Construction of an Open Data Service Ecosystem for Major Public Health Emergencies Based on the Citizen Science Model: Postprint

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Abstract

[Purpose/Significance] To address the current dilemmas facing open data for major public health emergencies, including low public attention and participation, poor data utilization, and inadequate platform services, this study introduces a citizen science model to construct an open data service ecosystem, providing insights to break the deadlock in the development of open data for major public health emergencies. [Method/Process] We analyze the main elements and implementation processes of citizen science projects in the context of open data for major public health emergencies, and construct a citizen science operation model. On this basis, we systematically examine key elements such as stakeholders, value creation models, and constraint and promotion mechanisms, to comprehensively construct an open data service ecosystem for major public health emergencies. [Results/Conclusion] This service ecosystem adopts the citizen science model as its basic architecture, with the open data platform for major public health emergencies as the key node. By providing comprehensive service content and targeted institutional constraints and promotion mechanisms, it guides the public, various industry institutions, and professionals to interact and collaborate at the macro, meso, and micro levels, integrating their respective advantageous resources and conducting service exchanges to achieve value co-creation. The research results help improve the social participation and utilization rate of open data, and provide actionable references for the construction of service systems and optimization of service levels on open data platforms for major public health emergencies.

Full Text

Building an Open Data Service Ecosystem for Major Public Health Emergencies Based on the Citizen Science Model

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Abstract:
[Purpose/Significance] In response to the current challenges facing open data initiatives for major public health emergencies—including low public engagement, poor data utilization, and inadequate platform services—this paper introduces the citizen science model to construct an open data service ecosystem, aiming to break the deadlock in the development of open data for major public health emergencies. [Method/Process] The study analyzes the key actors and implementation processes of citizen science projects in the context of open data for major public health emergencies, and constructs an operational model for citizen science. On this basis, it systematically examines critical elements such as stakeholders, value creation models, and institutional constraints and promotion mechanisms, and comprehensively builds an open data service ecosystem for major public health emergencies. [Result/Conclusion] This service ecosystem uses the citizen science model as its foundational architecture, with the open data platform for major public health emergencies as its key node. By providing comprehensive service content and targeted institutional constraints and promotion mechanisms, the system guides the public, various industry institutions, and professionals to interact and collaborate at macro, meso, and micro levels, integrating their respective advantageous resources and engaging in service exchange to achieve value co-creation. The research findings will help improve social participation and utilization of open data, and provide actionable references for open data platforms to build service systems and optimize service levels for major public health emergencies.

Keywords: major public health emergencies; open data; citizen science model; service ecosystem
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Major public health emergencies refer to public health incidents that cause or may cause serious damage to people's lives and property, such as major infectious disease outbreaks, mass food and occupational poisoning incidents, and chemical leaks [1]. From the 2003 SARS outbreak to the 2009 H1N1 influenza

pandemic, and most recently the COVID-19 pandemic that began in 2019, the acceleration of globalization has led to increasingly widespread impacts from major public health emergencies, posing severe challenges to economic development and social stability both nationally and globally. However, thanks to advances in network and big data technologies, the massive amounts of data generated by major public health emergencies are being stored, disseminated, and transformed on the internet, gradually becoming an important basis for governments to conduct epidemic prevention and control, public opinion monitoring, and resource allocation during such events [2]. Simultaneously, driven by both data open sharing policies and the ongoing COVID-19 pandemic, governments at all levels have begun opening major public health emergency data to the public through data platforms, hoping to curb rumors, reduce public panic, leverage social forces to achieve deep data utilization and value creation, and support the governance and prevention of major public health emergencies [3].

Nevertheless, current open data initiatives for major public health emergencies have not achieved the desired results and still face numerous challenges in promotion and implementation. First, although the construction of provincial and municipal data open platforms has been initially completed in recent years, public enthusiasm for data utilization remains low due to inadequate publicity and guidance, coupled with poor data usability [3]. Second, ordinary citizens struggle to independently propose research needs and directly process raw data, and they lack professional research guidance and assistance, resulting in blocked channels for public participation in data utilization and value creation [4]. Most importantly, data opening and utilization cannot be achieved by a single entity alone; they require collaboration among open data platforms, data owners, data users, and data consumers. However, stable and effective collaboration models are currently lacking among these three parties, and most platforms remain at the initial stage of data opening, lacking comprehensive service systems and only providing basic data opening services. These factors collectively prevent the realization of sustained and efficient open data value creation [5].

