Strategic Study of CAE 2022 Vol. 24 No.4
DOI 10.15302/J-SSCAE-2022.04.005

A New Pattern Framework and Innovative Practices in the Smart Court System-of-Systems Engineering Project of China

Xu Jianfeng[1], Sun Fuhui[1], Chen Qiwei[1], Wang Yingfei[1], Yu Jia[1], Liu Zhenyu[2]

1. Information Technology Service Center of People' Court, Beijing 100745, China
2. School of Information Management for Law, China University of Political Science and Law, Beijing 100088, China

Abstract: Developing large-scale complex information systems, such as the "Smart Court" system-of-systems (SoS) in China, is an engineering challenge worldwide. This paper aims to expound on the theoretical construction and practical progress of China's Smart Court system-of-systems engineering (SoSE) from a methodological perspective. Herein, the concept and key task requirements of SoSE are explored, the technical difficulties faced by the Smart Court SoSE are analyzed, and a "two-track parallel, six-ring linkage" pattern framework is proposed for a progressive and collaborative SoSE approach for large-scale autonomous information systems. Based on theories, including a universal information model, information metric system, and dynamic configurations of information systems, a key evaluation indicator system for the information SoS is proposed. To satisfy the SoSE design requirements, an overall design method based on information relationships and corresponding enabling tool are proposed, and a reference model for the Smart Court SoS is designed to provide a top-level reference for system development and integration of the Smart Court. Moreover, the development and collaborative integration of the autonomous and backbone systems in Smart Court SoSE are presented comprehensively. The nationwide application and promotion of the Smart Court SoS support the upgrade and transformation of the conventional judicial operation pattern of people's courts in China. Through continuous analyses of the quality and effectiveness of the Smart Court based on key evaluation indicators, targeted improvements can be made to further enhance SoS capabilities, thereby contributing to the progress in judicial civilization in the information age.
Keywords: smart court; system-of-systems engineering; judicial informatization; information theory; progressive collaboration

1 Introduction

Systems engineering (SE) has been applied to the development of large-scale systems in practice for a long time [1]. In the new century, information science and technology have brought significant benefits to SE. A larger-scale system composed of a series of complex systems, referred to as a system-of-systems (SoS), is receiving increasing attention [2–4]. System-of-systems engineering (SoSE) is an engineering implementation process for combining multiple systems with independent operations, independent management, different location distributions, emergent behaviors, and gradual developments. This not only maintains their respective independence but also realizes additional and strong capabilities for the entire system [5]. Undoubtedly, SoSE can inherit many mature concepts and methods of SE. However, as SoSE faces more difficult and complex problems [6], it is necessary to further enrich and deepen the related theories and methods to effectively solve the main problems, such as those

Received date: April 19, 2022; **revised date:** June 3, 2022
Corresponding author: Liu Zhenyu, associate professor of School of Information Management for Law, China University of Political Science and Law. Major research field is judicial information management. E-mail: lzhy@cupl.edu.cn
Funding program: The National Key R&D Program of China (2021YFC3340105)
Chinese version: Strategic Study of CAE 2022, 24 (4): 105-120
Cited item: Xu Jianfeng et al. A New Pattern Framework and Innovative Practices in the Smart Court System-of-Systems Engineering Project of China. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2022.04.005

concerning integration, sharing, coordination, evaluation, and optimization, when various complex systems converge to form an SoS.

In the information age, it has become a common trend to integrate or use different types of information systems to build a large-scale system. Therefore, it is crucial to study and solve the complex problems faced by information SoSE for applications in advanced information technologies and the promotion of modernization in all walks of life. (1) It is necessary to inherit and draw lessons from the mature methods of traditional SE, such as those in planning, research and development, standardization, modeling and simulation, testing and evaluation, and project management. This will facilitate the construction of a feasible, scientific, and efficient SoSE pattern framework according to the characteristics of the domain-specific SoS, including their compositions, structures, scales, objectives, and capability evolutions. (2) It is imperative to develop key performance indicators for specific fields according to universal information metrics and dynamic configurations of information systems. These should be based on a theoretical foundation of information science and the operation mechanisms of information systems to provide benchmark guidance for the analysis, implementation, and evaluation of SoSE, thereby leading to improvements in overall construction effectiveness. (3) For large-scale complex SoSE, there is a need to establish a set of design methods to effectively bridge the gap between SoS integration and individual system development. This should be performed by accurately expressing and maintaining the various information relationships between different systems but without becoming bogged down by tedious details. (4) It is essential to establish a balance between the development of the various individual systems and the integration of the large-scale SoS by reasonably allocating tasks. This is to optimize the overall performance of an SoS in response to the basic requirements of SoSE and integrate the various systems to achieve a wide range and a high level of sharing and collaboration. (5) With the expansion of an SoS, it is important to reshape the original business model in an all-around way so that the capacity and effectiveness of the SoS as a whole can be improved from local to global, short-term to lasting, and relatively simple ideal settings to complex practical environments. This can be accomplished through a continuous quality-effectiveness analysis with key performance indicators and popularization to achieve a good state concerning its stability, universality, long-term operation, continuous evolution, and continuous improvement.

In traditional SE, the primary task is to design an optimal system. In contrast, the primary task of SoSE is to correctly apply new and old technologies from various systems to achieve the overall goal(s) of an SoS through various system interactions [7–10]. The ideas and methodologies of SoSE have been widely studied and applied in many fields [11–14]. Examples include the Department of Defense Architecture Framework (DoDAF) and British Ministry of Defence Architecture Framework for architectural designs [15], combinatorial solutions and control processes for system resource allocation and optimization, multi-objective decision-making and evaluation under uncertainty [16,17], solutions for the interoperability of systems [18,19], and development of relevant tools for system modeling and simulation [20–22]. All of these have contributed significantly to the theoretical enrichment and practical development of SoSE. However, most current SoSE studies regard SoS as a controlled group with unified mission objectives and management. Thus, although the design and implementation of a complex SoS are relatively simple, certain key problems remain unaddressed.

In fact, many real-world systems have the characteristics of independent operation, different goals, and loose management when they join an SoS. Such systems are referred to as autonomous systems. The existence of many autonomous systems is a complex characteristic of SoSE. In information construction applications, such as in smart cities and smart societies, the development of an SoS comprising large-scale complex autonomous systems, to continuously improve the business collaboration capabilities of the entire SoS, is a common problem. We refer to this approach as progressive cooperation SoSE (PCSoSE). Given the above, there is an urgent need to explore and develop more targeted theories, methods, and tools for PCSoSE to meet the growing demands for system interconnection, information exchange, data sharing, intelligent assistance, and operational linkages within and between information systems in all walks of life.

The construction of China's Smart Court involves tens of thousands of autonomous information systems at all levels countrywide and represents a typical PCSoSE to share, link, and collaborate. Some studies have analyzed the background, development process, key issues, judicial effectiveness, and future direction of the Smart Court from the perspectives of law and social sciences [23,24]. However, relatively few studies have considered the engineering logic of science and technology in the development of China's Smart Court. The persons responsible for China's Smart Court have provided a valuable summary of their work [25]. However, this summary focuses on practical guidance but lacks analysis and elaboration on the academic principles.

DOI 10.15302/J-SSCAE-2022.04.005

This paper focuses on introducing and elaborating on the practice of the Smart Court SoSE from a methodological perspective. We analyze the key technical difficulties faced by the Smart Court SoSE and propose a PCSoSE pattern framework and key performance indicators for information SoS. We also describe a top-level reference model of Smart Court SoS for information system development and SoS integration, as well as comprehensively explain the three most important entity constructions in the Smart Court SoSE: autonomous system development, development and promotion of backbone systems, and collaborative SoS integration. In addition, we show the time series change curves of certain key performance indicators through a continuous quality and effectiveness analysis and system optimization and then epitomize some remarkable judicial achievements through the popularization and application of the Smart Court SoSE.

2 Requirements, pattern, and key issues of the Smart Court system-of-systems engineering (SoSE)

2.1 Construction requirements

The range of information systems developed in the Smart Court SoS project covers all the constituent organs of the people’s courts at all levels nationwide. The types of information systems include operational applications, data resources, infrastructures, information security, and maintenance support. In terms of applications, the information systems support all operations including litigation services, trial, enforcement, and management. They are accessible at the desktops of all judges in the courts across China through a variety of networking connections, and serve the public of China and users worldwide, thereby achieving the goal that “the whole operation is performed online, the whole process is open according to law, and all-round intelligent services are provided.”

The difficulty and complexity of the Smart Court SoSE project are embodied in the following aspects: (1) the scale of the SoS is very large; (2) spatial distribution is vast; (3) tasks and objectives of the different autonomous systems vary; (4) duration of existence for each system is different; (5) technical architecture is heterogeneous; (6) department coordination can be obstructed; (7) information silos are rampant; and, (8) demands for intelligent techniques are urgent. In particular, as a result of financial management regulations, the funds for the system construction of the People’s Supreme Court and local people’s courts must be used separately. This naturally forms a basic pattern of separate construction, independent operation, and decentralized management of the information systems for different courts. In principle, courts at different levels are first responsible for the development of their own information systems to meet the requirements for the tasks and objectives of the courts in the corresponding jurisdiction. Only within their capacities can the lower-level courts provide corresponding information and capacity support in accordance with the technical and management requirements of the higher courts. Therefore, these information systems can be regarded as typical autonomous systems in nature.

