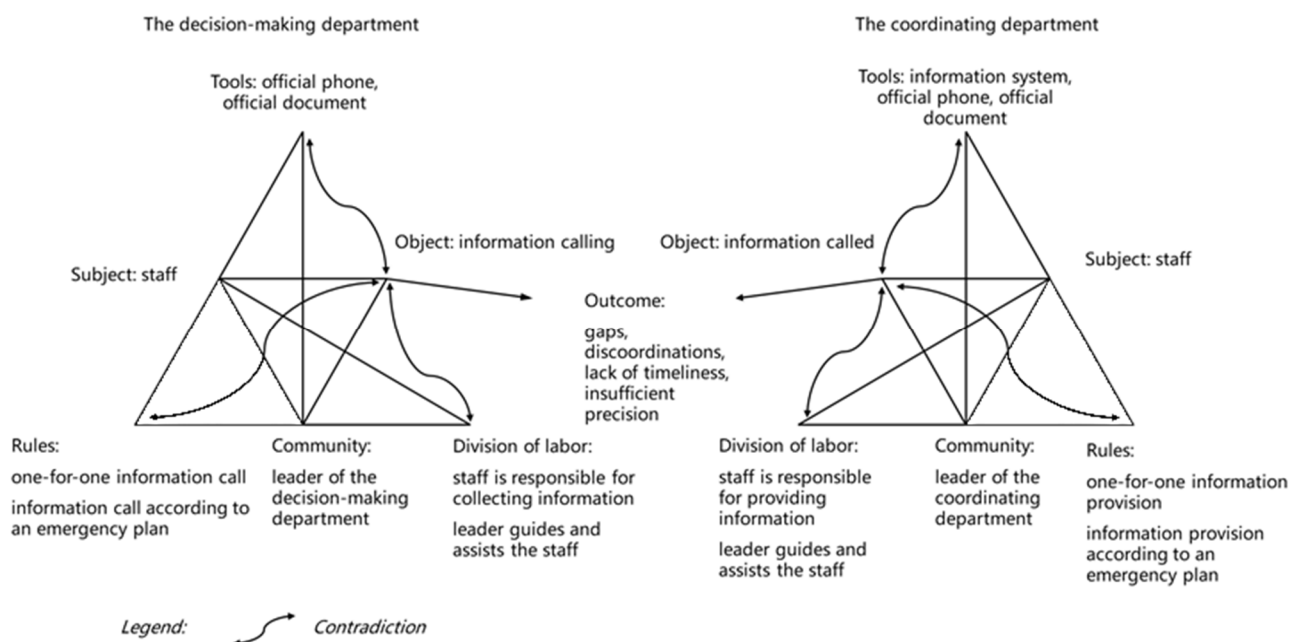


Figure 2. The contradictions in the activity systems of Dongtai City.

4.2. Step 2: Solution Objectives: An Integrated Activity System of COEIS for the Case City

Based on the investigation results, we identify the above three major contradictions that significantly affected the effectiveness of information coordination in emergencies. In the activity systems, multiple information calling/called actions occur sooner or later. The role of a department may shift according to the action status, and the interaction of various activity systems may also occur. Since each department must undertake decision-making and cooperation, the comprehensiveness, timeliness, and accuracy of information are necessary for all departments in the long run. The “14th Five-Year Emergency Management Plan” also strongly calls for the improvement of cross-sectoral data-sharing mechanisms and the full utilization of advanced scientific and technological equipment to improve coordination and linkage mechanisms. Introducing a new system with a new technical tool and mechanism to integrate multiple activity systems may resolve these major contradictions. Nevertheless, this new system is not intended to replace but build on top of the existing parochial systems.

To this end, we proposed an integrated information system of the COEIS as the solution, which replaces the tools used in the past (such as official telephone calls and official documents) and improves the effectiveness. With the help of the COEIS, we can integrate multiple activity systems into one activity system to coordinate information sharing. Then, all departments involved in calling or being called for information can form a community with a new information exchange mechanism. The key point is not to seek information providers based on the emergency plans but to stipulate that the decision-makers can set the channels and paths for obtaining information, regardless of the emergencies. The only principle is to share information unless there is a clear stipulation by law or higher authorities. The change in the structure of the activity system will dissipate the main contradiction between interest and responsibility. As such, the discussion-based relationship between the information calling and called parties is transformed into a long-term collaborative relationship. Moreover, it resolves the main contradiction of fuzzy division of labor: sharing or not sharing information is determined by the mechanism and

the technical tool rather than an individual. Figure 3 schematically depicts the information coordination activity system after the transformation of the contradictions. The figure is purposely simplified to exclude new contradictions between the information coordination and external activity systems.

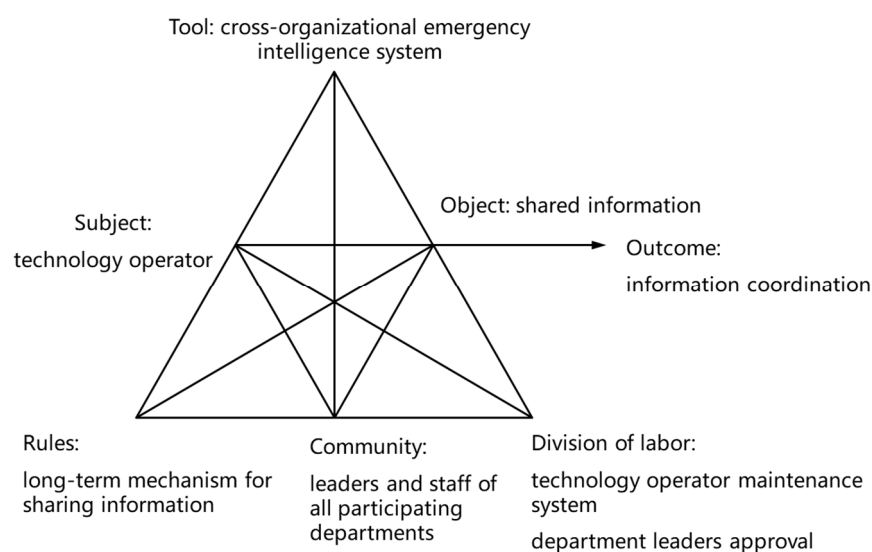


Figure 3. Activity system for information coordination in emergencies.

4.3. Step 3: Design and Development of the COEIS

4.3.1. Step 3-1: Design of the COEIS in Dongtai City

The COEIS in Dongtai City addresses three types of contradictions in cross-organizational collaboration by implementing a three-tier architecture of “data layer, exchange layer, and application layer” to integrate activity systems. This includes the Database Subsystem (DS), Information Sharing and Exchange Subsystem (ISES), and Emergency Intelligence Service Platform (EISP). This design transforms cross-organizational collaboration from a “disconnected activity system” relying on manual coordination into an “integrated activity system” sharing a common object (emergency incidents), ultimately deployed in the Emergency Command Center (ECC). Through physical infrastructure such as the data center and command hall, it enables standardized information flow across government departments. Figure 4 illustrates the COEIS architecture.

