Design and Realization of Joint Demonstration and Evaluation Supporting Environment for SoS based on Cloud Computing Mechanism

Zhang Jing, He Yan, Li Ze-min, Tang Li-jian, Zhang Bin, Chen Li-li

***Abstract*—**For the reason that System of Systems (SoS) being composed of various elements and the inner relationships being complex, when demonstrating and evaluating the capability and efficiency of SoS, all the important factors should be organically integrated and comprehensively analyzed with the corresponding methods. Yet it's difficult to deal with them for 4 reasons mainly: 1) the complexity of the factors being very high; 2) different methods should be provided to different factors; 3) different factors being mastered by different types of experts and in different places; 4) the inner relationship between factors being complicated either. To solve all the problems above, it's necessary to utilize the Joint Demonstration and Evaluation Supporting Environment for SoS, i.e. JD&ESE-SoS, usually. Then all the "problem-factor-expert-method" about the SoS could be combined well. Based on analyzing the mission and requirements of Joint Demonstration and Evaluation (D&E) for SoS, the design and realization requirements of JD&ESE-SoS were studied, the disadvantages of several existing relevant systems were clarified. According to comparing the SoS characteristics with cloud computing technology, JD&ESE-SoS was designed. Finally, the practical scheme and architecture for design and realization of JD&ESE-SoS were proposed, the prototype was completed and some applications were given. It proved that JD&ESE-SoS could organize the core business flow of SoS D&E and schedule the relevant resources very well.

***Keywords*—**SoS, System of Systems; Joint Demonstration and Evaluation; Cloud Computing; Service Oriented Architecture; Core Business Flow

I. Introduction

SoS demonstration and evaluation, SoS-D&E for short, is a kind of decision activities on development of SoS, which could insure the science and validity of the decision activity. SoS is very complex, immersed, structural and uncertain [1-4], which need to design and realize effective methods and tools for SoS-D&E to improve the result's science and validity. Therefore, it is important and urgent to design and realize the proper software supporting environment for SoS.

Meanwhile, it is necessary to consider all the effect factors to SoS, but these elements are always distributed, saved by different team, and could play special role in the different processes of analysis and evaluation. Therefore, it must combine all elements with the joint method to analysis and evaluate the capability and efficiency of SoS. Then, JD&ESE-SoS, Joint Demonstration and Evaluation Supporting Environment for SoS, was designed and developed by us to support the analytical mode and can run intelligently and efficiently which could be customized by demands either.

The paper studied deeply the demand and requirements of designing and realizing JD&ESE-SoS, discussed the present situation and disadvantages of some regular SoS demonstration and evaluation supporting systems. The paper proposed the principle, overall plan and key technologies, analyzed the correlation between cloud computing and SoS research requirements comprehensively, and completed the system's general design and overall software framework based on the cloud computing theory and technology. Then the JD&ESE-SoS prototype was fulfilled after some key problems were solved, such as the basic resources scheduling technology, the X on-Requirement service technology, etc. and has been put into application to deal with some SoS analysis issues.

II. Requirements Analysis of JD&ESE-SoS

A. Essential Demands

JD&ESE-SoS generally includes universal technological tools and implementation measures which can support Joint Demonstration and Evaluation and could serve the complex SoS. Precisely, according to the demand of SoS, JD&ESE-SoS is a series of basic programming framework and application programming systems/tools, which could be applied in the all procedure and various tasks of Joint Demonstration and Evaluation. Meanwhile, the framework and systems/tools serve the all procedure of analysis and evaluation and emphasize the feature of Information System's function and application.

Therefore, JD&ESE-SoS could standardize the procedure of Joint Demonstration and Evaluation. It should support all

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the key steps during SoS demonstration and evaluation, such as analysis discussion, scenario development, modeling and simulation, simulation evaluation, dynamic analysis, resource management, coordinated operation, etc. JD&ESE-SoS is an integrated, standardized, flexible and exoteric Joint Demonstration and Evaluation environment, which could be customized, can schedule resource independently and operate more efficiently.