Along with active innovations and developments in various autonomous systems by courts at all levels, especially at higher levels, the basic requirements of the Smart Court SoSE project further include activities such as establishing engineering guidance through development planning, overall design, technical standards, and testing and evaluation, popularizing mature technologies, backbone systems, and other advanced products, integrating tens or even hundreds of thousands of large-scale autonomous information systems to continually improve the collaboration capabilities of system interconnection, information exchange, data sharing, intelligent assistance, and operation linkage inside and outside the system. Together, these activities can achieve an organic unification with order and vitality.

2.2 Pattern framework

According to engineering requirements, a PCSoSE pattern framework, denoted as “two-track parallel, six-ring linkage” was proposed for the development of the Smart Court, and it is shown in Fig. 1.

The two-track parallel is a decomposition of the most important construction entities in the SoSE. Implementation of the Smart Court SoSE must include the development of various autonomous systems by courts at all levels in the country. However, the key to the SoS level is the integration of these different systems to achieve a wide range and high level of sharing and collaboration. The focus of the Smart Court SoSE should be on an overall and global capability evolution from beginning to end, rather than on specific implementation details of the autonomous systems. Therefore, the construction of entity systems can be divided into two parallel tracks: autonomous system development and collaborative system integration. (1) Autonomous system construction, i.e., the lower track, is the physical basis of the SoSE. Courts at all levels are in charge of the development and optimization of a variety of information systems, such as those for infrastructure, operation applications, data resources, network security, and operational maintenance. (2) The main goal of the integration of collaborative SoS, i.e., the upper track, is to improve the operation collaboration capability. In this track, tasks such as infrastructure, data, knowledge, application, service, and portal integrations are performed to continuously improve the levels of system interconnection, information exchange, data sharing, intelligent assistance, and operational linkage between the inside and outside of the SoS. The tasks of the upper track are mainly performed by the Supreme People's Court. The directional arrows of the two tracks indicate that the development and integration of the physical systems cannot be accomplished in a short time; rather, the two processes move forward dynamically, and hand-in-hand. The various collaborative capabilities of the entire SoS cannot all be in place at once, but rather gradually evolve, expand, and improve over a long period of development and integration.

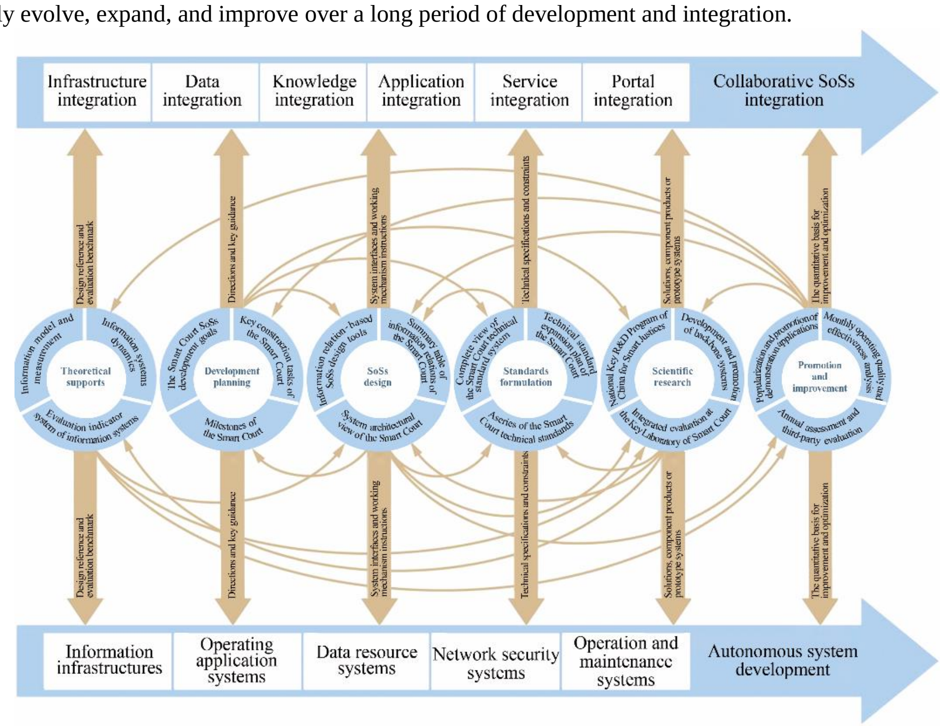


Fig. 1. "Two-track parallel, six-ring linkage" progressive collaboration system-of-systems engineering (SoSE) pattern framework for the Smart Court of China.

Moreover, the six-ring linkage plays a leading and driving role at the top level between autonomous system development and collaborative SoS integration. It includes six key links: theoretical support, development planning, system design, standards formulation, scientific research, and promotion and improvement, thereby highlighting the engineering characteristics of the interactions in the SoSE. Further details are provided as follows. (1) Theoretical support involves the establishment of a performance indicator system for information systems based on a general information model, information metrics, and dynamic configurations of information systems to provide a design reference and evaluation benchmark for related development and integration. (2) Development planning establishes medium- and long-term development goals, key tasks, and milestones for the Smart Court information SoS at the top level, providing directions and key guidance for the related development and integration. (3) The SoS design applies information relationship to describe, display, and maintain the various information relationships among the main information systems of the Smart Court with visual design tools, aiming to provide detailed system interfaces and working mechanism instructions for related development and integration. (4) The formulation of standards inherits the mature methods of SE and provides technical specifications and constraints for related development and integration through a series of means such as a complete view of a technical standards system, a standards expansion plan that keeps pace with the times, and specific technical standard documents. (5) The scientific research link conducts studies and experiments in advance for key and difficult technical problems of the SoSE to provide solutions, component products, or prototype systems meeting the requirements for technological maturity for related development and integration. (6) The promotion link chooses the demonstration systems with obtained remarkable results to promote them to the courts nationwide. Meanwhile, the actual operation data of various information systems are collected and gathered according to a key performance metric system to continuously monitor, analyze, and evaluate the operation quality and effectiveness of the entire SoS,

DOI 10.15302/J-SSCAE-2022.04.005

thus providing a quantitative basis for the improvement and optimization of related system development and integration.

2.3 Key issues

2.3.1 Basic theories on information measurement

It is generally known in modern engineering methodology to use quantitative evaluation indicators to measure construction achievements. In the field of information technology, information metrics based on entropy have laid the theoretical foundation for information science [26–28]. However, it is difficult for these metrics to meet the broader requirements for the design of systems, as well as those for the analysis of the information volume, diversity, authenticity, and so on, in modern information system engineering. Information entropy is a metric for measuring information uncertainty in the process of communications and is thereby limited to the measurement of information uncertainty. Consequently, many other information metrics have been explored. For example, there are abstract, realistic, and experimental construction metrics in the general information theory [29], along with an information richness metric [30], information granularity metric [31], and information credibility metric [32]. There are other metrics for information timeliness, popularity, and the degree of satisfaction with user needs [33]. In addition, various related metrics have been proposed based on the needs of engineering practice. For example, there are the famous 5V metrics for big data, i.e., volume, velocity, variety, value, and veracity [34].

However, the aforementioned studies each focused on a certain measurement of information from a specific perspective and thus have difficulty meeting the needs of developing and promoting complex information SoSE. The underlying reason for the lack of a clear and comprehensive information metric system is the absence of a universally recognized mathematical foundation for the concept of information. Furthermore, there is no scientific and rational framework for the information space or clear analytical approach to the efficacies of information actions. All these have become key issues affecting the rational research paradigm of information science, which further restricts the development of large-scale PCSoSE with autonomous information systems.

2.3.2 Methods and tools for SoS design

Once the evaluation indicators and capability objectives are defined, SoS design becomes the primary task throughout the process of SoSE and requires fine analysis, expression, optimization, and maintenance. As the scale of an SoS is becoming increasingly large and its structure is continually becoming increasingly complex, there have been many approaches to SoS design. Such SoS design approaches normally include a large number of design elements, leading to difficult conditions to follow. For examples, the DoDAF V1.0, released in 2003, requires up to 28 views for the design of a complex information SoS. The number of views required in DoDAF V1.5, released in 2007, has continued to increase [35]. However, in engineering practice, there are a few cases where all of these views are applied in the SoS design. According to the theory of information systems dynamics [36], the functions and values of information systems, as well as SoS, are all in the information flows and efficacies imposed on the information by each link inside. Therefore, as long as we can clearly describe the information interactions between systems and information services affecting the efficacies, we can locate the critical issues that the SoS design should focus on. This can play the role of outlining. Here, we refer to interactions and services between information systems as information relationships. Determining how to develop and apply simple and practical design tools for maintaining information relationships has become an urgent requirement for large-scale SoS designers.