As shown in Figure 5, the DS constructs foundational databases by extracting basic data (e.g., population, enterprises, and geospatial information) from departmental business systems through mechanisms of data collection, cleansing, and hierarchical storage. It further establishes thematic databases using routine and emergency operational data generated by departments such as transportation, environmental protection, water resources, and public security. This design corresponds to the tool-mediated element in activity theory, resolving tool inefficiency caused by cross-departmental information heterogeneity by establishing standardized data coding systems (e.g., unified geocoding rules and event classification standards). Simultaneously, the DS embeds data ownership identifiers (e.g., departmental source fields) within metadata management, technically defining data responsibility boundaries and providing an institutionalized solution to departments’ concerns about traceability of information sharing responsibilities.

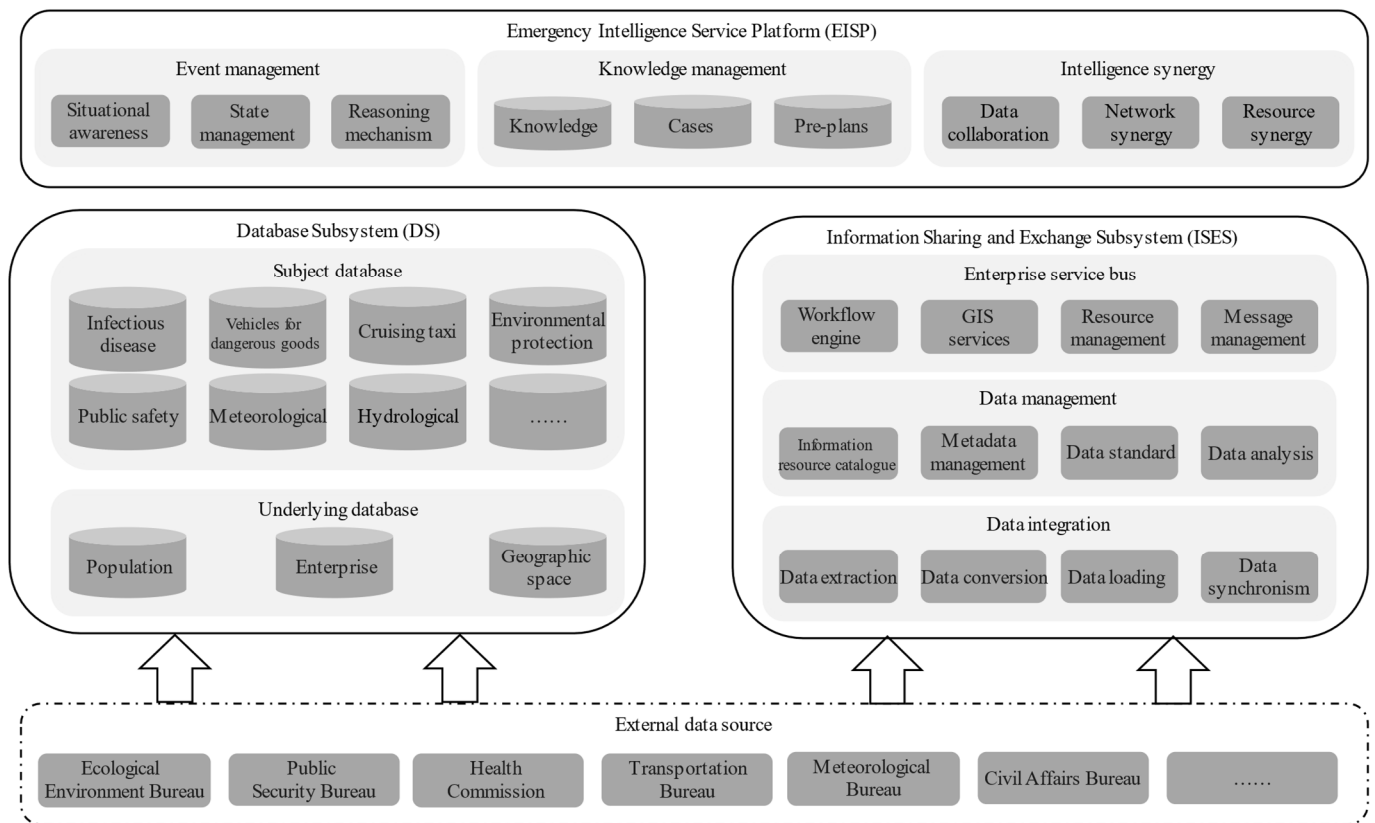


Figure 4. The architecture of the Cross-Organizational Emergency Intelligence System.

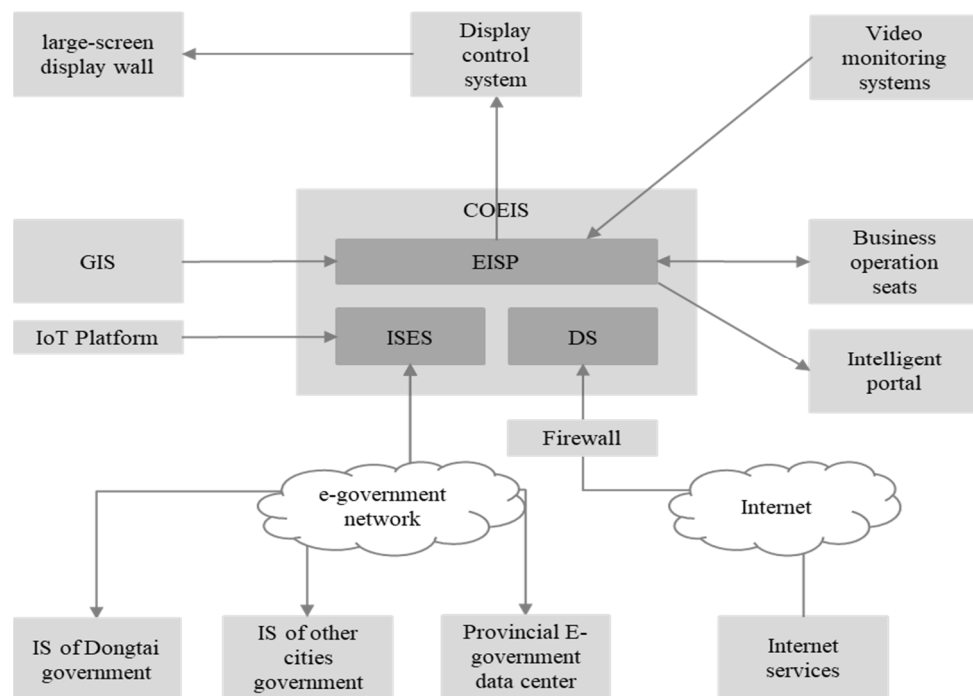


Figure 5. External system interface of the Cross-Organizational Emergency Intelligence System.

