Study on complexity of Sutong Bridge's objectives system and its meta-synthesis management

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Abstract: Objectives define the boundaries of complex engineering system. It is a hard work to identify the specific objectives of a complex engineering system. The objectives system development needs a complicated process, from nix to prototype, and to final definition. The total process will cover the following course: from chaos to well-ordered; from qualitativeness to combination of quantitativeness and qualitativenss, then from qualitativeness to quantitativeness (a recurrent process), expert experience and theoretical science, rationality and sensibility, synthesis analysis and meta-synthesis, routinization and non-routinization. Such process is explicit in phase development yet overlapped; mutually confined yet mutually independent; permeated conflicts yet pregnant in harmony. This article explores the complexity of Sutong Bridge's objectives development and the process of meta-synthesis in the Sutong Bridge engineering.
Key words: objectives system; complexity; meta-synthesis; Sutong Bridge

1 Complex system and meta-synthesis

1.1 System

System is a group of interacting, interrelated, or interdependent elements forming a complex whole. Such defined system is universal in nature, human society, and human body. Usually the interacting, interrelated and interdependent elements are called system structure. According to the complexity of system, system can be classified into simple system, simply huge system, complex system, complex huge system, special complex huge system-human society system[1].

In our opinion, the basic research task of systematology, especially complex huge system is to study how to define its integrity and function, reveal the characteristics of system's existence, evolution, principle of synergy, development and control. Overseas researches in this field are also based on this orienting.

1.2 Complex system (complexity of system)

Merriam-Webster International Dictionary defines the complexity this way, "a group of obviously related units of which the degree and nature of the relationship is imperfectly known", "characterizing by many interrelating elements, factors, details, concepts and requiring serious research and investigation to understand and deal with". That is to say, the more factors and amount, the more complex the system; the closer link among the factors and larger range of interrelation, the more complex the system.

What is more, the opener the system and the more frequent the interdependent and interplay between system and environment, the more complex the system will be. At the same time, complexity is close related with human's cognition, understanding method, all the system hard to analyze, synthesize, calculate, research, cope, model and forecast is complex system. Evidently, modern big construction usually is complex system, so all of them represent various complexities[2].

1.3 Meta-synthesis

Various organizations of human society are the most complex system in the world; therefore, its management needs complex system methodology. Ludwig Von Bertalanffy put it this way, "we are forced to use 'whole' or 'system' to cope with the complex problems". This pointed out the pith of complexity methodology.

In the 1970s, Qian Xuesen argued that when research complex system we should band together reductionism and wholism, then the system theory was formed.

In the early 1990s, Qian Xuesen brought out "from qualitative analysis to quantitative meta-synthesis" and its practical method is "from qualitative to quantitative meta-synthesis discussion hall system". He thought that we should research and solve problem at systemic level. So it is necessary to synthesize all kinds of information and knowledge at different fields

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and levels, and should adapt human-computer combination, integration experts system with their cooperation and wisdom, from qualitative method to combination of quantitative method and qualitative method, then meta-synthesis from qualitativeness to quantitativeness.

Meta-synthesis is to combine and integrate expert system, information, knowledge and computer science to form a highly intelligent human-computer system. This system have comprehensive, whole and intelligent advantage, which can integrate human thinking, experience, knowledge, wisdom, various wisdom, materials, information etc[1].

2 Complexity of Sutong Bridge's objectives system

2.1 Construction and its objectives system

Construction is a series of activities to achieve some aim, basing on scientific principle, integrate resources orderly. In nature, the construction activities are a series of optimizing value objectives integrating economic, technical, etc factors. It concerns the interest of main construction and many other social stake holders' interests as well[3].

As a purposive human activity, construction has specific objectives, which come from different expectations and requirements of stakeholders on various levels. Therefore, the objectives are multi-levelled. Different stakeholders have different objectives; different level objects have different motivational effect. The following allegory can describe the situation vividly.

Three masons worked together to build up a wall when someone passed by, and asked what they were doing.