2.3.3 Dialectical unity of order and vitality in SoS construction

The core issue in large-scale scientific and technological research and engineering practice has always been how to make the most effective use of the advanced achievements in science and technology to complete a large-scale scientific research and construction task in the shortest time, with the least manpower, physical resources, and investment [1]. In SoSE, there are a large number of entity system developments and integrations, which are almost always the most time-consuming, laborious, and costly tasks. As such, the contradiction between cost reduction and efficiency enhancement is particularly prominent. In particular, an unavoidable contradiction in SoS construction is between the independent development of autonomous systems and the normative integration of the whole SoS. If the number of autonomous systems is small and their functions are simple, there are usually few difficulties in SoS integration and a short lifecycle but a weak expected ability. In contrast, if SoS integration is in high demand and has rigid constraints, the difficulty in the development of autonomous systems can inevitably increase. However, in such cases, the capabilities of the SoS may not advance.

Therefore, an emphasis on order alone while ignoring vitality will lead to system rigidity, whereas an emphasis on vitality alone while ignoring order will lead to system chaos [5]. In addition, different autonomous systems have different primary and secondary contradictions, and the integration of an SoS has different priorities for different tasks. From the engineering philosophy that order and vitality (two opposing sides) are in a dialectic unity, correctly identifying and managing the main contradictions in an SoS at different levels, for different objects, and in different stages are always the key issues in Smart Court SoSE practice.

2.3.4 Continuous improvement of SoS quality and efficiency

In the information age, the application of advanced information technologies to reform government public services, improve quality and efficiency, reduce budgets, and increase trust between society and the government has become a core issue in e-government policies in various countries [37]. In the field of justice, many countries worldwide are committed to developing information systems for processing litigation-related information, thereby improving the traditional judicial process and providing a fair, efficient, and transparent judicial environment for the public to achieve a higher level of fairness and justice [38]. In the meantime, the focus of judicial informatization in many countries is on the development of single information systems with simple user inputs and shallow application patterns [39–41].

To the best of our knowledge, there are a few other projects, such as the Smart Court SoSE project of China, which have covered courts at different levels nationwide, implemented the sharing of various operational information, and supported a multi-operational, real-time, asynchronous, and cross-domain online communication operation mode between the public and judges. The maintenance of the Smart Court SoS (which consists of a large number of systems) is a safe, reliable, universally applicable, effective, and robust system, rather than a "flash in the pan." This is a key issue for engineering leaders to continually monitor.

3 Fundamental theories and application of information science for the Smart Court SoSE

From the most basic foundations regarding the definitions and models of information and information systems dynamics, we established a key performance indicator system for the evaluation of information systems in the Smart Court SoSE. This indicator system provides benchmarks and guidelines for entire-lifecycle engineering implementation.

3.1 Information model and measurement

In response to the diverse conceptual connotations and lack of a comprehensive metric system for information, the objective information theory has led to a philosophical perspective on information, i.e., that information is the objective reflection of things and their motion states in the objective and subjective world. Based on this, a mathematical model and the basic properties of information were proposed, and 11 information metrics were deduced [36,42,43], forming a basic theoretical system for information measurement (Fig. 2).

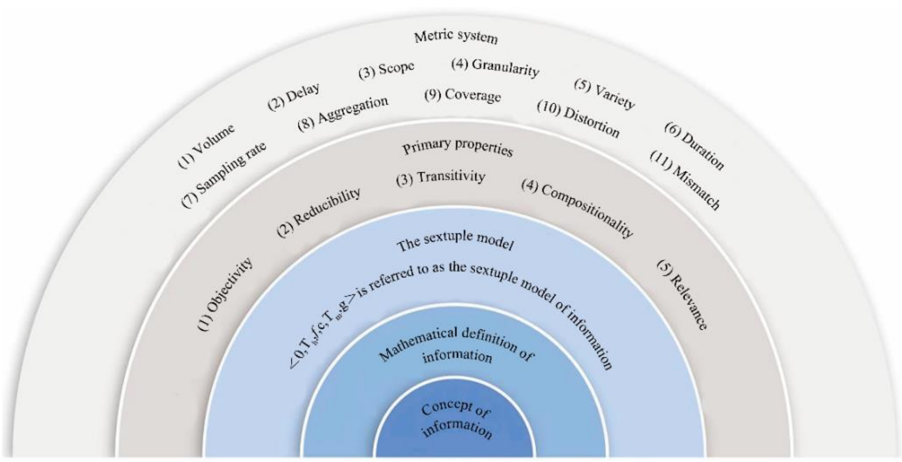


Fig. 2. Definition, model, nature, and metric system of information.

DOI 10.15302/J-SSCAE-2022.04.005

These theories employed set theory and mapping theory in mathematics to mathematically define information as a reflection from a state set $f(o,T_h)$ to a reflection set $g(c,T_m)$. The six basic elements, namely the noumena o, occurrence time T_h, state set f, carriers c, reflection time T_m, and reflection set g all together compose an information sextuple model, denoted as $I = \langle o, T_h, f, c, T_m, g \rangle$. This model deconstructs the concept of information in three important ways: the dual deconstruction of information subjects, temporal deconstruction of information durations, and form deconstruction of information contents. Most importantly, based on the sextuple model and the basic properties of information, we can infer 11 types of information metrics: volume, delay, scope, granularity, variety, duration, sampling rate, aggregation, coverage, distortion, and mismatch. These constitute a relatively complete and universal information metric system. The significance of such a metric system is that it provides important measurement guidance for the evaluation of information systems, apart from providing a basis for information measurement.

3.2 Dynamic configuration of information systems

A complete information SoS can be abstracted and summarized with five basic links: information collection, action, transmission, processing, and data space. Each of these can be considered a process of receiving input information, exerting various actions on information, and ultimately producing output information [36]. The main significance of an SoS and its various links comes from the various effects of the actions on the input information, which can be expressed through the output information. Therefore, through the 11 types of information metrics, we can establish 11 types of efficacies that information systems may have, i.e., efficacies of volume, delay, scope, granularity, variety, duration, sampling rate, aggregation, coverage, distortion, and mismatch. Furthermore, these efficacies can be applied to construct dynamic configurations of information systems, as shown in Fig. 3. Real-world information enters into the information systems through the information collection link, then the information flows along the links for information transmission, processing, and data space, and finally, the information can affect the real world through the link of information action. Every link can have certain effects on the measurements of the output information; therefore, each of the links has its efficacies. However, it is not necessary to consider all 11 efficacies for every link. The distribution of the major efficacies of the information movement across each main link provides us with an important reference for constructing and analyzing each link of an SoS.

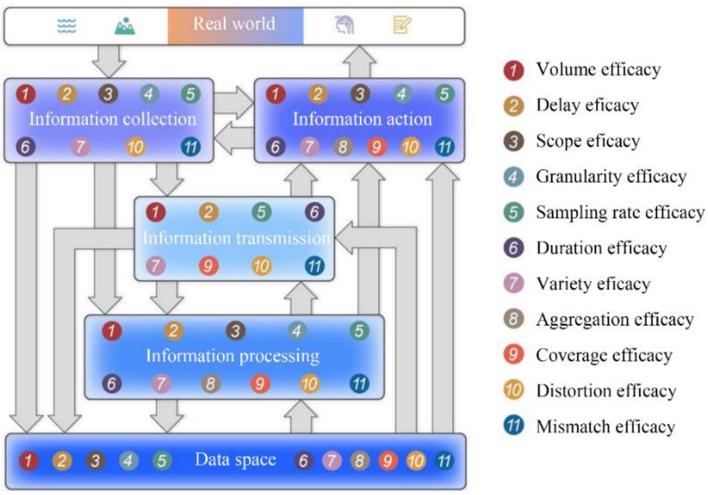


Fig. 3. Dynamic configuration of information systems.

3.3 Key evaluation indicators for information systems

Based on the information metric system and dynamic configurations of information systems, we established a reference evaluation indicator system including 65 key evaluation indicators for information SoSE (as shown in Table 1). As a general SoS can include a large number of systems and each system may include many subsystems, the evaluation indicators in the table can serve not only as comprehensive indicators but also as specific indicators for certain important subsystems. Therefore, these key indicators provide an important design and evaluation basis for implementing the Smart Court SoSE project.

Table 1. Evaluation indicator system for information system-of-systems engineering (SoSE).