B. Related Work

It is a universal method to establish specialized, comprehensive, integrated Joint Demonstration and Evaluation Environment to assist evaluation for SoS research and application. For example, since 1990's, based on the all services and arms' experience, USA has initiated unified modeling and simulation system framework, such as JMASS, JSIMS, JWARS, JICM, FLAMES and put it into practice, which had improved the evaluation ability level greatly [5].

Especially, on the global strategy research and long-term programme research of weapons, USA paid more attention to application of simulation systems and applied these systems into weapons lifecycle, including demands analysis, conception design, weapon type development, simulation experiments, and weapon disposition. USA has put into a large number of human and funds to some significant weapons simulation systems and has formed the implement specification, theory and technology of joint demonstration and evaluation.

Although SoS research began recently in China, it aroused much attention. And developing kinds of supported software or tools was also started for more than 10 years. The basic general supporting applications and engineering criterion were established, and some basic data and models were developed and accumulated.

C. Development Requirements

Now SoS research is still in the embryonic stage, and mainly serves single and special designated task. In order to meet the SoS characteristics and requirements, the software must satisfy the joint need [6, 7]. So the main functions which JD&ESE-SoS should support were listed as follows.

1) JD&ESE-SoS should be a technological support environment which could be adapted to the demands of different kinds and different application background tasks;

2) JD&ESE-SoS should be executed under the pattern of integrated, comprehensive, cooperative mode.

3）JD&ESE-SoS should meet all the demands of SoS research and should be more flexible, efficient and repeatable according to the idea of varied application, open structure, coordinated operating, X on-Requirement, etc..

4) JD&ESE-SoS should establish standard, unified, integrated analysis and evaluation procedure and operating pattern which should be explicit and adapt to the SoS researcher's habits.

5) Strengthen JD&ESE-SoS' application and carry out its extensive validation widely. And the basic model and data could be accumulated continuously and shared interactively by JD&ESE-SoS.

III. High Level Design of JD&ESE-SoS

A. Basic Principles

The determinants of the effectiveness and availability of the JD&ESE-SoS could be in essence abstracted for seven aspects,

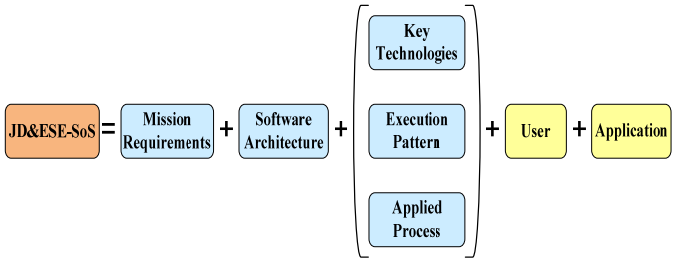

Fig. 1: Impact factors of JD&ESE-SoS

i.e. the mission requirements, software architecture, key technologies, execution pattern, applied process, user, and application, as shown in Fig. 1.

Among them, the first five factors could be looked on as the internal causes and should be solved by the system itself. ***Mission Requirements*** specify the objectives that the system design should achieved. ***Software Architecture*** guides the design, implementation and improvement. ***Key Technologies*** support the core functions of system. ***Execution Pattern*** affects the availability and practicality of system. ***Applied Process*** specifies and enhances the application ability of the system. The latter two factors are external factors, which can affect the system development application and effectiveness. ***Users*** include direct users and indirect users. The direct users are the related demonstration staff/institutions, who use the system directly to support its day-to-day works of various demonstration and evaluation. Indirect users are the superior officers of the various demonstration institution, who do not use the system directly, but would use the data and conclusions resulted by demonstration and evaluation system. And ***Application*** refers to the system be used by different users to earnestly solve specific problems. All the seven elements affect and restrict each other. Thus, Effective solutions must be established, since only balanced development can promote the improvement and the capacity of SoS-D&E.

B. General Scheme

JD&ESE-SoS requires an open software architecture, which could provide service-oriented solutions to a variety of techniques or application problems involved with the system design, development and appliance. The resources of SoS analysis, including basic data, model, and utility softwares or tools, could be treated as series of services. Then different kinds of services could be further composed and scheduled in a loosely-coupled, well-coordinated way. The general scheme was designed based on service-oriented theory and illustrated

by Fig. 2.