The first mason answered: I was building the beautiful future of this city. He became the mayor of that city years later. The second one answered: I was building a beautiful house. He became a famous architect years later. The third one answered: I was doing nothing but building a wall. Years later, he was still a mason.

During this simple walling, the objective levels of these masons are totally different. What the third one saw was just a partial objective, i. e. a serial of walls he built, and never thought what the walls would form. The second one's level was a bit higher, i. e. a total objective, a house making of walls, so he owned many houses years later; the first one's objective was higher than the one of the second. He not only saw the specific objectives, but also the goal and mission of the project, so he owned that city.

It is very hard to confirm the objectives system of construction specifically. The complexity of system makes a greater claim upon managers on collecting information, defining objectives, designing effective strategy ability. The interrelation among the factors forced us to pay attention to large number of features; therefore, we can not adapt just one kind of action in a complex system. It is very wise to keep the complexity in mind, not only take the specific objective into account, but also the effects on the other parts caused by it. The construction is multi-objective and evidently, it is more complex and harder than single-objective project.

2.2 Outline of Sutong Bridge

Sutong Bridge lies between Nantong City and Changshu (a county belongs to Suzhou City) in the east of Jiangsu Province, an important passageway across Yangtze River in the national key trunk planned by the Ministry of Communications from Jiayin in Heilongjiang Province to Nanping in Fujian Province, also an important part to the highway between Ganyu and Wujiang (Fig. 1). It is historically recorded that the bridge project will be on the largest scale and the construction conditions in general and the most complicated one ever built in China.

Sutong Bridge will play several important roles, such as in perfecting trunk road net of both our country and Jiangsu Province, promoting balance development in different areas, improving safety voyage conditions over Yangtze River, lessening the traffic pressure, and ensuring voyages' safety.

Sutong Bridge project starts from Xiaohai interchange of Tongqi Highway and terminates at Dong Bang interchange of Sujiahang Highway. The total length covered by the project is 32.4 km. It consists of three parts: north bank linking engineering, crossing engineering and south bank linking engineering.

Crossing engineering: total length is 8 206 m. The main bridge is a double-cable-plane double-pylon steel box girder cable-stayed bridge 100 + 100 + 300 + 1 088 + 300 + 100 + 100 = 2 088 m, which ranks first among the same types of bridges in the world. Special channel is 140 + 268 + 140 = 548 m T-type steel girder bridge, which ranks second of all the same type bridge engineering. Both north and south approach bridge are 30, 50, 75 m prestressed concrete continuous girder bridge. North bank linking engineering: the total length is 15.1 km and there will be two interchanges, a toll gate in the main line and a service zone. South bank linking engineering: the total length is 9.1 km, and there will be one interchange. Sutong Bridge adopts double-way six-lane highway standard for all the line. The calculated driving speeds are 120 km/h for

both north and south banks and 100 km/h for the crossing bridge, respectively. The design loads for all the bridges and culverts along the line are super class 20 for automobiles and 120 for trailers. The whole line requires steel 200 000 t, 100 000 m^3 of concrete for bridge and culverts, 300 000 m^3 of earth for filling. The total area of land to be occupied is more than 6.67 km^2, involving 100 000 m^2 of buildings that have to be resettled. The total investment for the project is estimated to be more than 6 billion yuan ($ 0.75 billion) and the planned construction period is 6 years.

