Techniques for System of Systems Engineering in Construction of a Smart Tourism Industry Information System

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***Abstract*—Currently, as many disciplines begin to cultivate a set of core methodologies, system of systems engineering (SoSE), which has its root in context of military programming, becomes a significant research focus and provides a new perspective to solve the emerging "system of systems" challenges in industrial analysis. Meanwhile, modern communication and information technologies have provided greater possibilities for socio-economic sectors to execute smarter decisions, and these technologies may advance the industrial application of SoSE. Therefore, targeting the rareness of government-oriented intelligent decision support system (DSS), and guided by the underlying system of systems thinking, this paper proposes a technical framework for designing a policy maker-responsive smart information system which focuses: (1) system of systems structural architecting; (2) geographical simulation using time-series remotely sensed data, GIS instrument and simulation bodies such as cellular automata (CA) and multi-agent systems (MAS); (3) SoS evolution description through network analysis and intelligent computing; (4) measurement of SoS effectiveness with two-tier and four-grade method; and (5) SoSE program for industrial optimization. Its application in tourism analysis will provide a smarter base for industrial policy-making, planning and forecasting, and will help reduce risk and cost in industrial restructuring. For this relatively new field of SoSE application, tools and methods are not perfect, so it is important to draw together academia, government, industrial organizations and enterprises to collaborate for further valuable achievement.**

***Keyword*—System of systems engineering (SoSE), geographical simulation, tourism, smart industry information system, intelligent computing**

I. INTRODUCTION

IN the information age, as computer communication, internet of things, distributed control, cloud computing and many other fields of technology advance, originally separated individual systems (or system elements) become capable of connecting to each other by information "ties", forming a meta-system that involves various heterogeneous distributed systems (including policies, economies or technologies) [1]. Decision makers within government and industry encounter a prevalent problem of increasing complexity, which are of system-of-systems type [1]. This is particularly evident in tourism industry. Tourism plays an important role in national economies of many countries. Therefore, growth of the industry results in complex networks consisted of expanding conventional components and newly generated cross-sector systems. These growing complexities, which is of system of systems type, have challenged the system-engineering-principles based industrial analysis in investigating the industry architecture and evolution, making effective decision-support become unmanageable [1].

This becomes a problem to be solved in construction of decision support system (DSS) as well. There are 3 different types of tourism-related information systems: (1) tourist-oriented information system (TIS). It provides information on tourist attractions, itineraries, logging and accommodations and tour guide, ect. for tourists or potential tourists. For instance, Ren developed a Tourism Information System for Wuhan City, China based on MapGIS K9, with the aim, principle, overall framework and function module design. The study emphasized the feasibility and broad prospect of the GIS technology in construction of such systems [2]; (2) Tourism enterprise-oriented information systems (TES). It is a tourism management information system aids managerial or marketing behaviors of individual corporate. Taking the Sanzhualun National Forest Park as an example, Wang and Chen introduced the use of WebGIS technology in forest park tourism information system development [3]. Wan and Tang established a persistent data frame using .NET platform and Castle technologies, and applied it into developing a travel management system [4]. (3) Policy/industrial decision maker-oriented system (Tourism industry information system, TIIS). It mainly provides support for decision making process of governments, industrial organization. Li and Zhan presented the realizing schemes and process of the object-oriented data model in the construction of a Tourism Information

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Management System (TIMS) [5]. A set of synthetical function indexes were incorporated into the system so that it can provide city tourism administration agents several decision making services such as tourist attraction analysis, regional tourism planning, tourism product and tourist itinerary design.

The information provided by the 3 types of information systems is significantly different. Differs from TIS and TES, TIIS has to concern more on macro environment dynamics and complex stakeholder networks, and it has more work to with big data. Therefore, smart or virtual communication is widely used in micro-management practices (e.g., corporate or profession administration), but when it comes to macro-management on industrial or regional level, due to the need of both large-scale geographical information and diverse simulation models, government/industry-oriented intelligent decision support system is relatively rare.

Therefore, inspired by the embedded "system of systems (SoS) thinking" in the text of military programming, this paper attempts to architect a policy maker-responsive smart tourism industry information system and proposes the related modeling techniques and approaches.