The ISES achieves cross-departmental data integration based on an Enterprise Service Bus (ESB), with its core function being the establishment of unified information exchange protocols and interface specifications. This design reflects the rule element reconfiguration in activity theory, resolving response delays caused by tool inefficiency by transforming

decentralized information retrieval processes (e.g., traditional tools such as phone calls and paper documents) into standardized API interfaces.

The EISP enables situational tracking of emergency incidents, retrieval of response plans, and decision support through an event classification engine and visualization interface. Its design embodies the division of labor element reconfiguration in activity theory: first, the built-in event classification standards (e.g., public health, natural disasters) clarify collaborative scenarios for departments, addressing the ambiguity of cross-departmental data ownership; second, tiered permission designs in the user interface (e.g., commander mode/operator mode) convert vague administrative divisions of labor into concrete operational divisions, institutionalizing responsibility structures through technical systems. By integrating information and task allocation, this subsystem maps cross-organizational collaborative objectives (objects) to operational tasks.

Furthermore, the COEIS integrates external hardware layers (e.g., video surveillance, IoT systems) and software layers (e.g., GIS, departmental information systems), creating a physical/digital hybrid mediating environment. GIS location services enhance the tool-mediated role in spatial dimensions, while the public push function of the intelligent portal expands the external boundaries of traditional divisions of labor. Each external system forms an information closed loop with the COEIS via API interfaces, and their interaction follows the “object transformation” principle in activity theory. Emergency incidents, as shared objects, undergo a three-stage mediation process (data standardization via the DS, exchange protocols via the ISES, and intelligence generation via the EISP) to ultimately become actionable decision objects.

4.3.2. Step 3-2: Implementation of the COEIS in Dongtai City

After the design step, the implementation team established an Information Resource Directory (IRD) covering 24 governmental departments by integrating China’s regulatory requirements for e-government data with the city’s emergency management needs. As the core standardization tool of the Database Subsystem (DS), the IRD regulates cross-organizational information access, exchange, and review behaviors, explicitly defining responsibility allocation for data sharing among departments. This effectively mitigates the “vague division of labor” problem and provides a standardized foundation for subsequent information exchange (ISES) and decision support (EISP) (partial content shown in Figure 6).

4.4. Step 4: Demonstration of the COEIS

During the system demonstration, this study simulated a catastrophic urban fire incident scenario using real data from relevant departments. Upon the incident occurring, the event information was first transmitted to the Emergency Command Center (ECC) via a call center. Operators then configured the initial location, status, and situational parameters of the emergency in the system backend (as shown in Figure 7). The Cross-Organizational Emergency Information System (COEIS) retrieved data from both foundational and thematic databases to generate a visual representation of event attributes and social environments. This included the following:

- Assessing the disaster severity of the fire;
- Estimating the distribution of affected populations;
- Designating traffic control zones;
- Recommending evacuation locations and rescue routes;
- Providing real-time data on emergency resources and surveillance cameras.

信息资源目录 Information Resources Directory

资源目录 Resource Directory

资源管理 Resource Management

资源信息 Resource Information

查询 Query

Transportation Bureau 交通局 (7)

Human Resources and Social Security Bureau 人社局 (1)

Health Commission 卫健委 (2)

Judicial Bureau 司法局 (1)

Urban Management Bureau 城管局 (3)

Market Supervision Bureau 市场监管局 (1)

Emergency Management Bureau 应急管理局 (3)

Political and Law Commission 政法委 (2)

Meteorological Bureau 气象局 (1)

Water Affairs Bureau 水务局 (5)

Ecological Environment Bureau 生态环境局 (4)

Rural and Agricultural Bureau 农村农业局 (2)

Water Supply Company 自来水公司 (1)

Natural Resources and Planning Bureau 自然资源和规划局 (3)

Civil Affairs Bureau 民政局 (2)

交通局-危险品运输... (18)

交通局-客运车辆... (18)

交通局-出租车... (18)

交通局-货运车辆... (18)

交通局-车辆基础... (10)

交通局-车辆管理... (11)

交通局-运营车辆... (13)

卫健委-电子健康... (22)

司法局-纠纷调解... (5)

城管局-东台部件... (24)

城管局-东台部件... (5)

城管局-事件基础... (18)

市场监管局-食品... (9)

应急管理局-江苏... (20)

政法委-城市管理... (11)

政法委-专项行动... (17)

民政局-救助管理... (6)

民政局-未成年人... (7)

气象局-气象数据... (29)

水务局-实时值表... (4)

水务局-水位日报... (5)

生态环境局-地表... (65)

生态环境局-大气... (4)

生态环境局-大气... (24)

生态环境局-水质... (13)

电信公司-东台小... (11)

自来水公司-水流... (16)

交通局-危险品运输...

序号	信息项编码	信息项代码	信息项名称
1	003600	cphm	车牌号码
2	003600	yysmc	运营单位名称
3	003600	gjjg	管理单位
4	003600	clzt	车辆状态
5	003600	bj	报警
6	003600	sjobb	数据版本
7	003600	sd	速度
8	003600	fx	方向
9	003600	cjsj	车机时间
10	003600	jssj	接收时间
11	003600	hybl	行业类别
12	003600	jyfw	经营范围
13	003600	jtblclx	交通部车辆类型
14	003600	gabcllx	公安部车辆类型
15	003600	hdzsl	核定载质量(KG)
16	003600	zws	座位数
17	003600	ysqy	运输企业
18	003600	lxsh	联系电话

Figure 6. The screen of the IRD in the Cross-Organizational Emergency Intelligence System. Legend: Red-colored boxes contain the field names translated from Chinese.

应急指挥系统

事件设置

事件类型

事件等级

事件发生位置

事件发生时间

事件处理单位

事件状态

操作

Event number 事件编号: EV20230926164340960

Event title 事件标题: 0926

Event type 事件类型: 火灾事故

Event subtype 事件子类型: 火灾事故

Event level 事件等级: 较大

Event location 事件发生位置: 盐城市东台市海陵北路

Event time 事件发生时间: 2023-09-26 16:45:35

Event description 事件描述: 一辆危化品运输车在...发生爆炸, 影响周边道路交通, 造成不...定数量的人员受伤。

Reporter 上报人: ...

Reporter contact information 联系人联系方式: ...

Event status 事件状态: 完结

Emergency Management Departments 处置部门: 交通局, 公安局, 卫健委

Emergency command organization 应急指挥部: 市消防安全应急指挥部

Deputy commander 副总指挥: ...

Commander in chief 总指挥: ...

Emergency rating standard 应急评级标准

Transportation Bureau

Public Security Bureau

Health Commission

Fire Bureau

Central Hospital

Figure 7. The emergency setting, event grading, and cross-organizational network configuration of a fire accident. Legend: Red-colored boxes contain the field names translated from Chinese.