Serial No.	Metric effects	Information collection	Information action	Information transmission	Information processing	Data space
1	Volume	Application system input data volume	Application system output data volume	Communication network bandwidth	The volume of information infrastructure storage resources Information infrastructure storage resource utilization	The volume of the data resources aggregated by information systems
2	Delay	Application system upload data delay	Application system operation response delay	Communication network information transmission delay	The volume information infrastructure computing resources and processing rates Information infrastructure computing resource utilization Application system information processing delay Security system safety protection processing delay	Various data convergence delays of information systems
3	Scope	Application geographical coverage and number of users	The scope of information provided by the application system to users		The scope of application system processing information	All source regions and sectoral scopes of the data aggregated by information systems
4	Granularity	Integrity rate of information items collected by application systems Resolution of video information collected by application systems	Integrity rate of information items provided by the application systems to users Resolution of output video information of application systems		Integrity rate of information items processed by application systems Resolution of video information processed by application systems	The integrity degree of information items aggregated by information systems
5	Variety	Number of types and methods of application system input information	Number of types and methods of application system output information	Number of types of information transmitted over communication networks	Number of types of information processed by application systems	The number of types of information aggregated by information systems
6	Duration	Effective working time of application systems Mean time between failures of application systems	Effective working time of application systems Mean time between failures of application systems	Effective working time of communication network systems Mean time between failures of communication network systems	Effective working time of information processing systems Mean time between failures of information processing systems	Length of time of all types of information aggregated by information systems
7	Sampling rate	Application system input data sampling rate	Application system output data sampling rate	Communication network bandwidth Communication network bandwidth utilization	Computing storage facility throughput Application system information processing cycle	Sampling periods of all types of data aggregated by information systems
8	Aggregation		Application system output data aggregation		Data aggregation processed by information processing systems	The aggregation degree of the total data aggregated by information systems
9	Coverage		Distribution and the number of application system users	Communication network coverage area	Security system information encryption effectiveness Accuracy of user authority control of security systems Safety isolation reliability of inter-network security systems	The regional distribution of information systems
10	Distortion	Input information accuracy of application systems	Output information accuracy of application systems	Bit error rate and packet loss rate of information transmitted over communication networks	Processing error of information processing systems	The confidence of the full data of information systems
11	Mismatch	Application system input information mismatch	Output information adaptability and user satisfaction of application systems	Format and type adaptability of information transmitted over communication networks	Matching accuracy of “user requirements—output data” of information processing systems	Matching accuracy of “user requirements—output data” of full data of information systems

DOI 10.15302/J-SSCAE-2022.04.005

4 Information-relation-based SoS design for the Smart Court SoSE

The objectives of an SoS can be achieved only through information flows between the component systems. Information relationships can represent the information interactions between various systems within an SoS, as well as the information services provided to maintain the information flows. Designing an SoS with the relationships between systems in the SoS as the main objects is an effective means for describing and representing large-scale SoS. Such an approach can simplify the complexity and focus on the main contradiction(s) in system integration in which the system interconnection, information exchange, data sharing, intelligent assistance, and operational linkage are critical concerns.

4.1 Objectives and requirements

The following main objectives of SoSE are required in SoS design based on information relationships. First, the name and main functions of any component system in the SoS should be clearly defined. Second, any component system should be able to be flexibly managed, added to, and deleted from the SoS. Third, the information relationships between any two-component systems of the SoS should be clearly defined. Fourth, the information relationships between any two-component systems should be able to be flexibly managed, added, and deleted. Fifth, the information relationships of any set of component systems in the SoS should be able to be visualized through auxiliary design tools. Sixth, the main functions, performance, component systems and their information relationships, main supported operation scenarios, information processes, and working mechanisms of the SoS should be able to be described in detail with documents.

4.2 Visualization tools for SoS design

In the engineering practice of the Smart Court SoSE, a set of visualization SoS design tools based on information relationship can be developed, as shown in Fig. 4. First, all the first-level component systems in an information SoS, including the application systems, data resources, infrastructure, network security, and operation and maintenance systems, are listed in a two-dimensional cross table in Excel. Then, the table is filled with the specific interactions between any two first-level systems in the entire SoS. In this way, the information relationships between the systems can be established, the elements in the table can be indefinitely expanded, and the information relationships between the two systems can easily be filled in. Furthermore, the hierarchical decomposition of an SoS or system can be expressed in a layer-by-layer manner within a single tab or different tabs in Excel. Thus, Excel can be regarded as a convenient tool for supporting SoS design with long-term maintenance capabilities.

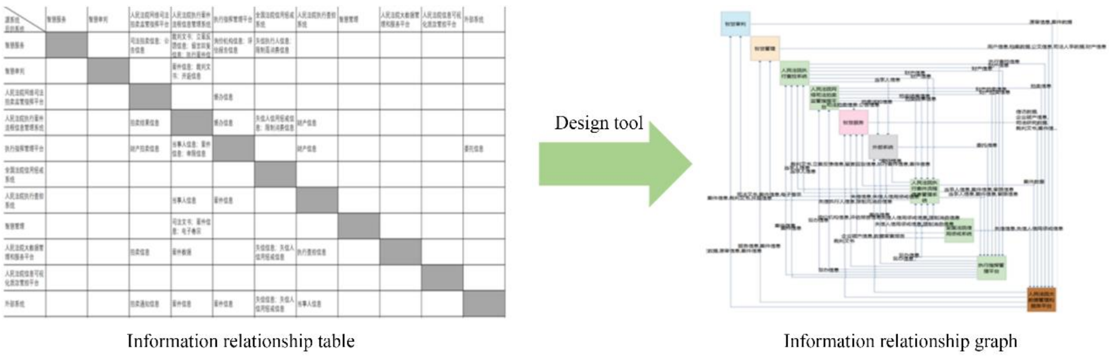


Fig. 4. SoS visualization design based on information relationships.

A dedicated tool for a table-graph transformation is also depicted in Fig. 4. This tool can form an information relationship graph with an arbitrarily selected component set from the entire information relationship table. This tool can greatly improve the visualization of the information relationship design and efficiently support research and analyses of engineering technicians at different stages of planning, design, development, testing, and maintenance. With this set of methods and tools for SoS design, we can construct a completely reusable, extensible, and maintainable database and chart libraries for SoS design to ensure the consistency and relevance of the design data. These cross tables and graphs provide important design drawings and a development basis, helping to genuinely realize the productization of design tasks and programming of design processes for SoSE.

4.3 Reference model for the Smart Court SoSE

A reference model is a top-level architectural view obtained by highly generalizing an information SoS with the information-relationship-based design methods and tools. The Smart Court of China is composed of a large number of extremely complex information systems. As shown in Fig. 5, the reference model concisely presents the main components and their relationships for the entire SoS. Not only is the reference model a concrete result of the application of the information relation-based SoS design methods but it also provides a basic reference for the subsequent layer-by-layer decomposition of the Smart Court SoS design.

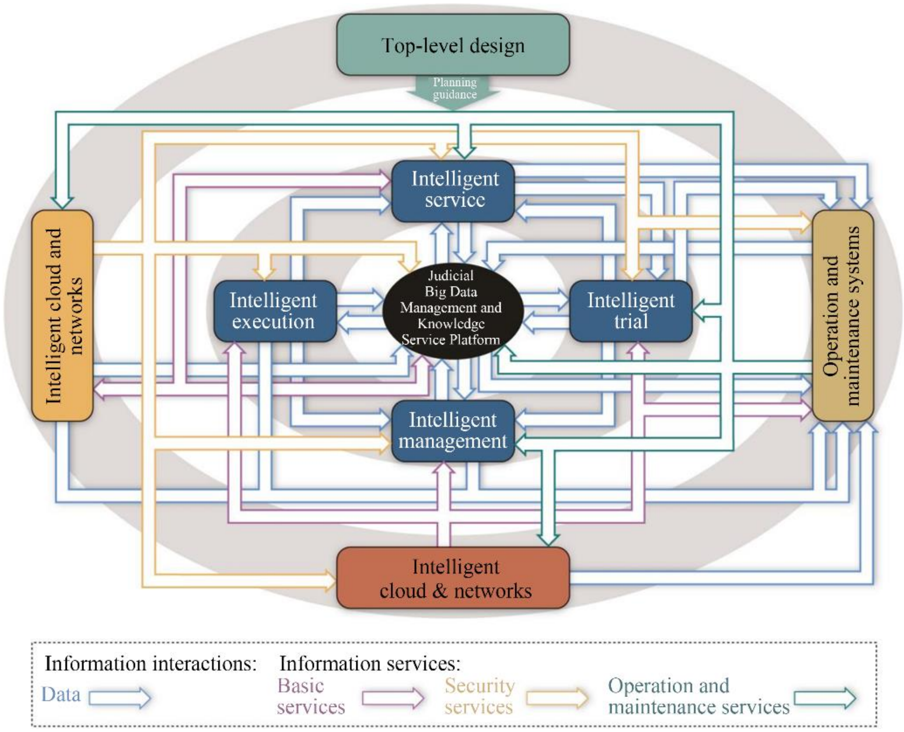


Fig. 5. Reference model for the Smart Court SoS.

The core of the Smart Court SoS of information systems is the Judicial Big Data Management and Service Platform, which gathers various types of operation data of the Smart Court and knowledge resources generated from the data. The intelligent service, trial, execution, and management systems in the inner ring are the major carriers for the Smart Court to serve different users. The Intelligent Cloud & Networks, integrated security systems, and operation maintenance systems in the outer ring are the basis and guarantee of the conditions for the operation of the Smart Court. In addition, the top-level design is referred to as a collection of tasks such as planning, design, and evaluation; these are not a physical part of the SoS but play important leading roles in the construction of various information systems.