II. System of Systems and System of Systems Engineering

A. System of Systems

Development of information and communication technologies have changed the form and frequency of the interactions among social systems, therefore, at the beginning of the 21st century, the concept of "system of systems" [6-7] began to become an emerging internationally research focus in system science[8]. Many research centers, such as the National Centers for Systems of Systems Engineering (NCSoSE) and the SoS Engineering Center of Excellence (SoSECE), were established to study complex systems of systems problem domains in different fields.

Though without a widely accepted definition, the core of concept is commonly recognized [9]. Sage and Cuppan suggested that a SoS has to meet the Maier's five criteria [10], and Keating defined SoS as a meta-system consists of multiple individual systems that diversified in operating context, geographic location, conceptual architecture and function mode [11]. To some extent, SoS is a task-oriented system alliance, which possess the resources and capabilities of each component system and performs more productive than the sum of the individual systems. Therefore, SoS is often designed to solve the multi-system interaction and /or integration problems[12], dealing with inherent complexity domains [13].

In recent years, differences between SoS and general system have been recognized, and architectural design, resource confrontation and performance evaluation for SoS have become increasingly emphasized in national defense, aerospace exploration, information or communication networks, transportation, energy, healthcare, environment preservation, management and many other application fields [12].

B. Socio-Technical Features of Systems of Systems

Differentiated from simple general system, system of systems has several significant socio-technical features [8]: (1) large in scale, complex in architecture, and composed of multiple component systems; (2) the component systems demonstrate wide geographic distribution, and they have operational, functional or managerial independence; (3) having unfixed targets under a specified purpose, and the SoS resources can be dynamically configured to meet diversified needs of multiple tasks; (4) components systems share interdependence, interoperability and can run concurrently in executing a specified plan; (5) developing under centralized planning and administration, and producing behavioral or functional emergence in process of evolution; (6) it is critical to explore and coordinate the capabilities/resources of different component systems or stakeholders to gain collectively provided upgraded capability.

C. System of Systems Engineering

Definition, abstraction, modeling and analysis of system of systems challenges ascribe to system of systems engineering (SoSE), which is a set of developing processes, instruments, and approaches providing design or re-construction solutions.

System of systems engineering methodology is initialized by U.S. Department of Defense, and is developed mostly in military applications in many countries. But in recent years, its superiority in dealing with emerging complex socio-economic or technical problems is increasingly recognized, driving the non-defense applications. SoSE is not simply systems engineering of monolithic and complex systems, as the solution design emphasizes uncertainties in the mission requirements and the component systems, and it contains multi-level and multi-dimensional consistent engineering programs [14-15]. Rather than systems engineering concentrating on building the system right, SoSE focuses on configuration of selected systems and their resources and interactions to meet the requirements of SoS capability.

There is not a single unified consensus for processes involved in system of systems engineering. DeLaurentis suggested a three-phase SoSE framework where a SoS problem is defined, modeled and analyzed [16]. Zhang et al proposed a two-level and four-grade measure approach focusing on SoS performance [12].

III. Technologies for Smart System Architecting

In recent years, systems science (especially complexity) and geo-spatial information science are emphasized in tourism study. complex networks analysis [17], cellular automata (CA) and multi-agent systems (MAS) [18] is widely used.

However, many studies only emphasized the static industrial architectures, but ignored the dynamic evolution mechanism towards the expected goal [19]. Yang analyzed the tourism industry network and its evolution, and pointed out that the formation and evolution of the networks were driven by internal heterogeneity and external uncertainty [19]. Xue and Weng analyzed regional tourism spatial layout using economics deductive model combined with agent-based calculation. The microscopic background, influence factors and dynamic process of tourism spatial architecture changes could be "dynamically" observed through the interaction of a large number of micro agents (enterprises, consumers etc.)[20].

These research applications provide a meaningful enlightment for constructing a smart tourism industry information system. Guided by the underlying system of systems engineering thinking, and based on an integration of information and communication technologies, this paper proposes a technical framework for designing a smart information system. The phases include: (1) system of systems structural architecting; (2) geographical simulation using remotely sensed data, GIS instrument and intelligent computational agents; (3) SoS evolution description through network analysis and intelligent computing; (4) measurement of SoS effectiveness with two-tier and four-grade measure method; and (5) SoSE program for industrial optimization.

The technical route is shown in Fig. 1, and the detailed information will be stated in the subsequent sections.