The emergency command center established a cross-organizational network to progressively mobilize relevant departments (e.g., fire services, Public Security Bureau, Health

Bureau, nearby hospitals, and transportation agencies) based on the evolving situation. The system continuously collected data to track the incident's progression and changes in the social environment. All participating emergency management units could access the COEIS through the network and provide timely updates on response processes and outcomes, enabling real-time information sharing and exchange.

All intelligence was aggregated via the Information Sharing and Exchange Subsystem (ISES) into the Emergency Intelligence Service Platform (EISP), where it was integrated with relevant subsystems and displayed on the ECC's large-screen display wall (see Figure 8). The EISP also incorporated Online Analytical Processing (OLAP) capabilities, enabling management teams to interact with links in windows on the touchscreen to drill down into detailed information or view live/recorded video reports. Figure 8 illustrates the cross-organizational coordination triggered by the urban fire incident.

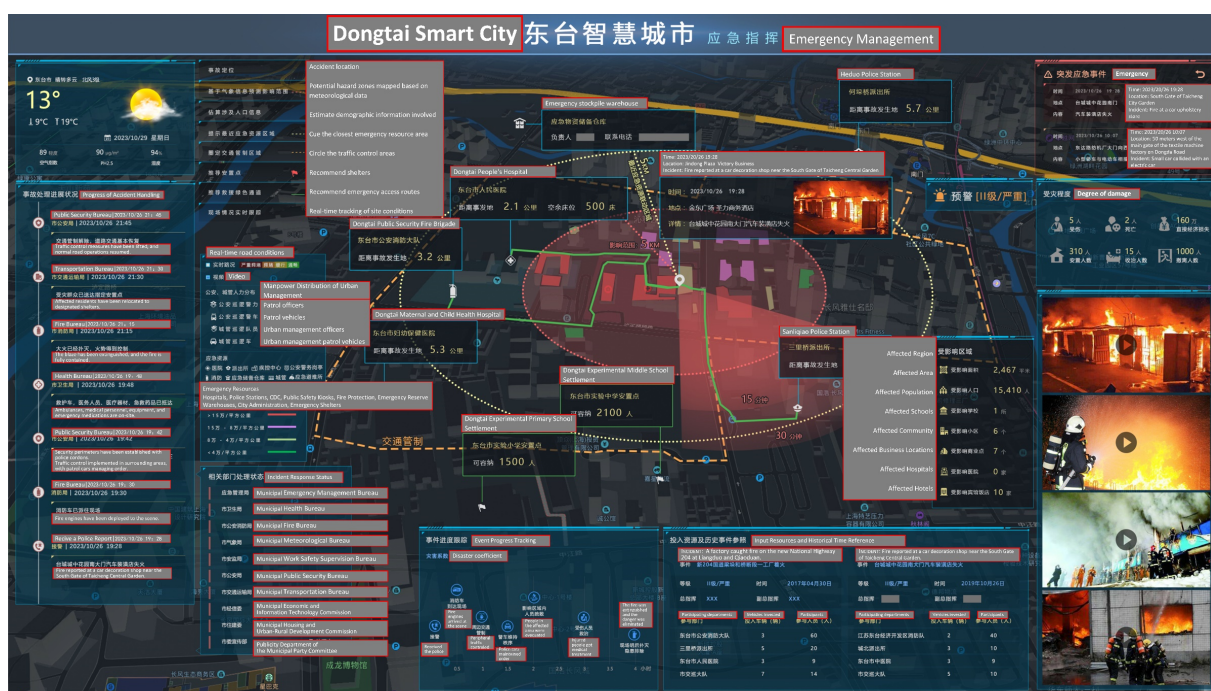


Figure 8. Integration of emergency response information in ECC.

4.5. Step 5: Evaluation of the COEIS

From the viewpoint of activity theory, evaluating the pros and cons of a system artifact is not enough; one must understand the underlying concepts and relationships within the system. Commonly, a survey instrument of system quality is used to evaluate the effectiveness of a system. However, such an instrument is constrained by preset knowledge and concepts that often cannot excavate deeper knowledge about people and the system. Moreover, user satisfaction surveys need a sufficient sample size to mitigate personal bias. As the user group of the COEIS is very small, the survey method is not suitable. Therefore, we adopted the well-established grounded theory methodology to obtain potential relationships and concepts from open interviews. The grounded theory is a common methodology for exploring how people behave within a social context when little is known or a new perspective of existing knowledge is needed [64]. With grounded theory, the researcher works in the actual environments in which the actions occur in natural situations to analytically relate informants' perspectives to the environments through which they emerge [65]. The role of grounded theory was, and is, the careful and systematic study of the relationship of the individual's experience to society and history. It bridges the gap between theoretically "uninformed" empirical research and empirically "uninformed"

theory by grounding theory in data that have been systematically obtained through “social” research [66].

4.5.1. The Grounded Theory Process

Following the grounded theory methodology, we visited and observed the pilot run of the system for three months, from November 2023 to January 2024, to interview the project team and the users. The semi-structured interviews lasted for 30 to 40 min. The interview guide containing the structured questions is listed in Appendix A. The initial interviewees include four persons in each job type, including system developer, technology operator, system planner/designer, and management personnel for the COEIS (see Table 1). In addition, two persons were recruited and interviewed, one system developer and one management personnel, to meet the conceptual saturation criterion suggested by the grounded theory methodology.

Table 1. Interview data collection.

Job Type	Identity	Interviewees
System developer	D1: Project manager D2: Database designer D3: System architect D4: User interface developer D5: User interface developer *	5
Technology operator	O1: System operator O2: Business operator O3: Business operator O4: System operator	4
System planner/designer	P1: Designer P2: Planner P3: Planner P4: Designer	4
Management personnel	M1: ECC’s management personnel M2: Emergency management director of other governmental departments M3: Information exchange and sharing manager M4: Section chief of Emergency Management Agency M5: Emergency management director of other governmental departments *	5

* Additional interviews to meet the conceptual saturation criterion.

After the first three interviews, we proceeded with open, axial, and selective coding. The audio recording of the interviews was transcribed into textual data and encoded with the NVivo12 software. First, two researchers independently conducted an initial round of line-by-line open coding and analyzed the texts to identify salient facts (e.g., “The business operator collects data from various departments and provides it to the manager after preprocessing. The manager can adjust the emergency response plan in time based on the data.”). The intercoder reliability was 84.67%, higher than 65%, signifying acceptable coding consistency and credibility. Then, the researchers held two discussion meetings with other co-authors to correct and optimize coding outputs. The interview facts were consolidated into 466 reference points with consensus. Furthermore, these reference points were collectively discussed and organized into groups and tagged with interpretive conceptual labels, each representing a concept (e.g., “Decision-making support”, “Cross-organizational

information cooperation”). A preliminary conceptual framework consisting of 60 concepts was developed. Throughout this process, discrepancies or different interpretations of the data and our conceptual framework were fully discussed to reach a consensus.