To break these constraints, this paper introduces the concept of citizen science, aims to create open data value, uses citizen science projects as the means, explores effective pathways for public utilization of platform open data, and constructs an open data service ecosystem for major public health emergencies. Citizen science refers to the participation of non-professional scientists, science enthusiasts, and ordinary volunteers in professional scientific research activities [6]. Under the citizen science model, research teams and the public engage in free collaboration, with researchers leveraging public wisdom to solve "difficult and complicated" problems of social and public concern, while the public enhances their scientific literacy and capabilities through participation in scientific projects, achieving optimal allocation of research resources and creation of public value [7]. This aligns perfectly with the government's original intention of opening major public health emergency data. Therefore, this paper embeds the citizen science model into the context of open data for major public health emergencies, explores models for public participation in data opening, and on

this basis clarifies basic elements such as stakeholders, value creation models, and institutional constraints and promotion mechanisms to build an efficient, sustainable, and open service ecosystem for major public health emergency open data. As a stable, independent, and self-regulating multi-level system [8], the service ecosystem will promote the formation of coupling relationships among different types of participants, guide public and professional research forces to carry out resource integration and service exchange [9], and achieve data value creation for major public health emergencies.

2 Related Concepts

2.1 Service Ecosystem

At the beginning of the 21st century, the rise of the service economy prompted a shift in value creation research perspectives from individual creation to co-creation [10]. S.L. Vargo and R.F. Lusch argued that value is no longer created solely by enterprises and consumed and destroyed by customers, but is instead co-created through interaction between enterprises and customers [11]. They proposed replacing the traditional goods-dominant logic with service-dominant logic (SDL) to guide enterprises in service innovation to maintain their market competitive advantage [12]. Subsequently, with the development of practical environments and the digital economy, service-dominant logic was further expanded and derived, shifting from a "customer experience" perspective focusing on binary interactions [13] to a "service ecosystem" perspective reflecting network-based collaborative interactions among multiple stakeholder groups [8], becoming the main paradigm for value creation research [10].

From a resource perspective, possessing scarce and valuable technologies or resources is the foundation for maintaining individual competitive advantages and participating in group cooperation [17]. In the context of open data for major public health emergencies, governments have accumulated large amounts of critical public health event data but struggle to fully exploit its value [18]; ordinary citizens possess abundant time and cognitive surplus [7] but lack the ability to directly process raw data and conduct independent research; research institutions and enterprises have data development experience and technology but face high difficulty and costs in independently collecting and processing research data [19]. Therefore, to achieve effective utilization of open data for major public health emergencies, all parties urgently need to seek external resource complementarity and cooperation. Additionally, mobile internet innovation and the popularization of smart terminals enable everyone to freely download and process data on open data platforms, becoming resource integrators and potential service exchange partners. Constructing an open data service ecosystem will promote coupling relationships among different types of participants, facilitate communication, collaboration, and resource complementarity, and achieve value co-creation for major public health emergency data [19]. From an organizational perspective, as an intermediate organizational model between hierarchical organizations and markets, the service ecosystem can reduce the investment in

specialized assets and the time and energy costs for public participants and research institutions [10]. Simultaneously, the promotion and constraint institutions within the system can reduce the probability of opportunistic behavior in interactive collaboration and safeguard the smooth progress of service exchange and value creation activities [20]. Overall, to guide the public, research institutions, and other social forces to participate in the integration and sharing of data, technology, and service resources, and to achieve value creation from major public health emergency data, building a complete service ecosystem is imperative.

In summary, exploring a collaboration model that enables social forces to participate in the integration and sharing of data, technology, and service resources, and ultimately constructing a stable, free, and sustainable open data service ecosystem for major public health emergencies, will help solve the many dilemmas facing open data for major public health emergencies and achieve long-term, efficient open data value creation.

2.2 Citizen Science Model

Citizen science is a new form of research crowdsourcing based on group participation and collaboration that evolved from introducing the traditional crowdsourcing model from commercial activities into scientific research [7]. In traditional scientific research projects, research activities are generally completed by professional researchers or teams, with the public playing the role of research subjects and experimental participants, rarely directly participating in the creation and practice of research outcomes [21]. However, as research has become more in-depth, research content has become increasingly complex and refined. Faced with overwhelming research data and variable research objects, more and more scientists and teams have realized that relying solely on their own strength is insufficient to properly handle the endless stream of research tasks [22]. At the same time, the development of network interconnection technology, improvements in education levels, and the need for self-actualization have provided sufficient conditions for the public to directly participate in scientific research activities, leading to the emergence of the citizen science model [23].