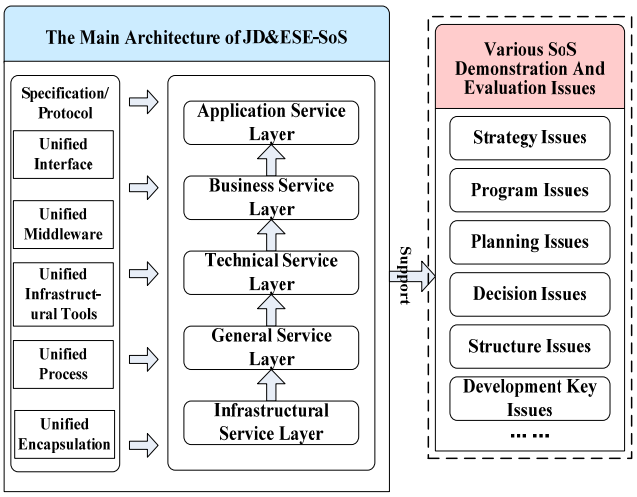

Fig. 2: The general, service-oriented architecture for JD&ESE-SoS

The general architecture contains a series of service sets for different JD&ESE-SoS tasks. The service sets can be organized as a layered structure; from bottom to up they are Infrastructural, General, Technical, Business, Application service layers. Each layer is composed of a series of services. The services in the same layer could be invoked by each other, and the upper layer can invoke the services in the lower layers.

must conform to the unified standard or specification. Through the unified interface, middleware, infrastructure, process, and encapsulation, the mechanism of service composition and execution can be properly implemented. To ensure all the services could be managed and scheduled by JD&ESE-SoS, they should obey some specifications and protocols to provide the unified interface, act as the unified middleware, execute under the unified process, as encapsulate in the unified formation. So the specifications and protocols would be one of the most important factors.

The Infrastructural Services Layer (ISL) refers to the underlying network environment, a variety of general-purpose /specific-purpose hardware and software equipment, which are necessary in the whole process of system design, development, execution and maintenance, DDEM (Design, Development, Execution, & Maintenance) for short. Meanwhile, the fundamental data of JD&ESE-SoS reside in the infrastructure services layer, so as to constitute the foundation hardware and software environment of DDEM system, and provide related support functions in the form of services.

The General Services Layer (GSL) includes a variety of basic public services that not directly related to the SoS-D&E tasks in the system DDEM process, including packaging and integration services, data access services, information directory services, logging services, document management services, two-dimensional graphics services, 3D rendering services, middleware services, which provide the underlying technology for supporting the organic functioning of the