This reference model (featuring one core and two rings) considers the characteristics of the general information system and aims at the main operations of the Smart Court. Notably, the emphasis that designers should consider the main components of the SoS and their interactions is where this reference model mostly differs from other technical reference models (the interactions are actually the information relationships, on which the SoS design methods are based). The information relationships between the four types of application systems, i.e., intelligent service, intelligent trial, intelligent execution, and intelligent management, mainly comprises information interactions. The application systems all have interactions with the Judicial Big Data Management and Knowledge Service Platform, and are supported by information services of the Intelligent Cloud & Networks, integrated security systems, and operation maintenance systems.

The Judicial Big Data Management and Service Platform provides data and knowledge services for the four types of application systems. The Intelligent Cloud & Networks is referred to as the sum of various types of information infrastructures and provides basic services such as the computing, storage, database, and communication networks for various application systems, the Judicial Big Data Management and Service Platform,

DOI 10.15302/J-SSCAE-2022.04.005

integrated security systems, and operation maintenance systems. Integrated security systems are a set of systems for providing various security protections such as identity authentication, border protection, and security supervision, as well as information security services for other systems. Operation maintenance systems comprise a set of information systems for ensuring system operation, treatment of system faults, and evaluations of operation quality and effectiveness, thereby providing operation and maintenance services for other systems.

5 System development and integration of the Smart Court SoSE

5.1 Research and development of the autonomous systems

According to the SoS reference model shown in Fig. 5, Smart Court SoSE relies on courts at all levels throughout the country to concentrate on the development of the following eight types of autonomous systems.

The Judicial Big Data Management and Service Platform is the core data space of the Smart Court information SoS. It interfaces with all types of operating application systems and realizes the comprehensive data convergence of the trial execution, judicial human resource management, administration, research, informatization, and external data. The efficient management of trials, executions, documents, blockchain certificates, and backup information is made possible by accessing the database, standard library, subject database, knowledge base, archive library, and recovery database. Plentiful big data and knowledge-based services are provided to all types of application systems and users through auxiliary tools, such as those for data exchange, judicial statistics, situation analysis and presentation, judicial indicator analysis, and economic and social development analysis.

The intelligent service system is an application system for providing online services for the public to participate in judicial activities or contact the court. It mainly comprises the online litigation service hall, litigation service platform, lawyer service platform, 12368 litigation service hotline, people’s court mediation platform, as well as the complaint and petition management system of the people’s court, providing online litigation, mediation, consultation, petition, and law popularization services to the masses.

The intelligent trial system is an application system for providing online services for judges to hear cases. Its main processing modules include those for case filing, case assignment, pre-court preparation, trial, collegial discussion, adjudication, case closing, and filing, as well as the information system for key places, such as the Science and Technology Court system and adjudication committee system. It facilitates the judges’ case hearing through online reviews, collegial discussions, trials, adjudication assistance, etc.

The intelligent execution system is an application system for providing online services for judges to supervise case execution. It mainly includes online investigation and control for civil cases, punishments for discrediting, online inquiry and evaluation, online auctions, online petitions, collaborative execution management, and other auxiliary execution systems. It also includes an execution command center management system and execution information disclosure platform, thereby providing executive judges with online case processing, searches for people or property, property disposals, punishments for breach of credibility, information disclosures, coordinated command, etc.

The intelligent management system is an application system for providing online services for all types of management staff, including office systems, trial management systems, human resource management systems, file management systems, and mobile office platforms. With the support of the Judicial Big Data Management and Service Platform, it offers online offices and human resource services, as well as administration, affairs, and file management services for court staff.

The infrastructure of the Intelligent Cloud & Networks is the basic platform for supporting computing, storage, communication, display, and operation control for all types of information systems. It utilizes private judicial networks, the Internet, external private networks, mobile private networks, and confidential networks as its hubs to interconnect all types of computing and storage resources to form court proprietary clouds, open clouds, and confidential clouds. Along with the specific information service platforms, such as litigation service halls, Science and Technology courts, execution command centers, and information management centers, the interconnection of all types of information systems of the Smart Court is thereby realized and serves as the foundation for ordinary operations.

The hierarchical scheme and protection systems provide security services for all types of information infrastructures, application systems, and data resources for the Smart Court, including identity authentication, border protection, rights management, security control, and security operation and maintenance systems. It provides security services to all types of information systems with different requirements, including host security, identity authentication, access control, classification, password encryption, firewall, security audit, and security management.

The quality-effective operation and maintenance guarantee system provides services such as operation, maintenance, and operation quality analyses to all types of information infrastructures, application systems, data resources, and network security systems. It enables focusing on the overall quality and effectiveness of informatization and integrates the mechanisms for the operational maintenance, effectiveness of the informatization, and degree of service satisfaction into a guarantee system for management and evaluation, thereby promoting the continuous improvement of the Smart Court information system.

5.2 Development and promotion of the key backbone systems

Although almost all autonomous systems are independently built up and managed by courts at all levels, the Supreme People's Court is responsible for research and development, making use of national key programs, and entrusting certain local courts to develop and promote certain key backbone systems to subsequently be applied nationwide. Such key backbone systems play a particularly important exemplary and leading role in PCSoSE. For instance, the national Judicial Big Data Management and Service Platform plays the role of the core data space for the Smart Court of China. The Litigation Service Guidance Center and the Online Service of the People's Court play a leading role and act like a spindle, respectively. The application for the generation and transfer of electronic documents is the main clue penetrating all types of intelligent trial systems. The information management system for the civil case execution process represents the confluence of all types of intelligent execution systems. The criminal case handling intelligent assistant system connects all types of public security, prosecutorial, and court platforms. The Online Court is the leading benchmark for the construction of the nationwide Smart Court.

These key backbone systems require more painstaking efforts from those in charge of PCSoSE, from requirement analysis, system development, test and evaluation, optimal selection, to popularization, and even contract funding, to effectively exert scientific, reasonable, and feasible implementation strategies recognized and supported by courts countrywide. Conversely, once these systems are proven successful on a large scale, they can become the key backbones of collaborative system integration and accelerate the development process of PCSoSE.

5.3 Integration of collaborative systems

In addition to the key backbone systems, those in charge of the Smart Court SoSE do not need and cannot explore the research and development details of all autonomous information systems. However, through a variety of system integration work, one of their central tasks is to continuously improve the collaboration capability of the systems, such as via system interconnection, information exchange, data sharing, intelligent assistance, and operation linkages. The integration of a collaborative framework includes the following six main components.

First, basic integration connects and integrates the information infrastructure distributed countrywide, including the private court network that connects tier-four courts and all of the dispatched tribunals nationwide. This provides interconnections among the Internet, external private networks, mobile private networks, and confidential networks on the premise of complying with security isolation standards. Meanwhile, with the further popularization of cloud computing facilities and their deep integration with the communication network, an intelligent voice cloud platform is being constructed for the national courts, utilizing cloud resources and cloud services as an integrated infrastructure to provide unified communications, computing, storage, and intelligent support capabilities.

Second, data integration builds up the Judicial Big Data Management and Service Platform of the People's Court and the data center for higher courts and above, physically or logically aggregates data resources distributed in local courts and all types of application systems, and conducts a quality inspection, correction, and association tasks based on corresponding data quality criteria. In addition, it is aimed at continual improvement and consolidating the volume, delay, scope, granularity, variety, duration, sampling rate, aggregation, convergence, distortion, and mismatches of judicial big data. Building an integrated data space to fully support the data exchange and sharing between all types of information systems is also integral part of data integration.

Third, knowledge integration is based on the rich resources of judicial big data and comprehensively utilizes multimodal artificial intelligence technologies such as text, voice, video, and natural language processing, through large-scale manual tagging, automated deep learning, and the confluence of professional knowledge. A unified judicial knowledge base and a judicial knowledge service engine are established based on legal rules and historical cases suitable for different application scenarios. Knowledge integration fully supports a full-dimensional,

DOI 10.15302/J-SSCAE-2022.04.005

integrated, and large-scale application of judicial artificial intelligence, and significantly improves the intelligent auxiliary abilities of information systems.

Forth, application integration promotes intelligent services, trials, executions, and management systems, mainly through online services, trial case processing, execution case processing, and office automation, respectively. With the Judicial Big Data Management and Service Platform as the core and a series of auxiliary intelligent applications as the entrance, a highly integrated application SoS is formed. The SoS fully supports information exchange, data sharing, and operation linkages between all types of business applications.

Fifth, service integration is necessary to promote more information system resources to support Smart Court applications in a service-oriented fashion, particularly in view of the trends of reducing costs and increasing efficiency, as well as the increasing popularity of cloud service technologies and systems such as infrastructure-as-a-service, platform-as-a-service, and software-as-a-service. Consequently, a physically distributed and centralized management service resource system has been initially built up and efficiently supports the unified collection, unified evaluation, unified release, and selective services of various information services.

Sixth, portal integration provides an integrated, personalized, and customized unified entrance portal for specific users on a court private network, Internet, or confidential network according to the respective characteristics of PCs, mobiles, and different operating systems. Consequently, all types of users can benefit from being familiar with the access, operation, and obtaining mechanisms for abundant information in the Smart Court information system.