In recent years, the citizen science model has been widely applied in research projects across multiple professional disciplines or interdisciplinary fields. These complex research tasks, after reasonable decomposition by researchers, are designed into relatively simple and clear scientific tasks such as data collection, data reporting, equipment sharing, participatory research design, collaborative information analysis, and assisted research and development [7]. The public freely participates in citizen science tasks according to their interests and abilities, contributing to breakthrough innovations in scientific research and the formulation and improvement of public policies [24]. Specifically, in the field of public health and health management to which major public health emergencies belong, exploratory applications and research on the citizen science model have also been conducted, mainly falling into three categories [25]: Medical diagno-

sis and treatment plan research, such as building databases to assist diagnosis and treatment based on endoscopic image data annotated by non-professional volunteers [26], and exploring potential pathogenic factors and disease course changes of allergic rhinitis based on public self-reported data [27]; Personal health management research, such as using patient feedback data to monitor medical product quality [28] and applying public suggestions to personalized health management research for users [29]; Public health governance research, such as mobilizing citizens to collect sample data to assess public health environmental conditions [30], issuing crowdsourcing tasks to aggregate data analyzing tick distribution to provide pest warnings for the public [31], and leveraging netizen power to debunk online rumors during the COVID-19 pandemic to purify the online environment [25]. This demonstrates that introducing the citizen science concept to explore collaborative models for open data value creation for major public health emergencies is both necessary and feasible: Open data platforms for major public health emergencies can use citizen science projects to expand their social influence and solve problems such as low public participation and data utilization; Researchers can leverage platform services and citizen science projects to guide the public in collecting, feeding back, and processing research data, reducing research costs while advancing research and practical applications in the public health field; The public can deepen their understanding of major public health emergencies and improve individual health literacy through participation in citizen science projects. Ultimately, all parties will achieve value co-creation and mutual benefit through communication and collaboration.

Furthermore, existing practical research shows that crowdsourcing (including commercial crowdsourcing, citizen science, etc.) is an important model for linking participants within service ecosystems, promoting resource integration and service exchange, and building network-based interactive collaboration systems to achieve value creation [20]. For example, V. Ramaswamy found through case analyses of companies such as BMW [32] and Mahindra [33] that enterprise platforms can serve as key nodes in service ecosystems, controlling core elements in production and delivery activities, while guiding participant communication and collaboration through "project crowdsourcing" to promote the integration and allocation of resources, knowledge, and skills, and achieve value co-creation with stakeholders [20].

In view of this, this paper introduces the citizen science model as the basic architecture for communication, collaboration, and open data value creation among participants, and uses the major public health emergency open data platform as the key participating node to construct a benign, sustainable, and open service ecosystem.

3 Exploring the Citizen Science Model in the Context of Major Public Health Emergency Open Data

3.1 Actor Classification in Citizen Science Projects

Early citizen science projects generally included three actors: the project sponsor, the platform, and the contractor. However, this model only allowed platforms to provide simple project publishing and data collection services, which could not meet users' practical needs such as citizen science project task design, project promotion, public training, and data curation, let alone address issues like project cold starts, dead loops, and full-process supervision [34]. Therefore, Zhao Yuxiang et al., from an "institutional perspective," proposed adding a fourth actor—third-party organizations—to provide comprehensive service guarantees for citizen science project operations [7]. Considering that governments at all levels have already launched open data platforms that regularly upload public health event data within their jurisdictions, possess data collection, review, and management functions, and can provide some simple data application, feedback, and API interface services, redeveloping citizen science platforms would cause unnecessary resource waste. Based on previous research, this paper integrates the functions of the platform and third-party institutions, with the open data platform assuming both roles, thereby simplifying the inter-actor collaboration network and interaction paths and saving platform development resources while improving project operation efficiency.

In the context of major public health emergency open data, citizen science projects include three actors:

(1) **Research Team (Sponsor)**: Refers to research teams with scientific innovation needs and professional knowledge and skills. Citizen science projects in the context of major public health emergency open data generally have high public welfare and social missions, with maintaining social stability and safety and protecting people's lives and property being important original intentions for their establishment. To fully leverage the role of mass power and collective intelligence in the public health system, rigorous planning and unified management are required, making these projects typically expert-oriented [22]. Research team members may include professionals from multiple fields such as universities and research institutes, medical institutions, government departments, technology enterprises, and news media.

(2) **Major Public Health Emergency Open Data Platform (Platform, Third-party Institution)**: Refers to the online medium through which research teams and volunteers cooperate to carry out citizen science projects. In this paper, the open data platform not only needs to collect and integrate public health data and open it to the public for free but also needs to provide research teams and volunteers with various services including citizen science project task design, project promotion, skills training, communication, and results incubation and promotion to ensure

the smooth implementation of citizen science projects.