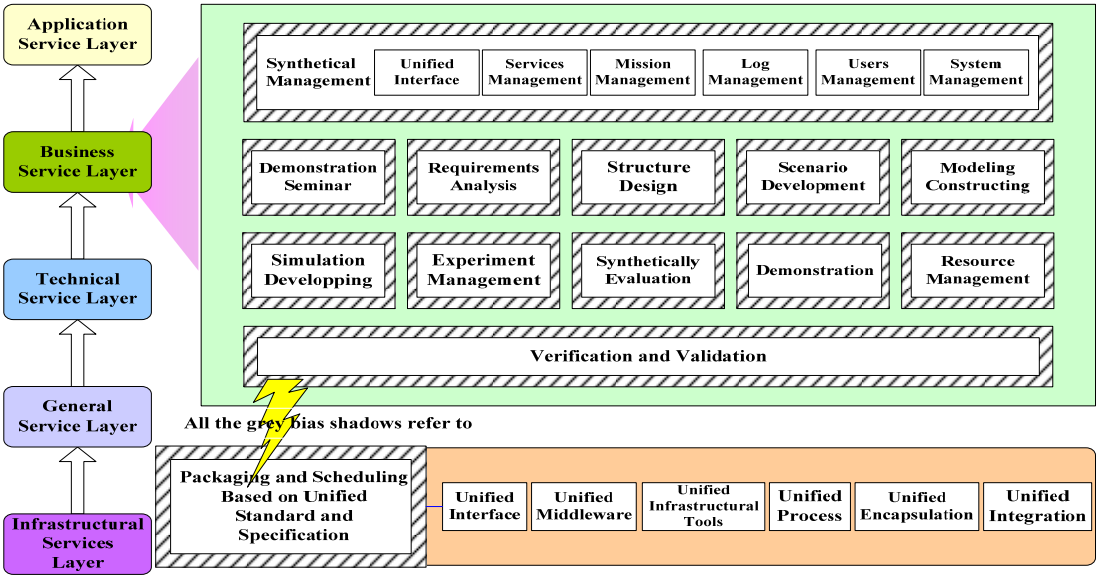

Fig. 3 The composition of the Business Service Layer

The invocations, either on the same layer or across layers,

The Technical Services Layer (TSL) includes the various technical services with direct relations to SoS-D&E tasks in the system DDEM process. It directly supports the implementation and use of key technologies of the platform. It mainly include technology services for requirements analysis

software environment.

of SoS, technology services for SoS demonstration data build / shared, technology services for demonstration task decomposition and scheduling, and so on, to form a set of technology-oriented system of joint demonstration and assessment service means. These services form a complete set

of technology service means for JD&ESE-SoS.

The Business Services Layer (BSL) refers to the specific business required to carry out for JD&ESE-SoS. It mainly includes demonstration seminar, requirements analysis, scenario development, modeling constructing, simulation development, experiment management, synthetically evaluation, demonstration, resource management, collaborative operation, and so on, which play roles in the delicate phase. By scheduling customized business services, achieve flexible organization for different A&E tasks. It provides management services synthetically, to implement the unified use of system, independent call, centralized management and co-operation. The composition of BSL is shown as Fig. 3.

The Application Services Layer (ASL) refers to the relevant outcomes which are formed by gradual accumulation in the long-running process and closely associated with specific applications.

And Fig. 3 gives a description of the composition of the Business Service Layer. It's composed of several modules, such as Synthetical Management Module, Demonstration Seminar Module, Requirement Analysis Module, SoS Structure Design Module, Scenario Development Module, Modeling Constructing Module, Simulation Developing Module, Experiment Management Module, Synthetical Evaluation Module, Demonstration Module, Resource Management Module, and Verification and Validation Module. And the grey bias shadows in Fig. 3 mean the unified specifications and protocols to package and schedule each module in different layers.

IV. The Scheduling Technique of SoS Evaluation Resources Based on Cloud Computing

Cloud computing is a mean of information processing and develops rapidly in recent years and has made a wide range of applications and tremendous benefits of commercialization [9]. In essence, cloud is a computational model, which distributes computing tasks among the resource pool of a large number of computers, enabling users to access to the computing power on-demand and timely, storage space and information services. Its features and requirements of SoS share many similarities, thus the cloud is particularly suitable to solve the problems of complex structure, large scale, diversity applications, hierarchy, massive data, and efficient computation. Although the cloud is mainly applied in the commercial field, as a new theory and technology, its highly integrated, advanced concepts, ingenious design and efficient performance, should attract the attention of SoS researchers'. With its guidance, it is expected to solve part of the hard problem, and may even have a revolutionary impact.

A. The Nature and Pattern of Cloud Computing

While cloud computing still lacks a precise definition and common understanding has not yet unified, the characteristics and usage patterns of it can be summarized as follows, that is a technology facilitating large-scale, low-cost computing units with a network connection to provide a variety of services. With the support of cloud computing, the applications do not need to run on the user's PC, mobile phones and other terminal equipment, but running in a network of large-scale server clusters. Data processed by users does not need to store locally, but stored in the data center of the network; the services provider of cloud computing is responsible for the management and maintenance of the data center; the users can access the services of any business at any time and any place, with any terminal equipment in any way on the network. As a result, we achieve the use-on-demand on the cloud.

At the meantime, cloud computing should meet the following requirements:

1) large-scale processing, a cloud computing system is a cluster consisting nodes of a certain scale.

2) smoothly expansion, the cluster system should have good scalability and flexibility.

3) resources sharing, the system can provide one or more forms of resource pools, and can be further abstracted and integrated to offer a variety of application services.

4) dynamic allocation, which requires automatic resource allocation management, including real-time monitoring of resources, and automatic scheduling.