6 Application promotion and quality improvement of the Smart Court SoSE

6.1 Reshaping the judicial operation pattern in all aspects

The key point and major difficulty in information engineering are "making use of it" rather than "building it up." No information system is perfect, not to mention the existence of information systems covering all sectors vertically and main business areas; in this context, unsatisfactory aspects seem unavoidable. In the case of the Smart Court SoSE in China, it is precisely by relying on strong popularization and promotion, as well as persisting in the mutual running-in and mutual promotion of "building up" and "making use" that many information applications have successfully covered the courts at all levels throughout the country to benefit the masses. Meanwhile, the judicial operation pattern of Chinese courts has been reshaped in all aspects (Fig. 6).

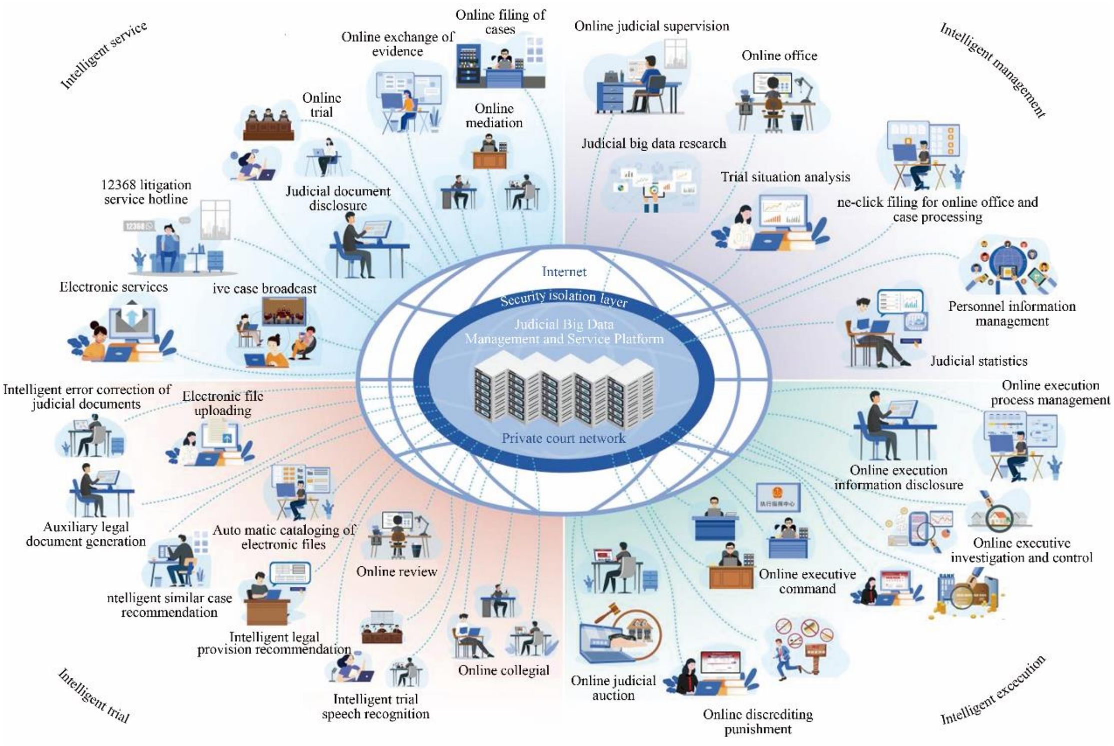


Fig. 6. Brand-new judicial operation pattern based on the Smart Court.

The Smart Court supports universal intelligent services at all times and in all spaces. In the past, the mediation, filing of cases, exchange of evidence, filing reading, opening of hearings, consultation on litigation matters, understanding of the litigation process, attendance at court hearings, access to judicial documents, and other activities used to be completed by parties or litigation agents in person; now, they can be realized through the Internet. Meanwhile, judges can utilize a dedicated court network to directly contact people through the Internet based on security isolation exchanges. Accordingly, the people involved in judicial proceedings may need to be present in person at most once or perhaps not even once, significantly reducing their efforts and costs in commuting.

The Smart Court supports a full process of intelligent trials assisted by intelligent technologies. The courts at all levels can instantly transmit litigation documents presented by the parties to the trial information system, by scanning paper-based documents submitted offline, or by directly uploading electronic documents submitted online. Thus, the case judges can easily review the documents and form a collegium online. Meanwhile, based on the intelligent recognition and processing of file information, the trial case handling system can provide judges with intelligent assistance throughout nearly the entire process, including the automatic cataloging of electronic files, intelligent recommendation of legal provisions, intelligent recommendation of similar cases, auxiliary generation of legal documents, and intelligent error correction for judicial documents. In addition, the above can be combined with speech recognition technology to support intelligent speech recognition in the trial and automatically generate high-accuracy court transcripts, significantly reducing the routine work of judges and clerks.

The Smart Court supports the intelligent execution of inter-departmental coordination. Since the whole nation should be well-coordinated in the enforcement phase, the Smart Court utilizes Internet technology to vertically connect the enforcement departments of courts at all levels across the country to realize linkages between the upper and lower levels. Further, it enables the horizontal sharing of information with industries such as finance, transportation, and the economy to achieve business coordination. Accordingly, executive judges can conduct their work online without leaving the house; various tasks were previously only possible in person, including the handling of cases, process node management, executive investigation, control and punishment for breaches of credibility, judicial auctions, information disclosures, and executive commands. The Smart Court not only reduces the time and cost spent on commuting for a large number of personnel but also provides an effective approach otherwise difficult to achieve through traditional offline methods. Therefore, it has become a new solution for Chinese courts to effectively solve enforcement problems.

The Smart Court supports intelligent management based on judicial big data and gathers a large amount of business and technical data in real time. It continuously accumulates six types of interrelated judicial big data resources: those for trial execution, judicial personnel, judicial administration, judicial research, informatization, and external data. Based on this, online offices, judicial supervision, and one-click filing can bring considerable convenience to judicial administration. The judicial statistics, personnel information management, trial situation analysis, and economic and social development research based on judicial big data have created a new approach that could not be achieved traditionally in terms of both efficiency and accuracy.

6.2 Promoting system optimization via continuous quality and effect analysis

According to the key evaluation indicators of the information system as combined with the main applications of the Smart Court, it was convenient to form a series of key evaluation indicators to reflect the operations of the Smart Court system. Based on this, once the research, development, and integration work of the Smart Court information system achieved a certain level, the stakeholders persisted in analyzing the quality and effectiveness of the system every month, i.e., constantly confirming the expected results, identifying problems, improving, and upgrading in time. In this way, the optimization of the entire system was realized step by step. Some critical indicator change curves are plotted in Figs. 7 and 8.

The number of open documents on China Judgements Online and the number of live cases on China Court Trial Online reflect a comprehensiveness indicator for judicial information. The visits to the China Judgements Online, visits to China Court Trial Online, and number of electronic services in the People's Courts reflect a coverage indicator for certain information in the intelligent service system. The number of online mediation cases in the People's Court reflects both the coverage and popularity of online mediation information. The trends of these curves imply the good performances achieved by the intelligent service system. The sharp ups and downs in certain periods are closely related to the operation or technical conditions at that time. Owing to the length

DOI 10.15302/J-SSCAE-2022.04.005

limitations of this article, the operations of the quality and effect analysis of the Smart Court will be analyzed in detail in subsequent dedicated articles.