(3) **Volunteers (Contractors)**: Refers to the public who voluntarily join citizen science projects driven by different motivations. They themselves mostly do not possess professional research literacy or backgrounds in public health fields and need to receive skills and knowledge training before participating in project content and complete research tasks under the guidance of researchers.

3.2 Implementation Process of Citizen Science Projects

In the context of major public health emergency open data, volunteers can undertake various tasks in citizen science projects including data collection, data analysis, data feedback, equipment resource sharing, and results promotion [7]. These citizen science projects can be categorized from shallow to deep participation levels as contributory, collaborative, and co-creative [35], or based on the value density of volunteer feedback results as non-emergent, quantitative emergent, and qualitative emergent [7]. However, overall, these citizen science projects follow similar implementation processes, roughly divided into three stages: pre-implementation, mid-implementation, and post-implementation [22]. In the context of major public health emergency open data, research teams, open data platforms, and volunteers interact and collaborate to jointly carry out citizen science projects. The specific implementation process is shown in Figure 1 [Figure 1: see original paper]:

(1) **Pre-implementation Stage**: All project participants mainly carry out project and resource preparation work. For example, research teams need to identify targeted research questions focusing on the progress of current major public health emergencies and public concerns, while simultaneously assembling research teams with professionals in data, medical, design, and other fields, applying to the open data platform to access relevant data needed for the research, and formally initiating the research project. The major public health emergency open data platform needs to timely collect relevant data accumulated by government departments during public health emergency response, while also aggregating multi-source heterogeneous data provided by all sectors of society to the government. After removing confidential data and performing data desensitization, the platform describes, labels, and categorizes the data according to unified standards. The integrated standardized data is then opened on the platform, and users are provided with search indexes, data API interfaces, applications, and other functions [36]. Additionally, at this stage, the volunteer actor has not yet formed but remains hidden among the public, maintaining attention to public health emergencies and potentially transforming into volunteers driven by different motivations after the official release of citizen science projects.

(2) **Mid-implementation Stage**: Citizen science projects are officially

launched, and communication and collaboration among actors become frequent. First, research teams break down and simplify research projects into a series of fine-grained tasks and formulate implementation rules for each task, including research methods, public participation approaches, and data submission formats [22]. Subsequently, these task rules are refined into requirements and submitted to the open data platform, which needs to design each task based on existing technical conditions and resources until it reaches a level that is easy for the public to accept and operate before it can be officially launched, promoted, and allow the public to register as volunteers for citizen science tasks based on their interests. However, before officially processing, analyzing, and uploading task data, volunteers need to complete training courses specifically designed for the task through the platform to ensure task completion efficiency and quality. Finally, research teams review and organize the volunteer task data collected and stored by the platform to lay the foundation for achieving research objectives.

(3) **Post-implementation Stage**: Citizen science projects move to results output and application. At this stage, research teams leverage public power and wisdom to reach final results or conclusions. These results are mainly released on the platform in the form of reports, papers, and data, or incubated into applications usable by the public with the help of the platform, contributing to the prevention, control, and governance of major public health emergencies. The public can also provide feedback and data to the platform after using project results or applications, for research teams to later optimize project outcomes and assess project social impact.

3.3 Citizen Science Model in Major Public Health Emergency Open Data

Based on clarifying the actor elements and implementation process of citizen science projects, this paper constructs a citizen science model for major public health emergency open data, as shown in Figure 2 [Figure 2: see original paper]:

In the context of major public health emergency open data, citizen science projects include three entities: research teams, major public health emergency open data platforms, and volunteers. However, the actor classification and implementation process do not fully reveal the complete context of citizen science project operations and the details of interaction and coordination among entities. This paper further refines three weak entities (which can depend on strong entities or serve as attributes of strong entities [7])—citizen science tasks, data, and results—within the relationships among the original three entities. As shown in Figure 2, the entire citizen science model unfolds with the major public health emergency open data platform at its core. The three strong entities aim to produce results as their ultimate goal, use data as operational resources, and employ citizen science tasks as implementation means. They interact and collaborate with each other, forming ten important relationships among the six

entities: Research teams and platforms respectively complete the formulation and design of citizen science task implementation rules; Platforms call corresponding major public health emergency raw data according to citizen science task requirements; Platforms publish and promote citizen science tasks through network channels; Volunteers register for citizen science tasks on the platform, and platforms provide training based on task content; Volunteers analyze major public health emergency data according to task requirements and upload it to the platform; Platforms open major public health emergency data to the public and manage and protect various data uploaded by research teams and volunteers; Research teams submit applications and requirements to the platform and maintain communication during project implementation; Research teams produce citizen science project results and conduct evaluation and optimization based on results application; Volunteers use project output results and provide feedback on experience data and suggestions; Research teams, platforms, and volunteers collaborate to complete citizen science projects and jointly incubate project results.