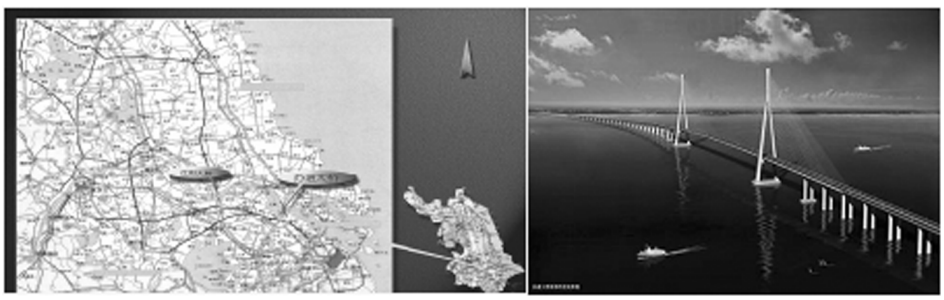

Fig. 1 Sutong Bridge

2.3 Sutong Bridge's objectives are a complex system

As a state-invested big infrastructure construction, Sutong Bridge is an open complex system, which has basic features of general system and typical system complexity. As an important part of such complex system, its objective system is complex as well. Internal and external environment complexity, multi-stake holders are determinative in its multi-objectives, and these objectives are crisscrossed. The objectives can be classified into individual's, contractor's, society's, even state's basing on different stake holders; and can be classified into long, middle, and short period objectives, strategic and tactical objectives, and different-phrased objectives basing on time dimension. From content and contracture of objectives, they can be classified into total objectives, system and sub-goal. Big construction's objectives are much higher. These different-level, different-stake-holders' objectives interplay into an unpredictable network, formed basic complexity.

2.4 Objectives system of Sutong Bridge

Sutong Bridge is a mixture of traffic engineering, public project and state strategic construction. Therefore, its objectives are multi-level inevitably. As a communication construction, it needs to achieve the basic transport function, in other words, to achieve it safely, efficiently with high quality; as a public project, Sutong Bridge has to consider the harmony between human and nature, its economic benefit; as state strategic project, Sutong Bridge has to consider to foster and cultivate participating companies' creativity, cultivate talents, facilitate technological progress and industrial upgrading in related domestic industries and enhancing China competitiveness. All things considered, Sutong Bridge defined its objectives system as the following: at macro level, this project's aim is to improve national competence and promoting social development and bring the harmonious development in industry and society; in middle level, it means contribution to society, protecting environment, saving resource, and more creative.

After overall consideration of all levels of objectives, Sutong Bridge's objectives are classified into three levels as following: a. macro level at state, enhance state competitiveness, boost industry and society development harmoniously; b. middle-level, i.e. society-level, contribute to society, protect environment, save resources; c. micro-level, achieve all the construction's objectives such as quality, safe, investment, processing etc. The objectives system is shown in Fig. 2.

This objectives system formation process is absolutely not a simple process; it comes into existence from zero, then final achievement. It comes through from chaos to order, from qualitative method to combination of qualitative and quantitive method, then from qualitative to quantitive cycle. During such cycle, it combines rational and irrational things, experts' experience and scientific theory, hard systemic and soft systemic methods; therefore it is a meta-synthesis process.

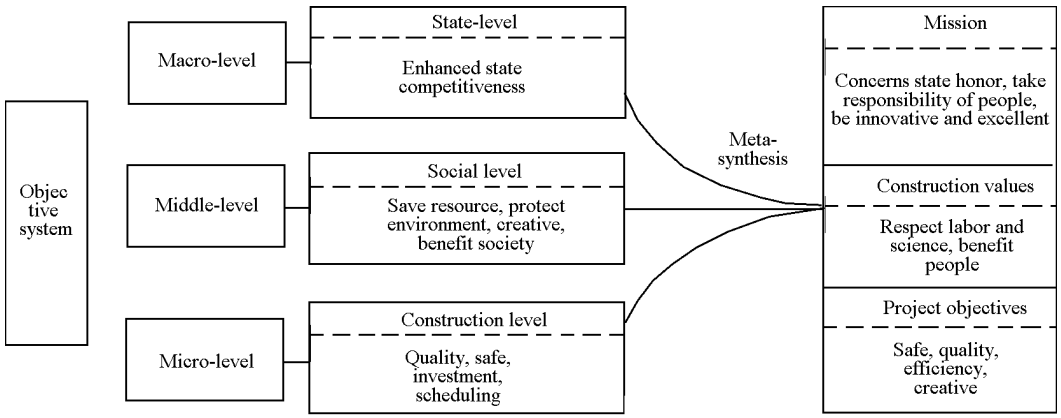

Fig. 2 Objectives system of Sutong Bridge

3 Meta-synthesis of objective system of Sutong Bridge

Object of meta-synthesis management is a complex system, so meta-synthesis must produce a complex management system with a complex managed system. Logically, this management's complexity is higher than that of the managed system. Therefore, we can not account meta-synthesis establish simple, ordinary system to manage a complex system[2].