B. Principles of the Cloud

Cloud computing is a result of mashing multiple technologies up. It's mature enough to play an important role in Civilian area, and it has generated huge economic benefits. According to the abstraction of various kinds of resources, cloud system is classified into 3 types mainly, i.e. IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service). These types of cloud provide the users with services from generic to specific, respectively [9].

IaaS cloud systems, such as Amazon's EC2 (Elastic Cloud Computing), encapsulate hardware appliances into a service for the user. In a IaaS system, the user is equivalently using a bare machine with disk(s), so he has the option to run any operating system. The system gives the users an illusion of "unlimited" resources, so as to use the resources more efficiently, but it also forces the users themselves to think about how to coordinate the resources. ***PaaS*** cloud systems, such as GAE (Google App Engine), provides an executing environment to the user's application. PaaS systems take the charge of dynamic scaling and fault tolerance of various resources, freeing the user's application from the coordination of nodes, while giving users much less options. Users have to use specific editing environment as well as programming pattern. For example, GAE only gives the options of Python language, Java language, GAE SDK and a web framework Django to users for developing online service applications. ***SaaS*** cloud systems have stronger pertinence and specificity by encapsulating a certain software into a service. For example, salesforce.com provides a CRM service. With the rapid development of cloud computing, the above mentioned cloud systems penetrate each other and melt together, in order to provide more convenient and complete service.

C. Using Cloud Computing to Schedule the Resources of SoS Demonstration and Evaluation

Clouding is a form of high-performance computing that focuses on data, with its specific patterns and technologies on data storage, data management, programming model, concurrency control and system management. In order to effectively provide various services with huge amount of resources, clouding computing comprehensively uses various technologies such as virtualization, distributed storage, parallel programming, data modeling, resource management, platform management, granularity computing, security management, greening computing, etc. These technologies which could be applied directly on System of System Evaluation include virtualization, distributed storage for mass data, parallel programming, multi-granularity/varying-granularity computing, complex system coordination, security management, etc. With these technologies, we can effectively solve the problems currently found in developing SoS Joint Demonstration and Evaluation Supporting Environment, such as lacking of advanced and efficient SoS analysis and processing methods, lacking of a universal framework that describes the activities of System of System Evaluation. Although it still remains to be in the stage of theoretical research and feasibility analysis, we think cloud computing is worth a try for solving the bottle neck problems in System of System research, according to the success stories of cloud computing. The comparison and analysis between SoS and Cloud Computing are listed in Table 1 as follows.

Table 1 Features of Cloud Computing VS. Requirements of SoS Research

objects / characteristics	Requirements of SoS	Features of Cloud Computing
Scale of processing	Depends on the complexity of target problem	Elastic; scale according to the complexity of target problem
Pattern of application	Complex, various; high demand on timeliness	Varied; suitable for frequent request and high concurrency
Computing capacity	High-demand; high- Ultra-real-time; often need large-scale of computing resource	High-demand; need to provide services and response in time
Pattern of execution	Based on LAN; executable on a single machine or a cluster	Based on the Internet; distributed
resource storage	Unified storage for authoritative data, public data and experiment data; sharing on demand; supporting local copies of	Unified storage and management; no local data copies
Security demand	Very high	High
Basic data	Complex types; large amount; big data	Complex types; large amount
Granularity computing	Hierarchical relationships between different applications; need different approaches	Provides multi-granularity/varying-granularity services for applications
Human-machine interaction	Need human-in-circuit analysis for researches as Confrontation Simulation, etc.	Suitable for different types of users, scenes with many user interactions
Usage mechanism	Application should be separated from the framework, allowing users to develop applications easily, conveniently and seamlessly	Being agile and flexible based on some standard, which is mature and easy to use

V. REALIZATION OF JD&ESE-SOS

A. The Execution Pattern

According to the demand of SoS Joint D&E mission, we have designed and implemented a cloud-based basic framework to schedule various resources of SoS D&E including models, data, systems and humans, as shown in fig. 4. With the mechanisms of cloud computing, we organically integrate the users, tasks, application requests and the service requests from terminal devices. And we use cloud systems to provide unified and efficient computing resource, storage resource and management mechanism. Because of the diverse nature of SoS research, this giant "cloud" will certainly fully cover IaaS, PaaS and SaaS modes. For example, Joint Exercise Deployment can base on IaaS, whereas model-driven development [10, 11] and integration would use PaaS, and resource verification, model certification and report generation will be SaaS.