A. System of Systems Structural Architecting

Tourism industrial SoS is a complex network of geographically distributed resources, market entities, consumers, stakeholders and their intensive communications, which evolutes both spatially and temporally in architecture and component systems. Emergence may be produced in the dynamic SoS evolution. Therefore, the first phase for constructing the smart industry information system is SoS architecting, namely, properly converting the industrial SoS into virtual properties in the simulation system. The structural architecting for tourism SoS is demonstrated in Fig. 2.

The basic elements of the tourism SoS to be simulated include resource entity, SoS architecture, SoS process and environment, and the component system itself is a composite element. Primary task of the study is to identify the basic units and the consequently assembled component systems, as well as structural relationships between the tourism SoS and the component systems. The smart information system consists of tourist geographical system, landscape system, industrial layout system and social System.

Fig. 2 only provides a simple conceptual model, and further improvement should be made to elaborate more elements, component systems and the embedded hierarchy and interaction networks. Moreover, an enhanced functional architecting is in need to identify the requirements for enhanced SoS functions.

B. Geographical Simulation: Cellular Automata with Geographical Multi-agent

In the second phase, the tourism SoS will be geographically simulated based on remotely sensed data, GIS modeling platform, CA and MAS instruments. Time-series simulation outputs though knowledge discovery (KDD) and data mining can provide support for the following analysis missions.