One of important tasks of Sutong Bridge's meta-synthesis management is to design overall management system basing on construction's natural, social and humanistic attributes in mission and construction values via integration its synthesis thoughts and methods. Fig. 3 shows the meta-synthesis process of Sutong Bridge.

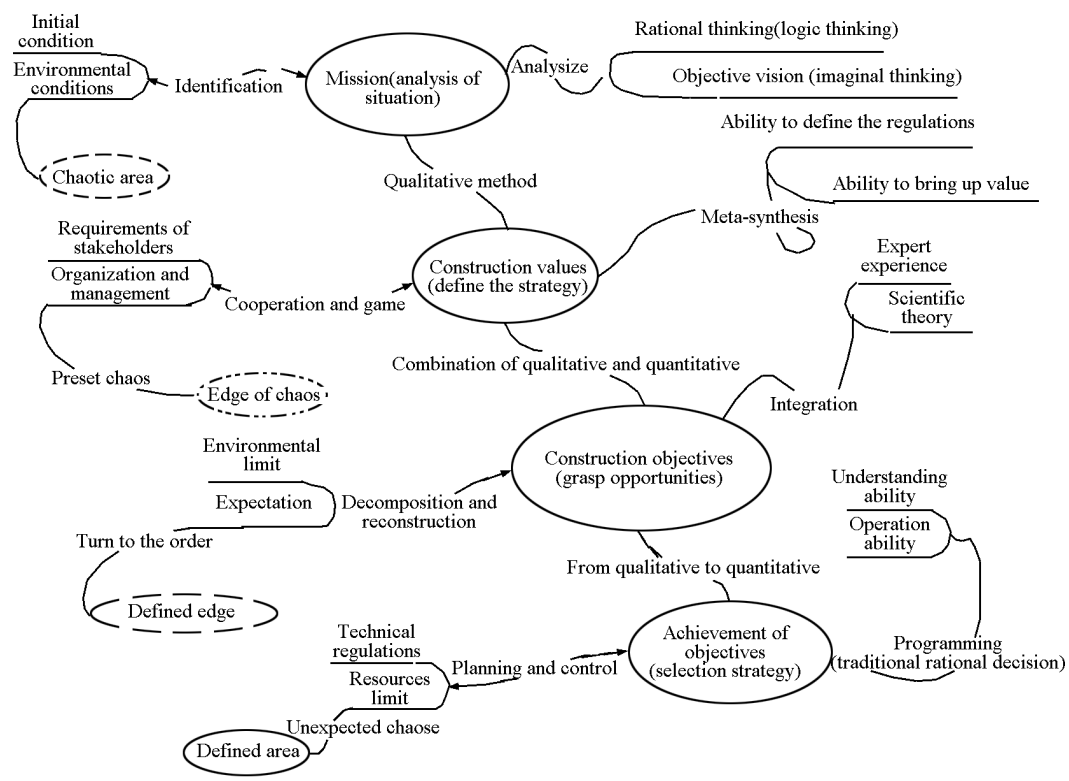

Fig. 3 Meta-synthesis process of Sutong Bridge[4]

3.1 Analysis of situation-mission and goal of Sutong Bridge

Objectives define the boundary of complex construction. Objectives system formation process itself needs a complex process as well. So before objectives system come into existence, all is in chaotic situation.

Large-scale projects are crucial strategic resources of country, via which some technical problems can be solved, some industrial standards can be established, innovative platform can be rose, the competitiveness was enhanced, other relevant industries benefited from it, and country's competitiveness increased. So the large scale projects play a vital and crucial role in country development.