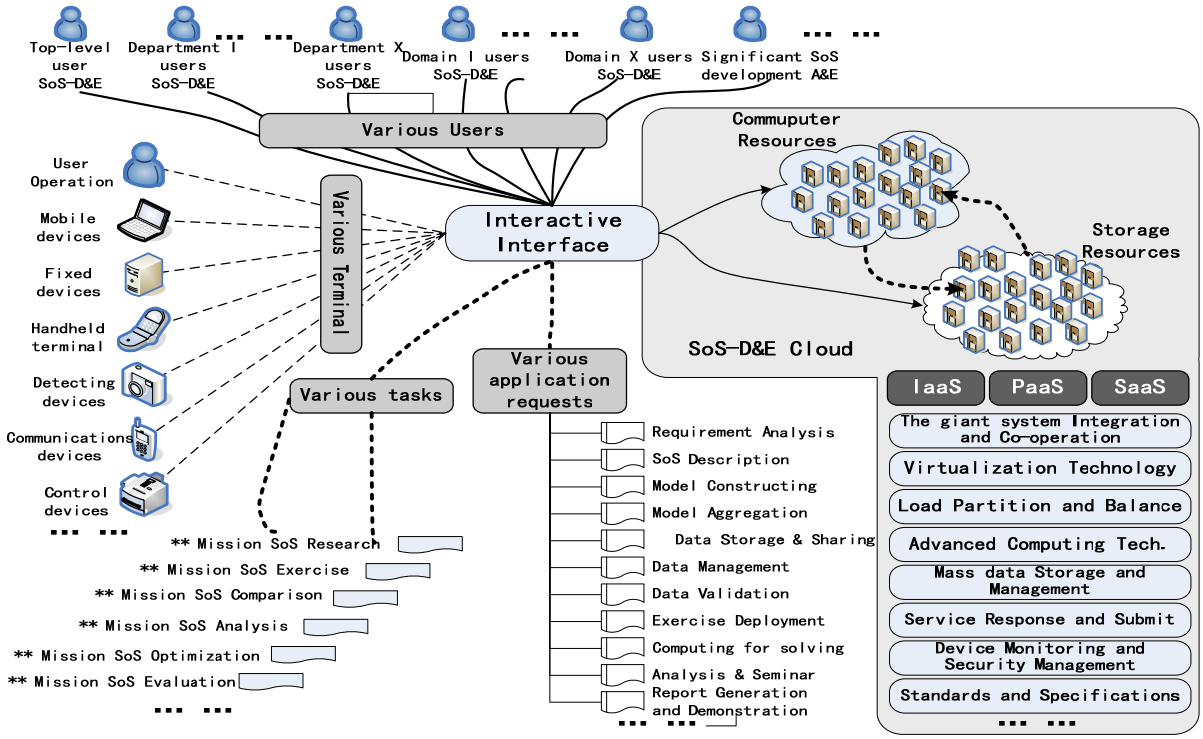

Fig. 4 Main technical framework of SoS Evaluation resources scheduling based the cloud technology

B. The Application Process

JD&ESE-SoS emphasizes to provide supports to SoS D&E's whole processes and all the businesses. And the supports could be customized on demands and organized dynamically. According to dividing and assigning the D&E mission, all the necessary resources would be supported to each participant by JD&ESE-SoS with the normative and standard manners. When accepting the SoS D&E mission, the D&E experts could deal with different types of D&E works in the special supporting environment. The basic application process is shown in Fig. 5.