This model reveals the forms and processes through which ordinary social citizens and professional research forces participate in major public health emergency data utilization and value creation, clarifies the core position and multiple roles of the major public health emergency open data platform in citizen science project operations, and provides a basic structure and coordination mechanism for all forces to participate in major public health emergency data value creation activities. At the same time, this model will also provide references for clarifying stakeholder relationships and value creation models, as well as designing platform service content and institutional constraint and promotion mechanisms. Overall, the research will promote the construction of a relatively independent and self-driven major public health emergency open data service ecosystem.

4 Building an Open Data Service Ecosystem Based on the Citizen Science Model

4.1 Stakeholder Analysis of the Open Data Service Ecosystem

In a service ecosystem environment, resource integration and service exchange activities eliminate the strict boundaries between traditional value creators (enterprises) and value consumers (customers), making all system participants stakeholders [10], whose roles continuously change with context and behavioral strategies [37]. Therefore, before formally constructing the service ecosystem, this paper will analyze the composition of stakeholders and their role evolution paths in the system's interactive structure based on the citizen science model for major public health emergency open data, as shown in Figure 3 [Figure 3: see original paper].

Stakeholders are distributed across various hierarchical structures of the ecosystem, connecting and transforming with each other to complete value creation and distribution. In the outermost macro environment, stakeholders include

three categories: institutions and practitioners in research, government, enterprise, medical, news, and other fields; government emergency management departments responsible for major public health emergency governance; and the general public. All major public health emergencies occur within the macro social interaction network formed by these three types of stakeholders, making them both direct producers of major public health emergency data and potential participants and beneficiaries of data value creation. In the macro environment, some stakeholders are driven by different motivations to gather in the meso environment, with their roles correspondingly transforming. Among them, government emergency management departments, in response to national data opening policies and to improve the emergency management system with social forces, launch major public health emergency open data platforms. Professional institutions and practitioners register as professional users on the platform to conduct research using data, while social citizens join the platform as ordinary users to understand health event progress and achieve self-actualization.

In the meso environment, platforms can provide various services and resources including raw data, task design, project training, and data management, forming a ternary interactive structure that bridges different users. The platform is both the main resource and service provider in the system and the key to promoting loosely coupled associations among other participants. With the platform's connectivity, some individuals in the professional user group gather around health event data research questions or common goals to form different research teams; ordinary users freely choose to join one or more citizen science tasks released by research teams based on their interests and preferences, becoming volunteers who directly participate in open data value creation.

In the micro environment, research teams and volunteers engage in binary interactions around major public health emergency data in citizen science projects, achieving the fundamental goal of data opening and serving as the core actors for value creation in the entire ecosystem. However, it should be noted that resource integration and service exchange between these two parties are still built upon the service support provided by the open data platform, making the open data platform also a key participant in core value creation activities.

4.2 Value Creation Model Analysis of the Open Data Service Ecosystem

In service ecosystems, stakeholders are key components and actors, while value creation is the driving force and ultimate goal of system operation, representing the fundamental meaning of the entire service ecosystem's existence [12]. In the context of open data for major public health emergencies, research teams and volunteers use the open data platform as a key medium, engage in resource integration and service exchange around citizen science projects, and constitute the core value creation model of the service ecosystem.

As shown in Figure 4 [Figure 4: see original paper], the major public health emer-

gency open data platform mainly provides research teams with raw data from databases and various services related to conducting citizen science projects, and provides volunteers with timely information on public health events, promotion of citizen science projects, and knowledge and skills training services related to citizen science projects. Volunteers respond to recruitment for citizen science projects on the open data platform, contribute their time and energy to participate in research teams' citizen science projects, and provide feedback on usage experience data to the platform. Research teams, during project implementation, use the platform to guide volunteers in conducting research work and provide them with incentive guarantees, sharing research results and data with the platform after completing research.

After a series of resource integration and service exchange activities, the open data platform, research teams, and volunteers have all created value for each other, achieving comprehensive value co-creation. Among them, volunteers improve their health literacy and personal protection capabilities while learning about event information and participating in project training and research, and can also receive material and spiritual rewards; research teams successfully solve scientific problems and reduce research costs with the assistance of the open data platform and volunteers, and their research results can be incubated and applied to achieve higher social utility; the major public health emergency open data platform not only expands its database content with feedback from research data but can also collect user feedback to drive platform service optimization and innovation, and use citizen science project results to assist government decision-making and improve the emergency management system.