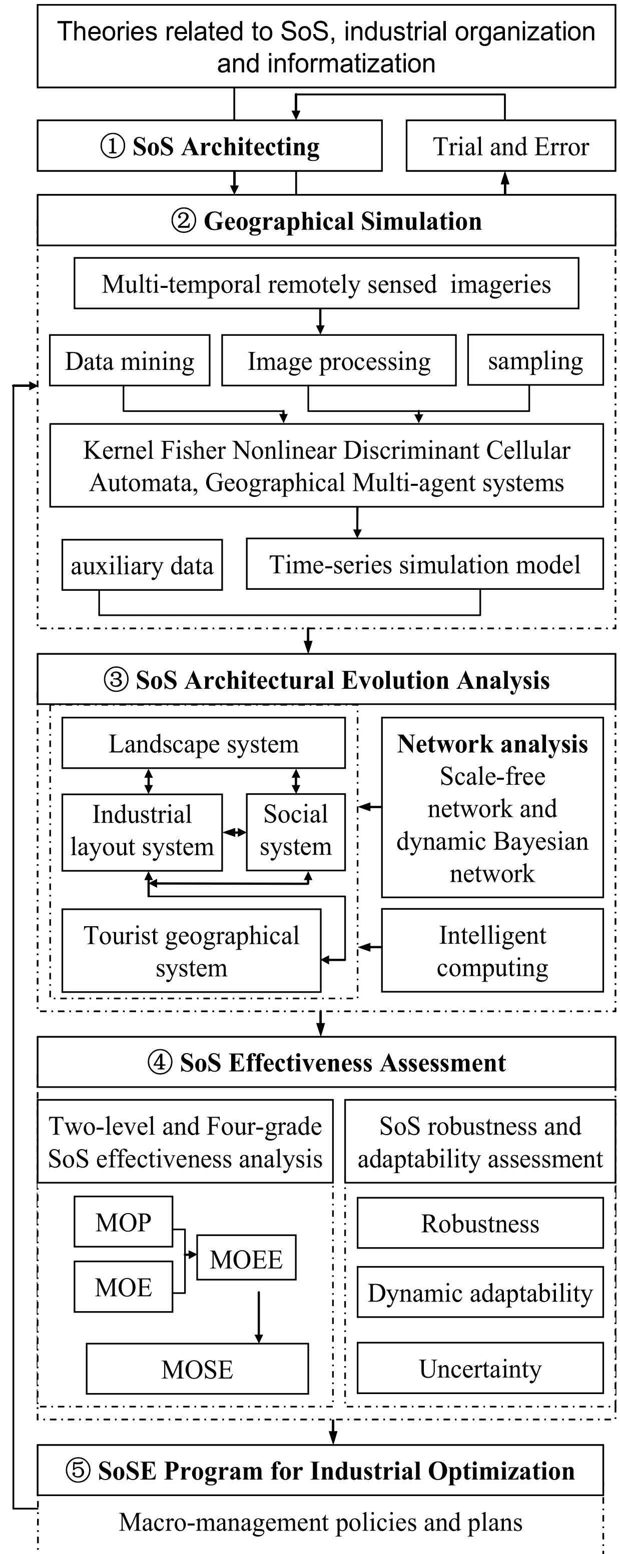

Fig. 1. Technical route for constructing the smart tourism industrial information system. The designation focuses 5 critical subsequent processes: 1) system of systems structural architecting; 2) geographical simulation using time-series remotely sensed data, GIS instrument and simulation bodies such as cellular automata (CA) and multi-agent systems (MAS); 3) SoS evolution description through network analysis and intelligent computing; 4) measurement of SoS effectiveness through two-tier and four-grade measure method; and 5) SoSE program for industrial optimization. Each of these processes is capable of outputting relevant industrial information.

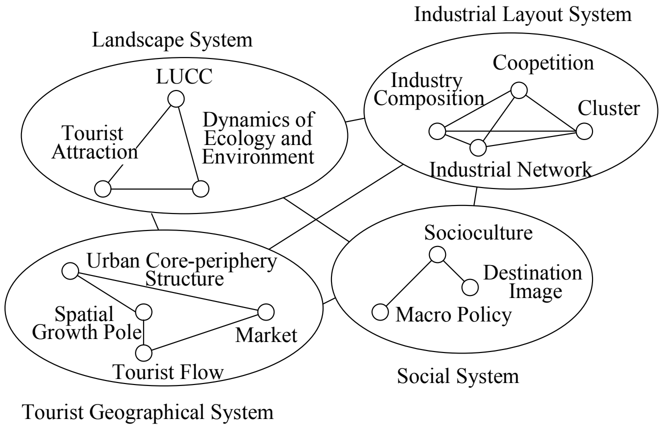

Fig. 2. Conceptual model for the smart tourism industrial information system.

The core of geographical simulation is to establish scientific geospatial systems model using appropriate research methodologies, based on application of complexity theory and combined with the inherent law of geography. Cellular automata (CA) and multi-agent system (MAS) are suited to study the complex geographic phenomenon [17].

CA is a grid dynamics model that is discrete in time, space and state, and is local in spatial interaction and temporal causal relationship. It is an important research tool and theoretical method branch of artificial life. Many studies have shown, the kernel Fisher nonlinear discriminant learning machine is superior to other methods in automatically extracting the CA transition rules. However, CA cell can not move, having limitations in dynamic environment and cell interactions, thus introduction of MAS modeling proves useful. MAS stems from a complex adaptive system, it is composed of multiple computing units (agent) mutually interacting. Spatial MAS resolves the macro space pattern formation though the interaction among microscopic individual (cell) or agent, it is very close to the real geographical world, and can reflect the characteristics of complex space systems in terms of emergence, chaos and evolution, thus has more analog advantage. MAS is a SoSE method, which can ensure the coherence of SoSE applications in tourism geographical simulation.

C. SoS Evolution Description: Network Analysis and Intelligent Computing

System network approaches such as small-world network analysis, scale-free network analysis, and social influence network theory (SINT) with dynamic Bayesian network, can be employed to simulate the growth and evolution of the tourism industry SoS. They are also effective in describing the complex interactions between the component systems. In this process, intelligent computing will play a critical role in data mining.

Small-world Network Analysis

A network in the real world usually has both certain rules and some randomness. To describe the transition from a network of rules to a random one, Watts and Strogatz introduced an interesting WS Small-world Network Model in 1998 [21]. The model can be used for analog of the derivative and evolution of a newborn or a simple component system in the tourism SoS.

Scale-free Network Analysis

Unlike the degree distribution for the exponent network, that of many large-scale complex network is a descending curve, following a power law distribution $P(k) \sim k^{-\gamma}$. As explanation of this power-law distribution, Barabási and Albert proposed the Scale-free Network Model [22, 23]. The evolution of BA scale-free network mainly has two aspects, namely growth and preferential attachment. New nodes are constantly added into the network, and it is with high probability for the new nodes to connect to the existing node with larger number of connections. The generation algorithm is as follows:

--Growth: Initially there are m_0 nodes in the network, and one new node is added at each step, the node is connected to one of the existing $m \le m_0$ nodes.