Next, axial coding was conducted to establish the homogeneous integration and the correlations for the generated concepts. These concepts were subsequently abstracted and categorized into 17 subthemes. We discussed the generated codes sufficiently and consulted with the related literature to reach a consensus for any subtheme in dispute. Finally, the selective coding integrates the highly correlated subthemes into three core themes: cross-organizational resilience, decision-supporting capacity, and information exchange mechanism.

After three rounds of coding (generating 60 concepts), we tested conceptual saturation by conducting two additional interviews. Only five new concepts emerged without altering the 17 subthemes, confirming saturation after the fifth interviewee per role. Figure 9 exhibits the coding process of this study, and Table 2 describes the themes, subthemes, descriptions of subthemes, and the number of reference points.

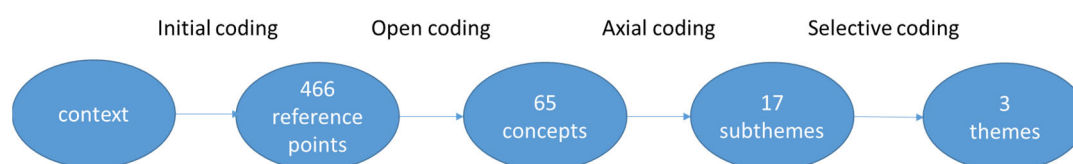


Figure 9. The coding process.

Table 2. Interview data coding.

Theme	Subtheme	Description	Reference Points
Cross-organizational resilience ^a	Involvement of multiple departments in emergency management	To realize emergency management under dynamic synergy, each department needs to flexibly join (or exit) the synergetic network.	9
	Uniform command	The emergency headquarters gives instructions directly via ECC.	27
	Organizing and dispatching resources	ECC is responsible for organizing and dispatching resources in a synergetic network, including material dispatching, personnel dispatching, and others.	24
	Islands of emergency information	Some ISs are not connected with COEIS, which affects the effectiveness of emergency cooperation. Barriers in public administration cause it.	19
Decision supporting capacity ^b	Cross-organizational information cooperation	Establishing cross-organizational underlying databases and subject databases realizes the information collaboration, sharing, and joint command between multiple departments.	79
	Data processing and analysis	All collected data are cleaned, converted, classified, summarized, and analyzed in COEIS.	17
	Respond to on-site emergency	COEIS acquires the field information in real-time and helps decision-makers to adjust emergency response plans dynamically.	27
	Operating intelligence system	Professionals are responsible for operating and maintaining COEIS, helping decision-makers acquire and analyze the cross-organizational information, and filling in the gap between information and decision-making.	19

Table 2. Cont.

Theme	Subtheme	Description	Reference Points
Decision supporting capacity ^b	Information support ^b	The decision-maker masters all information via COEIS, which combines data visualization and large-screen function to realize decision support and quickly respond to the user's demand.	73
	Fusion of multiple emergency plans and knowledge bases	When coping with serious and wide-range emergencies, there is a need to achieve a cross-organizational fusion of emergency plans and knowledge bases.	16
	Difficulty in acquiring data	The differences in information levels between departments, information security issues, and the barrier between departments increase the difficulty of data acquisition.	42
Information exchange mechanism ^c	Establishing IRD	The IRD helps increase the understanding between departments and promotes data sharing and exchange.	6
	Process of acquiring information	By standardizing the processes of application, review, and approval, ECC blocks unnecessary and risky data sharing and exchange.	21
	Reserving system interface	COEIS reserves the data interface for the ISs that have not yet been connected, such as the provincial e-government data platform, to expand the support of cross-organizational emergency management.	15
	Attitude affects the information exchange mechanism	The recognition and emphasis of government departments on COEIS affect the efficacy of the information exchange mechanism.	8
	Institutional guarantee of information exchange	Information exchange cannot succeed without related standards, specifications, and policies.	38
	The vertically deployed system causes a barrier	The vertically deployed information system by the central or provincial government restricts information exchange.	26

^a Representative quotations from interviewees are listed in Appendix B. ^b Representative quotations from interviewees are listed in Appendix C. ^c Representative quotations from interviewees are listed in Appendix D.

4.5.2. Evaluation of COEIS

The outcomes of interview data coding (Table 2) indicate that the cross-organizational information cooperation and the overall information support are two major COEIS sub-themes with 79 and 73 reference points, respectively. Furthermore, a comparative analysis of the effectiveness of the COEIS with that of the previous information system was conducted (see Table 3). The results indicate that the COEIS enhanced cross-organizational flexibility and decision support capabilities and established an effective clearinghouse mechanism in emergency response. This finding reveals that the COEIS can solve the problem of cross-organizational cooperation at the city level, substantiating our claims that the COEIS has the following capabilities:

1. Enhances cross-organizational flexibility by establishing shared databases and standardized protocols for joint command, addressing historical fragmentation in pre-2018 emergency responses.
2. Strengthens decision-support capabilities through real-time data preprocessing by operators (e.g., “Managers adjust plans dynamically based on operator-processed data” [M3]).
3. Resolves information exchange barriers via reserved system interfaces (15 reference points) and institutional guarantees (38 points), though challenges persist:

- (1) Forty-two reference points highlight ongoing data acquisition difficulties due to inter-departmental security hierarchies.
- (2) Twenty-six points expose contradictions with vertically deployed systems (e.g., provincial e-government platforms), aligning with activity theory's rule–tool tension.

These subthemes mainly reflect two aspects: the transformation of the internal mechanism of the information coordination activity system, which requires a long-term adaptation process, and the conflict between the technological conditions and mechanisms outside the activity system, which needs information coordination. It further signifies that the deployment of the COEIS is not only a technology issue but also a management issue.

Table 3. Evaluation of COEIS and previous information system.

Theme	System	Description
Cross-organizational resilience	Previous information system	- The ISs of departments are not connected, so there is no way to organize emergency cooperation effectively. - The departments involved in emergency management have already been determined at the initial stage, so it is difficult for new management personnel to join and rebuild the relationships among them.
	COEIS	- COEIS supports multiple departments joining or exiting the synergetic emergency management network at the different evolution stages of an emergency. - ECC is responsible for organizing and dispatching the synergetic network of emergency management. “In the past, various departments, such as Public Security Bureau, Fire Bureau, Healthcare Commission, and others, performed their respective duties and took the emergency response as an extension of their daily work. However, when encountering collaborative tasks, there are process and technology barriers. [...] Now, the emergency intelligence system provides cross-organizational information support, and the front-line personnel from various departments can cooperate.”—Interviewee D4. “Just like the explosion accident in the chemical plant last year, it made the municipal leaders shock too much. It is not the thing of a department or a city as the influence is so big. We didn’t encounter a disaster like that before, and we never imaged meeting with it. [...] We need to put down fire, rescue people, control environmental pollution and cope with the aftermath of a disaster. Houses must be repaired if they are collapsed. People will be compensated if they die. Such disaster covers wide involved aspects, so it is very complicated, and this system may be very helpful to a complicated emergency like it.”—Interviewee O3
Decision supporting capacity	Previous information system	- Each department masters only the information acquired from its channel but has no plan to cope with transboundary and new types of crises. - There is a lack of tracking for the evolution process of emergency and overall understanding of the social environment. - The information acquired by different departments is not consistent or even conflicts with each other. - There is a lack of mutual coordination on emergency management activities between different departments.