Firstly, in the D&E Synthetic Management step, the mission type would be determined according to consult and discussion. Then the proper execution flow framework to the mission could be created. And the detailed steps in the execution flow and the relevant requirements could be confirmed. Furthermore, all the necessary supporting technology to each D&E step could be drawn and the necessary D&E resources, such as data, model, software, hardware, and so on could be selected and constructed either. Then, an integrated and executable D&E core business flow would emerge finally. The business flow would be carried out and the corresponding results would be gotten, such as the result data, report, table, figure, and so on. Meanwhile, all the results could be analyzed and illustrated by JD&ESE-SoS

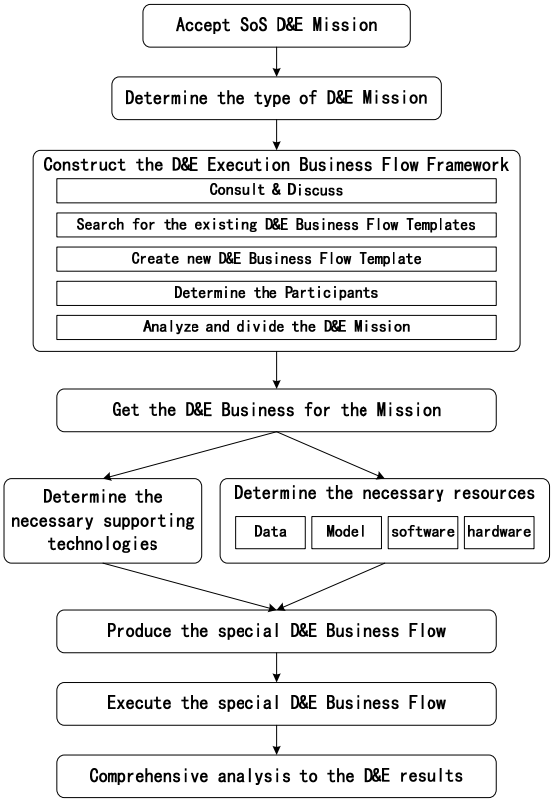

Fig. 5: Application Process of JD&EP-SoS

C. The Pivotal Technology

According to the introduction to JD&ESE-SoS in chapter III, the conclusion could be drawn that JD&ESE-SoS would

be a complicated huge software system. To design and develop it, many pivotal technologies should be solved at first. The main important technologies include 9 aspects as follows.

- the general design technology to JD&ESE-SoS;
- the requirement analysis technology;
- the architecture design technology based on service mechanism;
- the execution process technology based on the cooperative business flow;
- the various D&E resources scheduling technology based on cloud mechanism;
- the D&E model engineering technology faced to multiple business;
- the whole life-cycle data engineering technology faced to the joint D&E;
- the various kinds of evaluation technologies to SoS D&E;
- the integrated illustration and verification technology faced to different scene.

According to the cloud computing methods, techniques, and mechanism, we could find some good solutions to the technologies above. Based on solve the difficult problems through cloud computing, the Joint Demonstration and Evaluation Supporting Environment, abbreviation as JD&ESE-SoS, was designed and realized by our research team for about 2 years. Fig. 6 shows the main GUI of a system based on this. There are different sections in the interface to organize different processes of demonstration & evaluation (D&E). User could execute all the businesses to complete a special D&E mission in the same software environment and utilize all the resources stored in the supporting platform. Furthermore, all the hardware, data, model, application system, and so on, divided in the distributed network background, could also be utilized to operate cooperatively.

Meanwhile, JD&ESE-SoS was tested and utilized by some real different SoS D&E mission. From the application, JD&ESE-SoS was kept being improved. And the SoS D&E procedure could be standardized and specified. Furthermore, the most important benefit to use JD&ESE-SoS is that all the necessary D&E resources could be accumulated and reused. And all the work done by experts could be integrated as user's requirements. Then the efficiency and quality would be improved effectively.

Fig. 6: The main interface of JD&ESE-SoS prototype

VI. Conclusion

According to the mission of SoS research of present stage and its progress, for utilizing cloud computing we should focus on the following 5 points:

1) based on technologies of complex system coordination, build system framework of SoS research.

2) based on the computing-centric approach, design solutions of supporting environment for SoS Joint Evaluation, Joint Exercise, Joint Run.

3) based on data center, plan and construct the project of SoS research data.

4) based on services, start hierarchical and multi-purpose SoS research.

5) strengthen research on supporting technologies and basic services.

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