Sutong Bridge was in a specific historical environment, which determined its historical opportunity. Two Chinese proverbs put it this way, "a hero is nothing but a product of his time" and "it is as well to know which way the wind blows". The policy-makers can meet two kinds of questions when they research and estimate the present circumstances. One is environmental opportunity—what can be done; the other is ability and resource question—what can do. This is a strategic analysis process to answer the construction's mission question. It requires rational thinking and imagination ability of expectation as well. It also need to understand the circumstance and precaution of change possibility as a basic factor and condition, at the same time, pay attention to past and future situation, then form a correct judgment. However, it is hard to make a judgment in some chaotic circumstance.

This judgment requires overall and total grasp and understanding of initial conditions and environmental condition. In practical construction, this problem did not have enough attention and research, so people do not have enough analysis and judgment, which leads into a failure. It is a good lesson.

As regard to approval of construction, it requires not only investigation on scientific and technical advantage, commercial or economic benefit, but also in broader social level. For example, the meaning for national security and economic development, the influence on natural and biological environment, its boost on industrial technical development and country's power, even construction's progressive role in history etc. So we can not judge a construction good or bad simply, in other words this linear thinking can not produce this judgment. Sutong Bridge is "century expectation, millennium dream" of local people, even of country. But only in this century, Sutong Bridge can come into existence due to mature bridge engineering technology. This bridge is not only a pass-over in technical field but also ability of human resource.

This is a macro-level work, however analysis and judgment exists in every phrase of construction, but due to its sensibility of initial conditions, at the very beginning of construction, macro level analysis at internal and external environment is much more important. As most complex bridge construction in the world, State Council attached great importance to this project. State middle and long-term scientific and technical development planning abstract listed big bridge engineering as priority development in communication and traffic infrastructure and maintenance technology and equipment. Central government expected a landmark bridge in world bridge construction, achieved surpass into bridge power countries; highway and water way communication middle and long term scientific and technical development planning abstract made this construction as main technical innovation project to enhance the technical power in bridge engineering. "Concern national honor and responsibility, be innovative and pursuing excellence" became the mission of Sutong Bridge. This mission determined the highest level goal.

3.2 Identification of strategy—Sutong's values

The following is the strategic choice. There are so many stakeholders with various and different expectations and requirements. This partial interest brings out amount of conflicts. And these conflicts can be solved in bigger range. This construction cannot be achieved without such higher mission. The policy-makers meet such questions as who we are, what are important to us, what we should do etc. This process is much important for policy-makers of such big infrastructure construction. The common values system is not only the basis of objective identification and basis of policy-making. However, the process of values system is not established at once, it needs continuous betterment and optimization.

With a booming economy, on one hand, China has become the biggest construction site in the world, on the other hand, modern super big, over-long period, big investment constructions bring out bad influence on environment. As an activity of constructing, the constructions display the values and philosophy of designers, builders, and participants, the engineers' moral and values can affect the objectives system formation and its achievements[5]. Partial and economy-centered construction values arose many conflicts among construction, resources, and environment. So construction mission values should build on national strategy. The sustainable development value construction mission value emphasizes coordination among eco-

nomical, technical, cultural and biological function.

Manifesto of 2004 World Engineers' Conference—engineering and sustainable development future, pointed out that "engineers should take responsibility to make this world better". Engineers should work together with public, companies, non-governments and governments to build a new world, turn resources into products and services via knowledge. During this process, engineers should determine to keep the environment and biology in balance, make sure the resource and energy continual utility. Engineers should utilize new technology to decrease resource and energy consumption, decrease pollution, and protect human healthy and biological environment to bring out human better life.

Construction harmony means not only the harmony between construction and environment, construction and economical society, but also the harmony among all stakeholders. On some content, the conflicts among the stakeholders frequently raised contradiction in construction. If these problems can not be solved, the contraction can influence construction badly, even maybe destroy the objectives of safe, quality, process, technical innovation etc. The present problem is the stakeholders of big construction are so many and the relationship among them is at various complex levels and hidden (Table 1). The multi-stakeholders caused multi-values (Fig. 4).