Table 3. Cont.

Theme	System	Description
Decision supporting capacity	COEIS	• COEIS integrates information resources, so it can help to make decisions during an emergency quickly and comprehensively. • It is helpful for management personnel to perceive the situation, understand the emergency status and the impact of decisions, and thereby adjust the emergency response scheme. • Multiple departments can use COEIS simultaneously and acquire consistent and overall information. • Criticism: The fusion of emergency plans and knowledge bases is not fully realized, and it depends on the business coordination between departments in the future. “In the past, there was no emergency management system on the top level (Dongtai City). [...] Telephone and other communication methods are mainly used for information inquiry and on-site command, but they didn’t work very well. Nowadays, we can see the field video in ECC via the display wall. The situation is clear at a glance, including dispatching various emergency resources. Since the system can simultaneously coordinate all involved departments to deal with issues, it will improve timeliness and organization.”—Interviewee M3 “In the past, our information support was lack of network-based collaborative connectivity, every department could not master the whole situations, but receives instructions passively. However, COEIS facilitates network-based cooperation and ensures that every department understands the emergency, the surrounding environment, and their interactions. The decision can be quickly adjusted and even optimized.”—Interviewee D4
	Previous information system	• Every department does not know the information resource owned by others, so they are not clear what information call demand should be requested against which department. • After a department requests the information call demand, the responding department may not guarantee response efficiency and quality because of the shortage of corresponding management mechanisms and system support. • Related department worries about internal information leakage, causing a new disaster, or assumes the responsibility that is not deserved originally; thus, it has difficulty making up its mind to provide information.
Information exchange mechanism		• Via IRD, the required information can be easily retrieved, or even its source can be traced. • Information exchange needs strict review and specification, guaranteeing every department’s information safety and privacy. • The interfaces connecting the entities at higher-up and equal levels are reserved. They can be used when there is a larger-range cross-organizational emergency. • Criticism: The deployment manner of existing ISs in certain departments is the vertical deployment; the central government or provincial government controls it, and holds a conservative attitude toward information exchange.
	COEIS	“We have a method, namely, we require the unified data coding, and specify the transmission frequency, style, interface, sharing form. We have formulated the regulations on every aspect technically, including database, form information, and others, whichever are authorized or forced to share.”—Interviewee O3 “There is a directory, the department demanding the data can view IRD and then apply to the platform. The administrator will solicit the comments of the data provision department. In the past, one department could not know what information the other departments possessed. However, if you have this (IRD), you can know who should be sent the application to.”—Interviewee M3

5. Discussion

Recently, there have been calls to promote intradisciplinary IS research and mixed-method integration design [67]. This study employs mixed methods to design and develop a complex information system, where the DSRM provides a fundamental framework covering “problem identification, objective clarification, system design, system demonstration, and system evaluation”. Activity theory identifies contradictions in real organizational environments, while grounded theory conducts multidimensional effectiveness evaluations of COEIS, promoting complementarity, completeness, and expansion of IS research. Notably, this research innovatively introduces activity theory into the field of information system design, revealing dynamic relationships among information behavior, structural contradictions (e.g., conflicting interests, vague division of labor), and information exchange mechanisms, deepening the understanding of information practices in emergency management. We regarded the information coordination activity as an interaction process affected by institutional arrangement and event context, and proposed the activity system model for cross-organizational information coordination. This study contributes to the literature by combining technology and institutions to design and develop information system solutions that probe beneath the surface of reality. The COEIS improves information coordination by integrating technical tools, contradiction resolution, and mechanism transformation.

This research represents the first to evaluate information systems from multiple views through a grounded theoretical approach. Despite this, grounded theory has been used in the research of information system development [68]. Few studies have involved direct evaluation of the effectiveness of information systems; more common is the process of assessing information systems based on the user’s perspective [69]. Furthermore, prior research largely ignores the interaction between the organizational environment and the participants in the development process. By comprehensively evaluating the COEIS’s effectiveness from four participant perspectives, this work advances beyond traditional user-centric evaluation models.

From the perspective of the social implications, COEIS’s information exchange function facilitates the construction of a virtual collaborative network for emergency management, enabling relevant departments to conduct drills for diverse emergency scenarios on a unified platform. This promotes sustained development of cooperative organizations at effective relational levels, enhancing inter-agency mutual understanding and collective awareness. Consequently, cities can strengthen crisis response capabilities while maintaining ecological systems, thereby improving citizens’ quality of life. Moreover, cross-organizational information integration assists managers in assessing crisis scope and latent risks. By transcending traditional departmental boundaries and achieving decentralized coordination in the blurred techno-social interface, this capacity directly enhances urban system resilience against uncertainties and rebuilds public trust through transparent decision-making. Finally, mindful leadership and deep engagement from senior officials are critical success factors, mirroring cross-departmental collaboration patterns observed during the COVID-19 pandemic. System development revealed deficiencies in vertically deployed legacy information systems (interface delays caused by departmental hedging), demonstrating management bureaucracy’s negative impacts on information systems. This provides techno-institutional linkage solutions for establishing performance evaluation frameworks in governmental agencies.

6. Limitations and Future Research

There are certain limitations to this study. First, the IoT platform’s real-time data transmission may be limited because sensor networks are usually separated from the e-government network. For security purposes, information from the Internet has not been

connected to the system. In addition, the system needs front-end processors and a reverse proxy to prevent external hacking and attacks.

Second, the ability of information infrastructure to withstand disasters is still very fragile. When a disaster strikes, it may cause communication interruption and sensor failure (e.g., floods, fires, and earthquakes), and even the COEIS and ECC may be disrupted.

Third, although the system successfully resolved conflicts in Dongtai City regarding responsibility allocation, tool inefficiency, and unclear division of labor, its technical dependencies (e.g., reverse proxy, front-end preprocessing) may hinder direct replication in resource-constrained environments (e.g., regions with underdeveloped infrastructure), necessitating further validation of system adaptability.

Therefore, emergency management should not rely exclusively on digitalization, automation, and intelligent technologies. Future research must focus on constructing open technical frameworks and system ecologies, developing simplified interactive interfaces compatible with foundational communication technologies, reducing sensor network dependencies, and designing system integration mechanisms for broader scenarios. These include prioritizing distributed architectures during extreme disasters or exploring hybrid information coordination models combining digital systems with traditional governance structures (e.g., community mobilization). Such approaches should observe and evaluate cross-organizational network operations from expanded perspectives to provide solutions for diverse urban cross-organizational emergency management contexts.