Additionally, other stakeholders in the meso and macro environments will serve as value creation facilitators and recipients [37], providing necessary resources and assistance for core value creation activities while enjoying the value spillovers and services brought by value creation. For example, government emergency management departments provide data, policy, and financial support for meso and micro interactions; professional institutions provide research facilities, research suggestions, and technical support for citizen science projects; the public spontaneously uploads public health event-related data on the open data platform to provide data resources for citizen science projects. Ultimately, the resolution of research problems, the development of innovative applications, and the optimization and development of the open data platform will provide beneficial feedback, assist in public opinion and rumor governance, improve public health and scientific literacy across society, and solve prevention and control problems of public health emergencies.

4.3 Open Data Platform Service System Based on Stakeholder Needs

According to the five-level maturity model for data opening, most domestic data open platforms remain at the second and third levels of "data website" and "data portal" stages [5], showing a significant gap from the higher-level "data ecosystem" in terms of service system and data opening and application maturity.

At the same time, the major public health emergency open data platform is the core actor in the citizen science model and the key participant and main service provider in the service ecosystem. While various actors frequently use the open data platform to carry out resource integration and service exchange work, they also pose differentiated demands on the platform's functions and services. Existing research shows that targeted and systematically designed service platforms in service ecosystems can effectively enhance the value density after resource integration and the efficiency of service exchange, thereby influencing final value creation and service innovation activities [38]. Therefore, based on sorting out the needs of various participants, this paper refines and constructs a major public health emergency open data platform service system following a "needs-functions-system" sequence. This will improve the details of multi-party interaction in the service ecosystem while providing actionable references for platform service function design and improvement in later practice.

As shown in Table 1 , the entire major public health emergency open data platform service system can be roughly summarized into the following ten aspects: Account management: providing new and existing users with account registration, settings, and management services; Data opening: collecting and integrating various major public health emergency data within reasonable scope and opening it to all users; Project management: assisting research teams and volunteers in handling project-related affairs such as submitting project requirements, assisting task design, and participating in research tasks; Data curation: providing users with upload, download, collection, storage, and maintenance services for various data; Training and guidance: providing volunteers with basic knowledge and skills training for projects and answering various questions users have during platform usage; Social communication: providing functions and platforms for communication among project members and between different users; Promotion: promoting excellent projects or results in channels reachable by the platform to expand social influence; Intelligent recommendation: providing intelligent algorithm recommendations based on research team needs and volunteer preferences to optimize coupling efficiency and practical results; Results incubation: using platform resource advantages to assist excellent project results in transformation and application; Feedback: providing channels for users to express their views and suggestions to promote results optimization and service improvement.

4.4 Institutional Constraint and Promotion Mechanism Design

In service ecosystems, institutions operate at every level of the system, constraining the ordering and standardization of value creation activities while coordinating and promoting interaction and cooperation among participants, making them one of the key factors ensuring the stable operation of the ecosystem [16]. S.L. Vargo and R.F. Lusch define institutions as relatively independent norms, laws, symbols, rules, and processes that can promote and constrain participant behavior [15], while institutional mechanisms (institutional arrange-

ments) are collections of interrelated institutions [10]. To promote data opening and public participation and build a benign, sustainable, and open data service ecosystem, it is necessary to clarify various factors that can constrain and promote value creation activities. Essentially, open data value creation for major public health emergencies can be regarded as an organizational innovation behavior. According to the TOE (Technology-Organization-Environment) theoretical framework, technology (government IT level, technical support, technology availability, etc.), organization (government organization, decision-maker support, and funding, etc.), and environment (legal policies, institutional standards, public participation, etc.) are three major factors affecting organizational innovation [39]. These three factors are interrelated and mutually restrictive, jointly determining the efficiency and outcomes of innovation behavior. With the rise of government open data movements, scholars have attempted to use TOE theory to explore obstacles and incentives for open data utilization [40]. Therefore, based on the characteristics of value creation activities under the citizen science model and objective factors hindering their implementation, this paper attempts to construct institutional constraint and promotion mechanisms for major public health emergency open data service ecosystems from three dimensions: technology, organization, and environment.