(a) Curve of the number of open documents on the China Judgements Online

(b) Curve of the number of visits on the China Judgements Online

(c) Curve of the number of live-broadcast cases on the China Court Trial Online

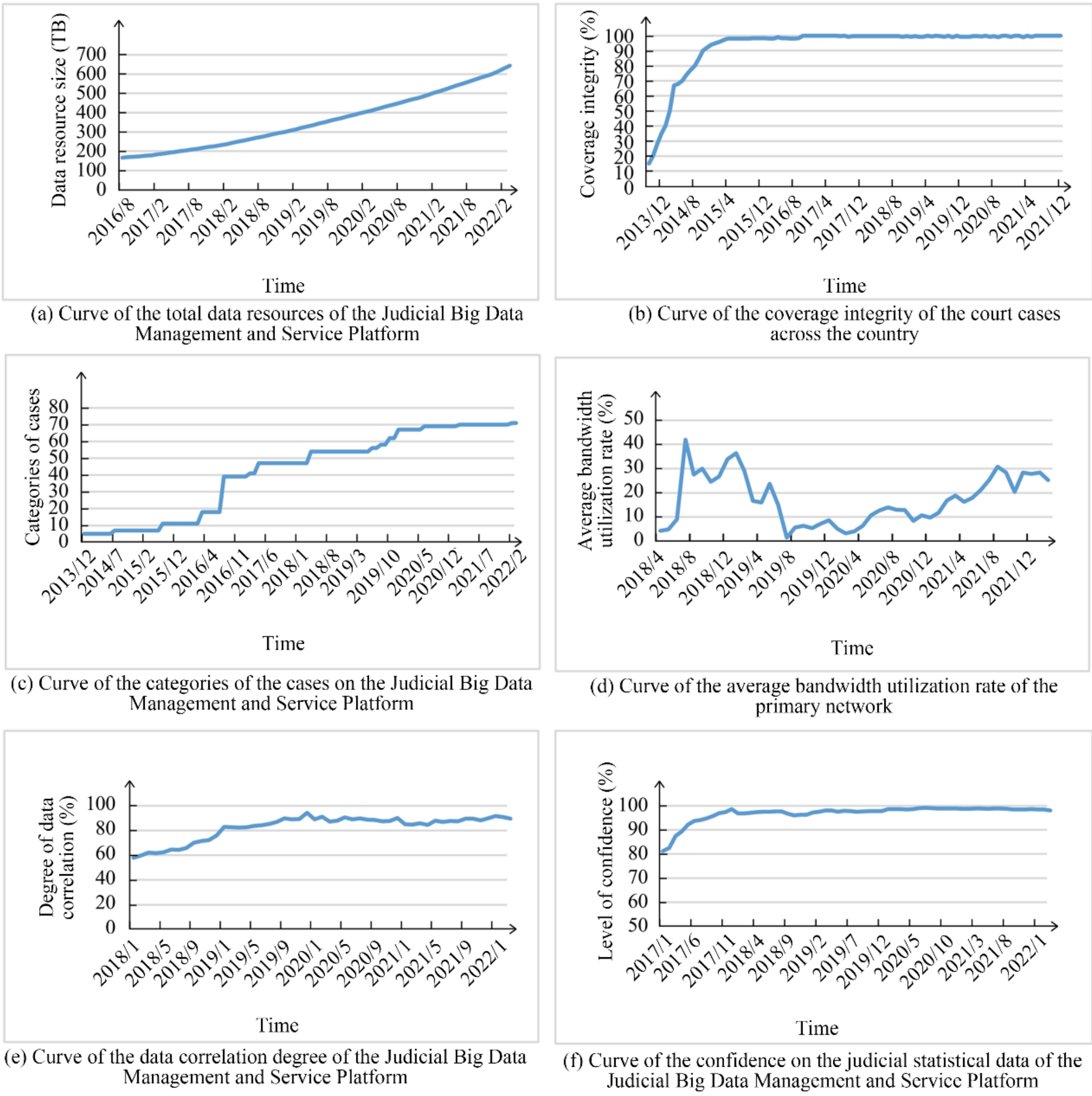
(d) Curve of the number of visits on the China Court Trial Online

(e) Curve of the number of online mediation cases in the People's Courts

(f) Curve of the number of electronic services in the People's Courts

Fig. 7. Changes of key indicators for the intelligent service systems.

The curve of the total data resources of the Judicial Big Data Management and Service Platform reflects a capacity indicator for the judicial information gathered by courts across the country, and the nearly completely smooth upward trend indicates that all types of judicial information are steadily gathering and accumulating in accordance with the requirements. The curve for the coverage integrity of court cases across the country reflects the meticulous granularity of judicial big data corresponding to all cases. It has been close to 100% since August 2015, indicating the comprehensiveness and detail of the aggregated information of the individual cases. The curve for the categories of cases on the judicial big data platform reflects the category index of the information gathered by the courts countrywide, and the step-by-step rising trend indicates that the types of information characterizing the cases are constantly being enriched. The curve of the average bandwidth utilization rate of the primary network reflects the information transmission capacity of the private communication network connecting the Supreme Court and each High Court. Even if the information sampling rate of the Supreme Court to the lower courts has changed many times owing to a variety of dynamic adjustments, the maximum utilization rate is never higher than 40%, indicating that the entire primary network can meet the information sampling rate required by the Supreme Court. The curve of the data correlation degree for the judicial big data platform reflects an aggregation degree index for the information gathered by the courts countrywide. Although the information capacity continues to increase, the data correlation degree does so as well, indicating that the work of information processing and aggregation has been progressing and that the value of the information is being increasingly highly considered. The curve of confidence on the judicial statistical data of the judicial big data platform reflects a negative indicator for the distortion of information aggregated by courts across the country; it has been close to and maintained at more than 99% since January 2018. This indicates that the accuracy of the aggregated data has been guaranteed through various data governance and quality control approaches and that it can be used as an accurate basis for all types of research and application.



(a) Curve of the total data resources of the Judicial Big Data Management and Service Platform

(b) Curve of the coverage integrity of the court cases across the country

(c) Curve of the categories of the cases on the Judicial Big Data Management and Service Platform

(d) Curve of the average bandwidth utilization rate of the primary network

(e) Curve of the data correlation degree of the Judicial Big Data Management and Service Platform

(f) Curve of the confidence on the judicial statistical data of the Judicial Big Data Management and Service Platform

Fig. 8. Changes in key indicators for the intelligent management systems.

In addition, the curves of the court coverage rates monitored by the Science and Technology courts, the curve of the system’s mean time between failures, curve of the average accuracy of provincial accents in trial speech recognition, and curve of the availability of merging the original case files reflect the metrics for the information scope, duration, distortion, and mismatch, respectively, and are continually being improved. The curves of the proportion of slow operations in the civil case execution and command platform, case volume of the online judicial auctions, operation times for the discrediting punishment system, and number of active users of the civil case execution inspection and control system reflect the metrics for the information delay, scope, and coverage, respectively, and are stably upgrading. The trends of these curves all indicate the good performances achieved by the intelligent trial systems and intelligent execution systems.

The above-mentioned indicators represent only some of the 65 categories and hundreds of quality evaluation indicators that need to be considered and analyzed every month in the implementation of the Smart Court SoSE. It

DOI 10.15302/J-SSCAE-2022.04.005

is through uninterrupted monthly analyses and continuous improvement that the unity of "building up" and "making use" of the national Smart Court information system has been ensured, and it is constantly being optimized and improved. The Supreme People's Court has been conducting a comprehensive evaluation of the indicators for building up the national Smart Court since 2017. As shown in Table 2, the indicators for building up the Smart Court at all levels have been increasing yearly since 2017, reaching excellent levels by 2020. 2021 was the beginning of the new five-year plan, and the evaluation criteria were raised. Although the grades in 2021 decreased compared to those in the previous year, they maintained a general level higher than 80, and the actual quality and efficiency were significantly improved.

Table 2. Changes of the indicators for the construction of the Smart Court during 2017–2021.

Category	2017	2018	2019	2020	2021
Nationwide	72	78	85	88	84
Supreme Court	80	83	86	90	83
Intermediate Court	70	78	86	90	85
Basic Court	67	73	83	86	83

6.3 Remarkable Outcomes from Judicial Applications

The effect of the Smart Court SoSE is reflected in its great contribution to the progress of judicial civilization. It enables the mass crowd to accomplish their litigation processes with the need of being in person at most one time and can reduce the clerical work of judges by more than 30%. The efficiency of the trial has been improved by more than 20%, and the solemn promise of "basically solving the difficulties in enforcement in two to three years" has been realized. Judicial openness has comprehensively enhanced the judicial transparency of China. The Quality of Judicial Process Index, which mainly reflects judicial informatization, was ranked first in the world by the World Bank in 2020. From 2019 to 2021, the Smart Court reduced public travel costs equivalent to 200 000 man-years and saved 302.4 billion CNY in social expenses. The Smart Court in China has not only provided strong information support for social fairness and justice but has also won wide attention and high praise globally [44, 45].

On this basis, the Supreme People's Court of China has successively issued *Online Litigation Rules of People's Courts*, *Online Mediation Rules of People's Courts*, and *Online Operation Rules of People's Courts*, so that the joint forces of advanced technology and judicial operation can be further refined in the form of judicial interpretation and normative documents. Therefore, the use of the online judicial model is being effectively promoted toward a higher level of digital justice.

7 Conclusions

The Smart Court SoSE projects of China inherit the experiences and methodologies of traditional system engineering. According to the collaborative operation requirements of a large-scale autonomous information system, a set of "two-track parallel, six-ring linkage" PCSoSE pattern frameworks with strong pertinence and practicability is established and applied. Based on the original basic theories, such as the universal information model, information metric system, and information system dynamic configuration, the key evaluation indicators for an information SoS are proposed. In addition, according to the principles of the information system dynamics and characteristics of system design, an SoS design tool based on information relationship is introduced, and a reference model for a Smart Court SoS is established. Through such innovation, combined with development plans, the establishment of standards, and achievements from scientific research, construction of the vital components in PCSoSE (such as research and development on autonomous systems and the integration of collaborative systems) has been following well-defined initiatives and guidance.

The Smart Court SoS project has fully reshaped the operation mode of the People's Court. Through continuous monitoring and monthly analysis of a series of key evaluation indicators, the entire information SoS is in a good state of progressive development and constant optimization and is making an important contribution to the progress of judicial civilization in the information era. The exploration and practice of PCSoSE pattern framework, key evaluation indicators of an information SoS based on fundamental information theories, system design methods based on information relationships, application and promotion of large-scale information SoS, and quality efficiency improvement methods are not only applicable to the vertical sectors of the Smart Court, but also provide useful references for e-governments, Smart Cities, and other large-scale information SoSE projects.