7. Conclusions

This paper was guided by activity theory in applying the design science research methodology (DSRM) and grounded theory processes to develop the COEIS for addressing cross-border crisis management challenges at the urban level. First, through participant observation tracking cross-organizational collaboration across 31 departments in Dongtai City, contradictions within activity systems were identified and analyzed, leading to the formulation of integration objectives for activity systems. Subsequently, a new technical instrument (COEIS) was designed and developed to achieve these objectives. Supported by the COEIS, the integrated activity system embedded organizational members into information coordination activities, reorganizing labor divisions through a novel information exchange mechanism. Finally, the system was implemented and tested in real organizational contexts. Qualitative analysis methods were employed to evaluate the COEIS's effectiveness from multiple perspectives, focusing on improvements in cross-organizational resilience, decision-support capabilities, and information exchange mechanisms. Additionally, this study gained insights into challenges encountered during system design, development, and deployment.

The findings demonstrate that the COEIS not only significantly enhances collaborative efficacy and operational performance of organizational networks in cross-border crisis responses but also optimizes cross-organizational information integration and decision coordination mechanisms, thereby strengthening organizational resilience and situational awareness. Specifically, the COEIS enables structural transformations of activity systems while resolving critical contradictions in original systems, including conflicts over interests/responsibilities, tool inefficiencies, and ambiguous labor divisions. Furthermore, the COEIS supports both centralized and distributed user interfaces, overcoming heterogeneity and inefficiencies in legacy technological tools. Its implementation has proven effective in enhancing crisis response synergy, promoting organizational coordination and decision transparency, thus providing a viable pathway for sustainable urban governance. Finally, this study emphasizes that information system development must transcend technical tools by constructing dynamic adaptation models based on organizational contradiction

analysis. Due to ongoing organizational restructuring of China’s emergency management institutions, this research could not fully investigate post-reform scenarios or conduct comprehensive data analysis. Future studies should continue optimizing system design through context-specific approaches, verifying collaboration mechanisms under institutional reforms, and exploring adaptive strategies across different regions.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Interview guide.

Category	Structured Questions
1. Introduction and discussion on the role of interviewee	• Experience in implementation, position, and duration of cross-organizational EIS (COEIS), more extensive benefit within the project’s scope.
2. Explanatory questions	• What is the motive of developing COEIS? How does the system help deal with a new type of crisis and transboundary crisis? • What are the emergency management organization mode and the decision-making supporting mode in the past? • What is the relation among intelligence systems, technology operators, and management personnel under COEIS? • What is the objective of planning the system? Has the objective been achieved or not?
3. Illustrative questions	• How does ECC organize the synergetic network and obtain the information in emergency response? • How does COEIS connect with other ISs? Why does the system adopt the technology of ESB? • What is the mechanism of realizing information sharing and exchange? What is the difficulty in implementation? • Is there any technological difficulty or limitation of the management system in planning, design, development, or implementation? Please describe with examples.
4. Ending questions	• What are the three key challenges to be solved? • What suggestions do you have for the planning, design, development, and implementation of COEIS?

Appendix B

Table A2. Representative quotations of cross-organizational resilience.

Subtheme	Representative Quotations
Involvement of multiple departments in emergency management	“(Synergetic network) is dynamically adjustable. Due to the diversity of emergencies, it can’t be set as the fixed type. Since you have no way to determine which category the emergency belongs to [. . .], the design of dynamic configuration allows to coordinate departments or select some departments on demands.” Interviewee D2 “How do you know which department will join? Which data will be required? Which departmental will be needed? So we should establish the leading group according to the characteristics of the emergency.” Interviewee M2 “(Management function) rather dispersive. In addition to the command headquarter, there are other 23 special headquarters involved in many departments. For example, a public health emergency involves multiple departments such as healthcare commission and others.” Interviewee M4
Uniform command	“There is a site assigned to the emergency headquarter. The collaboration between departments can be instructed directly by ECC.” Interviewee D1 “There is a unified ECC; top management uses it for viewing the overall and total information.” Interviewee O2 “We provide terminals, operation seats for every main department to access their business systems, such as Public Security Bureau, Urban Management Bureau, Committee on Housing, Roads and Traffic Authority. COEIS connects departments’ business systems by the distributed disposal form and makes their disposal process and feedback. ” Interviewee O3
Organizing and dispatching resources	“Sending information to departments, making feedback, and then acquiring the real-time information. The synergetic network is organized like this.” Interviewee D2 “We deployed the system terminals to related departments, so they can use the system to organize the synergetic network.” Interviewee O2 “The COEIS is connected with the Weather Bureau and Water Affairs Bureau systems. So they can send information to ECC in flood seasons, such as the prewarning of rainfall and geological disaster. Then ECC further understands the conditions of towns and sends the prewarning information to the subordinate units. If the disaster is huge, there is a need to report the higher-level government and start the higher-level emergency response.” Interviewee M4
Islands of emergency information	“The information barrier between departments is a problem existing in reality; it is also why we need to design the system, i.e., the purpose of such system is to promote the change in flow and mechanism and promote the cross-department cooperation.” Interviewee D1 “There is also a barrier between departments due to various reasons, and data sharing is a certain difficulty.” Interviewee M1 “There is a problem when COEIS runs: The information islands of departments are interconnected or not, they share information or not.” Interviewee M2

Appendix C

Table A3. Representative quotations of decision supporting capacity.

Subtheme	Representative Quotations
Cross-organizational information cooperation	“Through IoT and the e-government network, the system can obtain the information for dealing with production accident, natural disaster, disaster prevention and mitigation, such as traffic, weather forecast, hazard sources distribution, emergency supplies, and other data.” Interviewee M4 “Constructing COEIS enables governmental agencies and industrial sectors to transmit data according to the uniform requirements. The system serves as a middleware platform to complete the functions of data processing, distribution and sharing, finally, support the emergency management more efficiently.” Interviewee P1 “We hope that more departments will participate in the collaboration. By highlighting information collaboration, we prefer to exert the important role of emergency management agency in crisis.” Interviewee P2
Data processing and analysis	“There are various types of data for emergency management, including static data, dynamic data, basic data, and the data for specific problems” Interviewee O2 “We are responsible for connecting systems and dispatching data. We also analyze the operation status of the city, give early warning and forecast for emergencies, and prepare reports for leaders’ reference.” Interviewee O3 “Considering the risk factors and the location of the disaster outbreak, the system focuses on the analysis of the surrounding environment and response measures, including the path of hazardous chemicals vehicles, the traffic restriction measures around the incident point, and provides suggestions to the decision-makers according to the weather, temperature and other conditions.” Interviewee P1
Respond to on-site emergency	“The system has obtained the real-time data of cruising taxis. But the data quality is not ideal, including inaccurate vehicle positioning and poor regularity of successful data extraction. It’s important to find out the root cause of the problem, and I speculate that it may be the transmission problem.” Interviewee O3 “Only after establishing the IoT system of city infrastructure to perceive the entire operating status can we get enough information to provide decision-making support for emergency management.” Interviewee M1 “Through the large screen display wall, we can observe the scene in real-time [. . .] We can track the entire process and progress of the emergency response. Through the visual interface, each department can get the information synchronously.” Interviewee M3
Operating intelligence system	“The operators of information technologies, who are professionals, must be very familiar with COEIS and be able to provide the managers with the information needed to support decision-making at the right time in case of emergencies.” Interviewee D1 “The front-end agents of ECC are set for the relevant emergency departments. - They provide corresponding information support for decision-makers, and the managers conduct comprehensive research and judgment. The operation of an information system requires a thorough understanding and professionalism of IT, and managers should make decisions from a top-level perspective.” Interviewee O1 “There is such a mechanism of reporting to superior, conveying to subordinate, and timely feedback. In the business process, software architecture and software functions support this mechanism. ECC can transmit alarm information to relevant departments that need to process or cooperate with others through COEIS.” Interviewee P2

Table A3. Cont.