(1) Institutional Constraint Mechanisms. At the technical level, first, it is necessary to unify open data formats and standards for major public health emergencies, break down "information silos" and "information gaps," improve technical compatibility between different platforms, and reduce the difficulty of public data value-added utilization and value creation. Second, it is necessary to improve the programmatic management level of the citizen science model, using computer technology to encapsulate operations related to the citizen science project implementation process into fixed procedures, standardizing the value creation process for major public health emergency open data, and protecting the rights and interests of all parties involved in potential sensitive issues such as national security, data confidentiality, and public privacy. At the organizational level, first, top-level design planning should be strengthened to establish a top-down network of public health data functional institutions with organization, coordination, and management functions to ensure the orderly progress of data opening and utilization work. Second, a responsibility system needs to be clarified, defining the authority of various departments in public health data development, incorporating data opening service quality into departmental and personnel performance evaluation and assessment to avoid phenomena such as responsibility shirking and formalism. At the environmental level, first, public health data opening review rules need to be improved. To adapt to platform opening of major public health emergency data, it is necessary to formulate public institution data resource inventories and data opening catalogs, optimize existing non-differentiated review mechanisms, improve data review efficiency, and ensure open data quality. Second, legislation in the public health data opening field needs to be promoted. The current lack of targeted laws makes it difficult to reconcile contradictions and protect rights and interests among

participants in data opening value creation, urgently requiring clarification of the rights and obligations of data openers and data developers from a legal perspective.

(2) Institutional Promotion Mechanisms. At the technical level, first, open data platform construction should be optimized. Considering that technology is an important factor driving service innovation in service ecosystems and that the major public health emergency open data platform is an important hub for resource integration and service exchange in the system, it is necessary to learn from advanced domestic and international experience and technology to optimize platform database capacity, hardware facilities, and operational capabilities to enhance user experience and work efficiency. Second, supporting technical talent system construction should be strengthened. The proposal of the citizen science model and the construction of a new service system pose new challenges to service personnel of existing major public health data open platforms, requiring timely updates of their technical capabilities according to user needs and contextual changes. At the organizational level, first, the guiding role of government departments should be leveraged. In the initial introduction of the citizen science model, cold start problems are often faced, requiring government departments and open data platforms to exert subjective initiative to actively guide the participation of research-capable teams and ordinary citizens, gradually cultivating users' interest and habits in participating in major public health emergency data value creation. Second, policy and funding inclination toward data value creation activities needs to be strengthened. Since citizen science projects usually have strong public welfare and social attributes, requiring high self-drive from research teams and volunteers, material and spiritual rewards from the government and platform for projects with high social attention and practical significance can effectively enhance the enthusiasm of all parties in organizing and participating in citizen science projects. At the environmental level, first, public participation in open data should be improved. The public is both the producer of major public health emergency data and the ultimate beneficiary of data value. Public participation, feedback, and suggestions are indispensable for improving platform service systems, optimizing project research results, and even formulating macro public health policies. However, due to limited interaction channels between government and the public and insufficient public awareness of data needs, public participation has long remained at a low level, hindering the value realization process of public health emergency data [39]. Second, property rights protection regulations need to be improved to promote results incubation and application. Since value creation activities in the service system involve multiple actors including the public, platform, and teams, policies need to clarify the ownership of final scientific research results among all parties to reduce potential disputes. Additionally, major public health emergency open data platforms have significant advantages in results application and practice, providing results incubation services for research teams to effectively shorten the time for them to benefit society and solve social problems.

4.5 Major Public Health Emergency Open Data Service Ecosystem

Based on clarifying the citizen science operation model in the context of major public health emergencies, this paper systematically examines key elements such as stakeholders, value creation models, and institutional constraints and promotion mechanisms, and comprehensively constructs an open data service ecosystem. The system mainly consists of three interactive structures at micro, meso, and macro levels, as well as institutional constraint and promotion factors, covering the entire process from data generation, collection, integration, and opening to value creation, utilization, and feedback. Major participants such as open data platforms, the public, and personnel from various industry institutions interact and associate within the system, integrating their advantageous resources through citizen science projects as the means, engaging in service exchange and complementarity to achieve co-creation of open data value, as shown in Figure 5 [Figure 5: see original paper].

At the **micro level**, research teams and volunteers form loosely coupled associations based on the common goal of creating value from major public health emergency open data, distinguishing themselves from other users outside the project. During project operations, volunteers contribute their time and energy, while research teams provide professional research guidance and external incentive measures. The binary interaction between them constitutes the basic unit of value creation activities in the entire service ecosystem and is the key prerequisite for producing project results and achieving value transformation and distribution.