--Preferential attachment: When selecting the node to which the new node attached in the network, choice is made according to Π probability. If the degree of the node i is k_i, then the probability of the existing node to be selected is defined as:

$$\prod(k_i) = \frac{k_i}{\sum_j k_j} \tag{1}$$

In this way, after t steps, a network with $N = t + m_0$ nodes and mt edges is generated. In such a network, there are a few nodes having a very high degree (i.e., the number of nodes connected to it), while the majority of the nodes show relatively low degree. Tourism SoS is open, elements (nodes) are constantly added and the attachment features as unequal probability. Therefore, when the tourism SoS and its component systems have evolved into the near mature or mature stage of the life cycle, the application of scale-free network model will produce more realistic descriptions.

Social Influence Network and Dynamic Bayesian networks

To achieve the desired objective for the smart tourism industry information system, the SoSE program guiding the SoS evolution should make clear how to configure the SoS and achieve the best SoS configuration through circulated SoS measurements. The Social Influence Network Theory (SINT), combined with Dynamic Bayesian Networks (DBN), can fulfill this dynamic process. The SINT depends on the individual's coordination processing on the conflict viewpoints, stances and attitudes. But the output of the conflict processing results depends on the structural relationship between the individuals, such post, influence of interaction and one's sensibility (that is, to what extent can an individual be influenced) to it. Its expression is as follows:

$$y_i^{(t+1)} = a_i(w_{i1}y_1^{(t)} + w_{i2}y_2^{(t)} + \cdots + w_{iN}y_N^{(t)}) + (1-a_i)y_i^{(1)} \tag{2}$$

Wherein, t is period of time; y represents the viewpoint, position or attitude of the individual i ($i=1,2,\cdots,N$, N is the number of individuals in the group) in time period t, its initial value is $y_i^{(1)}$; w_{ij} is the weight for the influence of individual i upon individual j ($0 \le w_{ij} \le 1$), and $\sum_{j=1}^{N} w_{ij} = 1$; individual i's sensibility $a_i = \sum_{j=1, j\neq i}^{N} w_{ij}$

One of the methods to estimate w_{ij} is DBN. Bayesian network is a product of the combination of probability theory and graph theory, and is composed of network structure and conditional probability distribution. Its specific applicative architecture is determined based on knowledge principle and the structure of variable relationship. For a Bayesian network with total number of N nodes, its network architecture depends on the following set of conditional independence assumptions:

$$P(v_i | v_1, \cdots v_{i-1}, v_{i+1}, \cdots v_N) = p(v_i | parent(v_i)) \quad (3)$$

Wherein, $i=1,2,\cdots,N$; $parent(v_i)$ is the parent node corresponding to node v_i. Thus, it can be inferred from the chain rule of probability that, the joint probability distribution for the node set V is:

$$P(V) = \prod_{i=1}^{N} p(v_i | v_1, \cdots v_{i-1}, v_{i+1}, \cdots v_N) = \prod_{i=1}^{N} p(v_i | parent(v_i)) \quad (4)$$

DBN provides a strong support for the extraction of the complex interactions between systems or elements within the tourism SoS. Therefore, it can be used in overall analysis of the SoS, producing in the smart tourism industry information system a resource allocation program conducive to industrial optimization.

Intelligent Computing in SoSE

Application of intelligent computing may contribute to improving the system of systems engineering effectiveness in the smart industrial system's operation. As an essential stream of artificial intelligence, intelligent computing is an empirical computer thinking program in data processing after sequential set of steps of intelligent acquisition and recognition. The computing model is of hierarchical nature, and it generally features six levels[24], namely, operational simulation, existential experience, evaluation, inference of change limit, intelligent computing experience system and multi-link simulation and behavior capture (Fig. 3).

Intelligent computing body is capable of self-growth and being more adaptive with time and record of changes. Algorithms for intelligent computing includes neural networks, machine learning, bio-computing, fuzzy logic, pattern etc.