Subtheme	Representative Quotations
Overall information support	“(Managers) can know what they are facing, what should be doing, and what effect they will achieve [...] Give them the information he needs at the right time. It is helpful for managers to make the most accurate and scientific decisions according to the current situation.” Interviewee D1 “(Officials) should grasp the overall situation. They always listened to oral reports in the past, and the information they got may be inaccurate, incomplete, and not necessarily true. Moreover, the situation would change rapidly. If they arranged emergency measures according to the past, there would be no feedback. Officials don’t know the effect and whether their instructions have solved the crisis. Finally, problems will arise. So COEIS mainly solves these problems.” Interviewee O3 “The resource elements in the city, such as schools, residential areas, shelters, and risk elements, such as gas stations, will be planned into a view from the perspective of full information. We will make a comprehensive display of the static focus and dynamic risk elements for the reference of decision-making departments.” Interviewee P1
Fusion of multiple emergency plans and knowledge bases	“(For coping with an explosion of dangerous chemical transport vehicle), It needs to be able to quickly determine the extent of the impact and how to deal with the explosion to prevent the occurrence of subsequent disasters, which requires a large professional knowledge base [...] The leaders of emergency headquarter are restricted by their professional background, so they can’t understand all the disposal schemes.” Interviewee D1 “Through the continuous accumulation of historical events and expert knowledge, we can quickly respond to these types of crisis. It is an important function.” Interviewee O1 “There are new knowledge or emergency plans that need to be integrated across organizations and departments, but it is difficult for us to fusion them. Emergency Management Bureau has no right to do this, and other departments will not consider anything outside their departments.” Interviewee O2
Difficulty in acquiring data	“It has been noted that there are security issues, such as privacy, restrictions, and authorization. Some data of government departments may involve secrets. There may be risks in providing it. It is not a question of ‘to give or not to give’ the data.” Interviewee M3 “Some key units have weak information ability, which leads to the lack of data. It’s not that they don’t want to exchange information. They have no information to offer. Information exchange may damage other departments’ benefits, leading to some obstacles. There is no way to collect certain sensitive data.” Interviewee P1 “The system can’t get all information it wants, or it can’t get some information in real-time. In many cases, the organizational structure or institution has some problems, not purely technological problems.” Interviewee P2

Appendix D

Table A4. Representative quotations of information exchange mechanism.

Subtheme	Representative Quotations
Establishing IRD	“For example, 24 commissions, offices, and bureaus subordinated to Dongtai City [...] The system can access the general data of these departments. If there is a certain special demand, the technology operators will apply for the data in the system. After approval, they can get the data quickly.” Interviewee D4 “Now we have set up a set of IRD, docking over 30 ISs. We have processed the data and shared it with the departments in IRD, and the departments can view the relevant business data provided by others through IRD.” Interviewee M1 “We have an IRD. After searching the directory, the department that needs data can apply to the platform.” Interviewee M3

Table A4. Cont.

Subtheme	Representative Quotations
Process of acquiring information	“The information service is not the so-called relation of ‘calling’ and ‘being called’, but an equal exchange relation. Therefore we designed an information exchange mechanism to promote open data access.” Interviewee D4 “We put forward data requirements, or various departments involved in emergency management put forward requirements among themselves. We can obtain the relevant information as long as according to the regulation. Each department does not ask for data unilaterally but also provides data to other departments. It is a fair and reasonable process, and the effect of information exchange is better. We have established such a mechanism.” Interviewee O2 “The administrator will consult the department providing the data. Only with the approval of these departments will the system administrator put the index of the data into the IRD. However, it is mandatory to share the data without damaging the interests of departments.” Interviewee M3
Reserving system interface	“In the design, we consider the issue of the system interface. If there are other services, applications, and data sources in the future, they can access COEIS according to the protocol and standard.” Interviewee D2 “Migrating some ISs from department offices to the data center can not only concentrate the data but also reduce the repeated investment of various departments. In this way, the relationship between the various systems becomes closer.” Interviewee O3 “The plan requires that information services provided by various departments should be registered and integrated into COEIS through APIs, such as the service of pollution sources detection.” Interviewee P1
Attitude affects information exchange mechanism	“First of all, budget is needed for project implementation, which needs the attention of top leaders and the cooperation of business departments. When a project becomes the ‘top leadership project’, it will be easier to coordinate and promote.” Interviewee D3 “We urgently need the data of the Public Security Bureau. As you know, this department is ‘strong’. The core data of Public Security Bureau is difficult to obtain and process, which is a typical example.” Interviewee O1 “Since the deployment of COEIS, in the business process of dealing with emergencies, each department is no longer in charge of itself. They all have to bear their responsibility through the system to achieve division of cooperation. Therefore, institutional reform has been promoted.” Interviewee O3
Institutional guarantee of information exchange	“There’s a law about classified protection of information security [. . .] COEIS is deployed on the e-government network. The data from the Internet can’t enter the database at will, and the system can’t connect to other systems at will without security protection.” Interviewee D3 “To break the information barrier, we need to adjust the mechanism, reform the management system, and even introduce some laws and regulations to support information exchange.” Interviewee M1 “There are certain related management regulations to rely on in the information sharing and exchange at the city level. That is to say, what conditions must be met to exchange? This exchange is conditional. There are also cases of unconditional sharing and non-exchangeable information.” Interviewee P2
The vertically deployed system causes a barrier	“The provincial government develops some ISs, and Dongtai City government has only the right to use them. The data of some ISs are not available locally. All these need to be coordinated by the government at a higher level. There are also security and privacy issues, which I understand are caused by vertically deployed systems.” Interviewee D1 “Some systems are vertical systems; they are managed vertically by the province or the central government. There are some security restrictions or confidentiality requirements to get their information and data. Even without these problems, They (the data providers) have some concerns.” Interviewee O2 “Some systems are deployed vertically, which do not have an existing interface for COEIS. Instead, we need to coordinate with the superiors to obtain interfaces. We may encounter some setbacks in the process of coordination.” Interviewee M3

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