At the **meso level**, stakeholders mainly include several micro environments as well as three categories: the major public health emergency open data platform, professional users, and ordinary users. Among them, research teams in the micro environment are mainly formed by some professional users focusing on specific health event data research questions, while volunteers are transformed from ordinary users who voluntarily join citizen science projects. Therefore, both can also be regarded as specific identity labels for meso users in specific micro contexts. At the same time, due to the differentiation and complementarity of stakeholders' core capabilities and resources in the service ecosystem, users need to rely on the open data platform to indirectly achieve binary interaction and cooperation with other users, both in meso and micro environments, thereby forming a ternary interactive structure with the open data platform as the interaction hub. In this structure, the open data platform integrates its advantageous resources to build a complete service system, providing comprehensive services including user management, data opening, project management, and social communication for all participants to prepare, launch, and participate in citizen science projects, while receiving value feedback from all parties and ultimately achieving comprehensive value co-creation.

At the **macro level**, the scope of stakeholder groups further expands, with industry institutions and their practitioners, government emergency management

departments, and even the entire public being incorporated into the interactive network of the service ecosystem. However, due to relatively loose connections among stakeholders in the macro interactive network and the lack of unified coordination and guidance, resources and services cannot be effectively integrated and exchanged. Therefore, in most cases, stakeholders in the macro environment only exist as facilitators and beneficiaries of value creation activities, indirectly providing various resources and services such as raw data, financial support, equipment sharing, and technical guidance for major public health emergency data value creation activities, while enjoying the value spillovers and services brought by value creation. Only some macro stakeholders, driven by different motivations, gather in the meso environment to become ordinary or professional users and potential direct participants in value creation activities.

Additionally, to ensure the overall stable operation of the service ecosystem, it is necessary to construct targeted institutional constraint and promotion mechanisms from three aspects: technology, organization, and environment. For example, by unifying data opening formats and standards, improving programmatic management levels of citizen science projects, strengthening top-level design planning, clarifying responsibility systems, improving review rules and laws and regulations in the public health data opening field to constrain the orderly and standardized conduct of value creation activities; and by focusing on optimizing open data platforms and technical talent system construction, strengthening government guidance, increasing policy and funding support, improving public participation, and promoting results incubation and application to coordinate and promote interaction and cooperation among participants.

Overall, the three interactive structures of the major public health emergency open data service ecosystem are interconnected, and the roles of internal stakeholders also change and evolve with the continuous deepening of value creation activities. The citizen science model serves as the basic architecture for value co-creation activities, linking platforms, data developers (research teams and volunteers), and other stakeholders, while also defining resource integration methods and service exchange paths for all participants, constituting the core value creation model of the service ecosystem. Under this model, major public health emergency data produced in the macro environment is collected, integrated, and opened through meso-level open data platforms, and ultimately participates directly in micro-level core value creation activities as key resources. In addition, financial, technical, and equipment support provided by the macro social network, as well as user data, will indirectly promote resource integration, service exchange, and results application optimization activities at meso and micro levels. In return, value content such as citizen science project results and user feedback created at the micro level is transformed at the meso level into innovative applications, research data, service innovation, and other forms, playing roles in multiple macro social domains such as preventing and controlling major public health emergencies, building professional public health intelligence, formulating emergency management policies, and governing public opinion and rumors. Ultimately, a cross-level resource, service, and value exchange cycle structure is

formed, which will ensure that the entire service ecosystem achieves self-driven and continuous cycling without external strong intervention constraints.

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Author Contributions

Xue Xiang: Paper writing and revision;
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Building Open Data Service Ecosystem of Major Public Health Emergencies Based on Citizen Science Mode

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Abstract: [Purpose/significance] At the present stage, the data opening of major public health emergencies is faced with many difficulties, such as low public participation, poor data utilization, and imperfect platform services. This paper introduces the citizen science mode to build an open data service ecosystem, aiming to provide ideas for breaking the deadlock in the development of open data on major public health emergencies. [Method/process] This paper analyzes the main elements and implementation processes of citizen science projects in the context of open data on major public health emergencies, and explores the citizen science operation mode. On this basis, it systematically sorts out key elements such as stakeholders, value creation mode, constraints and promotion systems, and comprehensively constructs an open data service ecosystem for major public health emergencies. [Result/conclusion] In this service ecosystem, the citizen science mode is the infrastructure, and the open data platform for major public health emergencies is the key node. By providing all-round service contents, targeted system constraints and promotion mechanisms, this system guides the public, various industry institutions and professionals to interact and cooperate at the macro, meso and micro levels, integrate their own advantageous resources, and carry out service exchange to achieve value co-creation. The results of this paper will help to improve the social participation and utilization of open data, and provide an action reference for the construction of service system and optimization of service level of open data platform for major public health emergencies.

Keywords: major public health emergencies; open data; citizen science mode; service ecosystem

Note: Figure translations are in progress. See original paper for figures.