Owing to growing user demands and the rapid evolution of information technologies, there remains plenty of room for improvement for the Smart Court in China regarding intelligence, integration, collaboration, universality, and convenience. The methodologies and pattern framework of SoSE, as well as the innovation of PCSoSE, must continuously drive further development. First, there is an urgent need to constantly deepen and summarize the relevant academic theories and technical models formulated on the methodology to construct a rich and systematic SoSE model and tool system as a reference for the penetration of information and intelligence in more vertical industrial sectors. Second, given the increasing popularity of cloud service models, it is indispensable to explore collaboration theories and methods to implement service-oriented integration to promote the transformation and upgrading of Smart Court SoSE from self-built systems to shared services. Third, it is crucial to incorporate the directions of advanced technologies, such as artificial intelligence, 5G, blockchain, and meta-universe, to improve the adaptability and flexibility of the PCSoSE pattern framework and to enable deeper integration of advanced science and technologies into judicial operations. Fourth, the construction and enrichment of theoretical system dynamics for information systems can provide sufficient scientific support for SoSE. Meanwhile, in addition to technical implementation, the construction of the Smart Court inevitably involves processes such as user feedback, reform of the judicial system, and the establishment of related systems and norms. Enforcing research work on the integrations of science and technology, legal theory, and social sciences will certainly provide more powerful support for the construction of the Smart Court in China to achieve more promising results.

References

[1] Qian X S. On systems engineering (new century edition) [M]. Shanghai: Shanghai Jiao Tong University Press, 2007.

[2] Jamshidi M M. System of systems engineering: Innovations for the 21st century [M]. Hoboken: John Wiley & Sons, Inc., 2009.

[3] Sose.org. International conference on system of systems engineering [EB/OL]. (2022-02-15) [2022-04-05]. http://www.ieee.sose2007.org.

[4] Chen P, Clothier J. Advancing systems engineering for systems-of-systems challenges [J]. Systems Engineering, 2003, 6(3):170–183.

[5] Guo L. Estimation, control, and games of dynamical systems with uncertainty [J]. SCIENTIA SINICA Informationis, 2020, 50(9):1327–1344.

[6] Hipel K W, Jamshidi M M, Tien J M, et al. The future of systems, man, and cybernetics: Application domains and research methods [J]. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 2007, 37(5): 726–743.

[7] U.S. Department of Defense. System of systems engineering [R]. Washington DC: U.S. Department of Defense, 2004.

[8] Keating C, Rogers R, Unal R, et al. System of systems engineering [J]. Engineering Management Journal, 2003, 15(3): 36–45.

[9] Kaplan J M. A new conceptual framework for net-centric, enterprise-wide, system-of-systems engineering [R]. Washington DC: National Defense University, 2006.

[10] Luzeaux D, Ruault J R, Wippler J L. Complex systems and systems of systems engineering [M]. Hoboken: John Wiley & Sons, Inc., 2013.

[11] Office of the Deputy Under Secretary of Defense for Acquisition and Technology. System of systems engineering guide: Considerations for systems engineering in a system of systems environment v1.0 [M]. Washington DC: Office of the Deputy Under Secretary of Defense for Acquisition and Technology, 2008.

[12] DeLaurentis D, Sindiy O, Stein W. Developing sustainable space exploration via system-of-systems approach [C]. Reston: Proceedings of AIAA Space 2006 Conference, 2006.

[13] Fritz S, Scholes R J, Obersteiner M, et al. A conceptual framework for assessing the benefits of a global earth observation system of systems [J]. IEEE Systems Journal, 2008, 2(3): 338–348.

[14] DeLaurentis D. Understanding transportation as a system-of-systems design problem [C]. Reno: 43rd AIAA Aerospace Sciences Meeting and Exhibit, 2005.

[15] Hause M. The unified profile for DoDAF/MODAF(UPDM) enabling systems of systems on many levels [C]. San Diego: 2010 IEEE International Systems Conference, 2010.

[16] Hossain N U I, Jaradat R M, Hamilton M, et al. A historical perspective on development of systems engineering discipline: A review and analysis [J]. Journal of Systems Science and Systems Engineering, 2020, 29(11): 1–35.

[17] Keating C B, Katina P F. Systems of systems engineering: Prospects and challenges for the emerging field [J]. International Journal of System of Systems Engineering, 2011, 2(2–3): 234–256.

DOI 10.15302/J-SSCAE-2022.04.005

[18] Sahin F, Sridhar P, Horan B, et al. System of systems approach to threat detection and integration of heterogeneous independently operable systems [C]. Quebec: Proceedings of 2007 IEEE International Conference on Systems, Man and Cybernetics, 2007.
[19] Curry E. System of systems information interoperability using a linked dataspace [C]. Genova: IEEE 7th International Conference on System of Systems Engineering, 2012.
[20] Sahin F, Jamshidi M, Sridhar P. A discrete event xml based simulation framework for system of systems architectures [C]. San Antonio: 2007 IEEE International Conference on System of Systems Engineering, 2007.
[21] Mittal S, Martin J L R. Netcentric system of systems engineering with DEVS unified process [M]. Boca Raton: CRC Press, 2013.
[22] Sharawi A, Sala-Diakanda S N, Dalton A, et al. A distributed simulation approach for modeling and analyzing systems of systems [C]. Monterey: Proceedings of the 2006 Winter Simulation Conference, 2006.
[23] Zhou X. Formation mechanism and development trend of smart court [J]. Journal of Xi'an Jiaotong University (Social Sciences). 2021, 41(3): 131–140.
[24] Li X. Theoretical basis and Chinese practice of the construction of smart court [J]. Journal of Political Science and Law, 2021 (5):128–138.
[25] Xu J F, Sun F H, Chen Q W. Introduction to smart court system engineering [M]. Beijing: People's Court Press, 2021.
[26] Shannon C E. A mathematical theory of communication [J]. The Bell System Technical Journal, 1948, 27(3): 379–423.
[27] Rao M, Chen Y, Vemuri B C, et al. Cumulative residual entropy: A new measure of information [J]. IEEE transactions on Information Theory, 2004, 50(6): 1220–1228.
[28] Asadi M, Zohrevand Y. On the dynamic cumulative residual entropy [J]. Journal of Statistical Planning and Inference, 2007, 137(6): 1931–1941.
[29] Burgin M. Theory of information: fundamentality, diversity and unification [M]. Singapore: World Scientific Publishing Company, 2010.
[30] Daft R L, Lengel R H. Information richness: A new approach to managerial information processing and organization design [J]. Research in Organizational Behavior, 1983 (6): 191–233.
[31] Liang J Y, Qian Y H. Information granules and entropy theory in information systems [J]. Science in China Series F: Information Sciences, 2008, 51(10): 1427–1444.
[32] Gaziano C, McGrath K. Measuring the concept of credibility [J]. Journalism quarterly, 1986, 63(3): 451–462.
[33] Alberts D, Garstka J. Basic principles and measurements of network-centric actions [M]. Translated by Lanke Research Center. Beijing: National Defense Industry Press, 2007.
[34] EMC Education Services. Data science & big data analytics: Discovering, analyzing, visualizing and presenting data [M]. Hoboken: John Wiley & Sons, Inc., 2015.
[35] Department of Defense Architecture Framework Working Group. DoD architecture framework version 1.5 volume I: Definitions and guidelines [EB/OL]. (2004-04-23) [2022-04-05]. https://dodcio. defense.gov/Portals/0/Documents/DODAF/DoDAF_Volume_I.pdf.
[36] Xu J F, Liu Z Y, Wang S L, et al. Foundations and applications of information systems dynamics. Engineering [EB/OL]. (2022-07-11). https://doi.org/10.1016/j.eng.2022.04.018.
[37] Organization for Economic Co-operation and Development. The E-government imperative [M]. Paris: OECD Publishing Service, 2003.
[38] Rosa J, Teixeira C, Pinto J S. Risk factors in e-justice information systems [J]. Government Information Quarterly, 2013, 30(3):241–256.
[39] Magnus R, Courts S S. e-Justice: The Singapore story [C]. Washington DC: The 6th National Court Technology Conference for the National Center for State Courts, 1999.
[40] Andrade A, Joia L A. Organizational structure and ICT strategies in the Brazilian justice system [J]. Government Information Quarterly, 2010, 29(1): 32–42.
[41] de Vuyst B, Fairchild A. The phenix project: A case study of e-justice in Belgium [C]. Boulder: Proceedings of the 8th International Conference on Electronic Commerce, 2006.
[42] Xu J F, Tang J, Ma X F, et al. Research on metrics and models for objective information [J]. SCIENTIA SINICA Informationis, 2015, 45(3): 336–353.
[43] Xu J F, Wang S L, Liu Z Y, et al. Objective information theory exemplified in air traffic control system [J]. Chinese Journal of Electronics, 2021, 30(4): 743–751.
[44] Thorne S. Report: AI in the law [EB/OL]. (2018-11-08) [2022-04-14]. https://www.diplomaticourier.com/posts/report-ai-in-the-law.
[45] Maldonado J. China's supreme court will allow blockchain to authenticate Evidence [EB/OL]. (2019-02-22) [2022-04-14]. https://www.natlawreview.com/article/china-s-supreme-court-will-allowblockchain-to-authenticate-evidence.