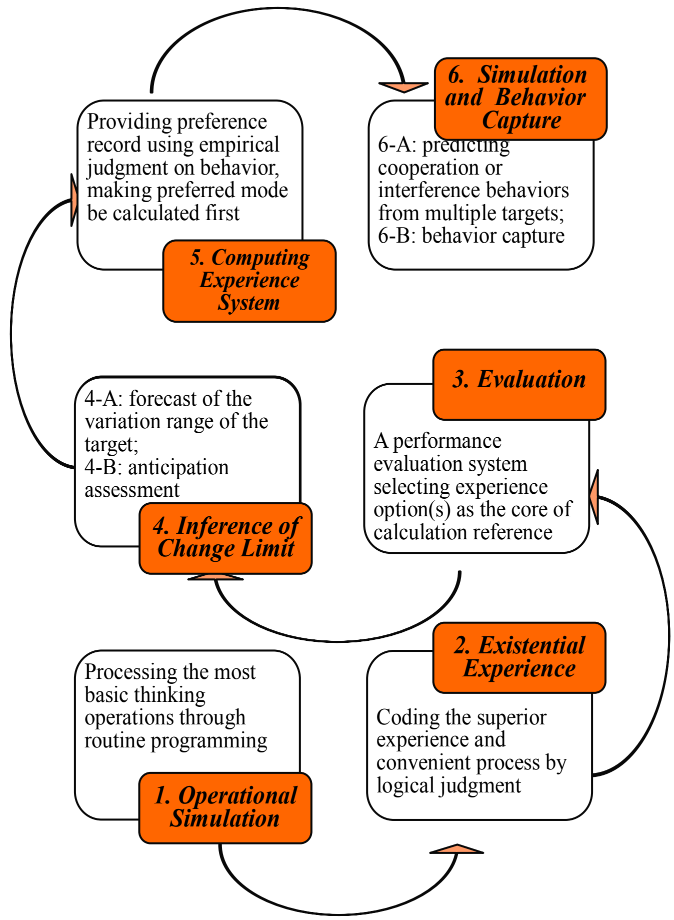

Fig. 3. Intelligent computing process in system of systems engineering. Six levels are included with respect to: operational simulation, existential experience, evaluation, inference of change limit, intelligent computing experience system and multi-link simulation and behavior capture.

Intelligent computing frame and algorithms can be used in system of systems engineering processes including data mining, complex network analysis, big data processing and policy forecast. The effectiveness and functionality of the smart tourism information system will be significantly improved through hybrid embedded intelligent computing algorithms and systems.

D. Emergence and SoS Effectiveness Measurement: Two-level and Four-grade Method

Measurement and evaluation of a SoS can be conducted on aspects including SoS effectiveness, robustness and adaptability. The overall performance is the extent of to which the SoS have a beneficial role in the mission process and outcome. Corresponds to hierarchical characteristics of SoS architecture, a two-level and four-grade measure method was proposed in [12:253-259]. The method mainly includes measures of performance (MOP), measures of effectiveness (MOE), measures of emergence effectiveness (MOEE) and measures of system of systems effectiveness (MOSE). Among the four grades, MOP and MOE are oriented to component subsystems of a SoS, while MOEE, and MOSE are oriented to the SoS' top-level mission operations.

Measures of Performance (MOP)

Performance of system unit is the inherent properties or characteristics of a given SoS. Suppose a SOS consisted of n system unit, namely

$$SoS = \{s_1, s_2, \cdots, s_n\} \quad (5)$$

Wherein, p_i is the subsystem level performance corresponding to any system unit s_i $(i = 1, 2, \cdots, n)$. Suppose the numer of performance metrics for system unit s_i was r_i, p_i will be presented as:

$$p_i = \{p_{i,1}, p_{i,2}, \cdots, p_{i,r_i}\} \quad (6)$$

Performance metrics of system unit s_i would be subject to the restriction of a specific low-end performance threshold (denoted by p_i^*) as well as the technological constraints for high-end performance.

Measures of Effectiveness (MOE)

Effectiveness aggregation of multiple cooperating and mutually administrative system units constitute input into measures of effectiveness for emergence-level behavior characteristics. MOE for each system unit is likely to contain multiple aspects, i.e. for any system unit s_i $(i = 1, 2, \cdots, n)$, its corresponding system effectiveness will be:

$$e_i = \{e_{i,1}, e_{i,2}, \cdots, e_{i,l_i}\} \quad (7)$$

Wherein, l_i denotes the dimension of system effectiveness e_i for system unit s_i; for each specific system effectiveness dimension, its corresponding MOE is:

$$e_{i,j} = f_{i,j}(p_i) = f_{i,j}(p_{i,1}, p_{i,2}, \cdots, p_{i,r_i}), \forall j \le l_i \quad (8)$$

Similar to MOP, there is a minimum threshold $e_{i,j}^*$ for MOE as well.

Measures of Emergence Effectiveness (MOEE)

A SoS comprises a number of hierarchical systems, each system composite has a corresponding emergence grade. while the overall characteristics and behavior of the SoS or its system composites are an outcome of emergence of all cooperative and interconnected subsystems within them. Therefore, MOEE serves as the core of SoS measurement, and also shows certain hierarchical characteristics.

--MOEE on bottom-line emergence grade: system composites corresponding to the bottom-line emergence grade are system units. Suppose MOEE for a bottom-line emergence grade was EE_i, and it contained o_i aspects, where each aspect corresponded to a sub-operation of the mission, that is:

$$EE_i = \{EE_{i,1}, EE_{i,2}, \cdots, EE_{i,o_i}\} \quad (9)$$

Therefore,

$$EE_i = \Omega_i(m_i, e_k, e_p, e_q, \cdots) \quad (10)$$

Where Ω_i is MOEE function corresponding to emergence grade i; e_k, e_p, e_q indicates the effectiveness values of the interrelated system units s_k, s_p, s_q, which act in accordance with homologous emergence levels and complete missions corresponding to SoS or system composite, while m_i indicates the quantitative architecture of these interrelated system units

--MOEE on non-bottom-line emergence grade: system composite on any non-bottom-line emergence grade contains at least one lower-leveled system complex. They share the same measures and constraint function types with the bottom-line emergence grade MOEE, just differing on each variable's indicating meaning.

Measures of System of Systems Effectiveness (MOSE)

Measures of system of systems effectiveness refers to assessment of SoS goal's final achievement status, determined by the effectiveness of the behavioral characteristics on global emergence grade. Suppose SoS' overall MOSE was E, and it contained l aspects, namely

$$E = \{E_1, E_2, \cdots, E_l\} \quad (11)$$

Then,

$$E = E(N, EE) = E(N, EE_1, EE_2, \cdots, EE_o) \quad (12)$$

Wherein, E denotes function of MOSE for SoS; EE is effectiveness function of behavior characteristics on homologous emergence grade, and it includes o aspects, corresponding to o sub-operations of the SoS respectively, namely $EE = \{EE_1, EE_2, \cdots, EE_o\}$; While N indicates the quantitative structure of these sub-operations.

Eventually, industrial optimization projects can be carried out based on the "hidden order" of the tourism SoS evolution that discovered by the smart industrial system. It is the ultimate aim of constructing such a system.

IV. Conclusion

Currently, as many disciplines begin to cultivate a set of core methodologies [25], SoSE, which has its root in context of military programming, is proven to be a notable research focus, providing a new perspective to solve the emerging system of systems challenges in industrial analysis. SoS thinking is of great significance in cross-disciplinary study [12], and it may lead a new research paradigm. Its application in tourism analysis will provide a solid foundation for industrial policy-making, planning and forecasting, and will help reduce risk and cost in industrial restructuring.

Modern communication and information technologies provide greater possibilities for socio-economic sectors to execute smarter decisions. These technologies will advance the SoSE industrial application. Therefore, targeting the rareness of government oriented intelligent decision support system (DSS), and inspired by the "system of systems thinking", this paper presents a technical route for constructing a policy maker-responsive smart tourism industry information system.

System of systems architecting, geographical simulation, network analysis with intelligent computing and SoS effectiveness evaluation are focused in the smart system construction. The overall design include: 1) system of systems structural architecting; 2) geographical simulation using geo-science instruments, CA and MAS; 3) SoS evolution description through network analysis and intelligent computing; 4) SoS effectiveness measurement using two-tier and four-grade method; and 5) SoSE program for industrial optimization.

However, SoS tools and methods are not perfect, so it is important to draw together academia, government, industrial organizations and enterprises to collaborate in the related studies. According to the 10 hot issues leading the future development of SoSE [7, 8], future research directions for the tourism SoSE may include: (1) Flexibility, adaptability, and capability of rapid recovery; (2) Model-driven SoS architecture; (3) Multi-view product for SoS architecture; (4) Net-centric vulnerability; (5) Evolution; (6) Guided emergence and capability engineering.

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