Table 1 Expectations and requirements of stakeholders of Sutong Bridge

All level governments	Stir economy and innovative ability, train talents, enhance country competitiveness etc.
Investor	Investment control, investment yield, decrease investment risk
Owner	Overall objectives
Contractors and suppliers	Pricing, period, company profile, fame etc.
User	Products and service price, safe, personalized services
Construction builder	Working environment (safe, comfortable, personalized), income, stability, career proud
Project peripheral organizations	Environment, viewing site, and relics protect

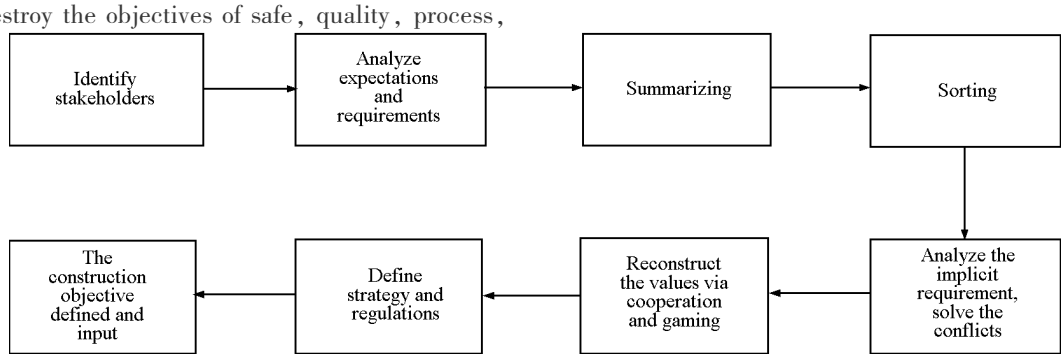

Fig. 4 The development of values of Sutong Bridge

3.3 Grasp opportunity—objectives identification of Sutong Bridge

After the identification of construction values, the common vision under these values must be achieved by a specific and measurable objectives system. Objective formulation is a question of strategy design, and this process embodies self-organization behavior, i. e. construction system actively influence environment and achieve its objectives. During this process, many questions need quantitative description such as how-much, how-long, and other functional index. If impose a specific and measurable objectives process to a complex and changeable environment by force, may cause rigidness, simplicity and false safe sense.

But the truth is, within some limitation, environment always enhances its multi-function and complexity[6], therefore objectives system's connotation and denotation continue to expand. The policy-makers choose simplified strategy, which is to simplify the complex question. But this streamlined solution is not such simplification. The system's evolutionary process is a process of complexity increase and simplification is just to simplify this process. They have essential differences which should be paid high attention by policy-makers. Complex question can only be solved by complex method. The construction objectives' identification and description must adapt to quantative and qualitive method, and it will be more ample and implicit with the process of construction.

Based on expectations of stakeholders, analyzed by synthesis and integration, all the direct objectives of construction such as quality, safety, processing, investment, etc. are designed which are then filtrated, combined, condensed and reconstructed to form a ker-

nel objective, and kept balance among its multi-objective.

To condense and reconstruct objectives is not that simplification conventionally understood, but that intrinsic quality of objectives' interrelation. Reconstruction is to synthesize and recombine the objectives basing on more profound understanding and grasp of construction complexity and complexity of policy-making. Sometimes, it includes the new objective due to the changes in the construction process. The difficulty of condensing and reconstructing is to solve the conflicting objectives including the coordination among stakeholders, adjustment of preference and objectives.

When we analyze the situation, it is very crucial to catch, grasp and utilize the opportunity. To identify the objectives means to grasp the opportunity, opportunity is a chance to grasp the future expectation and an environment limit as well. For Sutong Bridge as an instance, underneath structure construction should avoid flood season, top structure construction should avoid typhoon season, and deck pavement should avoid hot temperature during summer…. Losing any favorable opportunity may cause failure even collapse of total objectives system.

During the identification of objectives process, there are so many questions requiring situation analysis and policy-making. This process needs collection relevant information and guidance of theory, and also the experts' experience and intuition. Experts' long-term careering and knowledge accumulation make them know a thing or two. They usually can hit the nail on the head and choose satisfactory answer from options. To respect experts is to respect science. A feasible and scientific objectives system must be built on experts' experience and scientific theory, especially for Sutong Bridge, an innovative construction (Fig. 5).

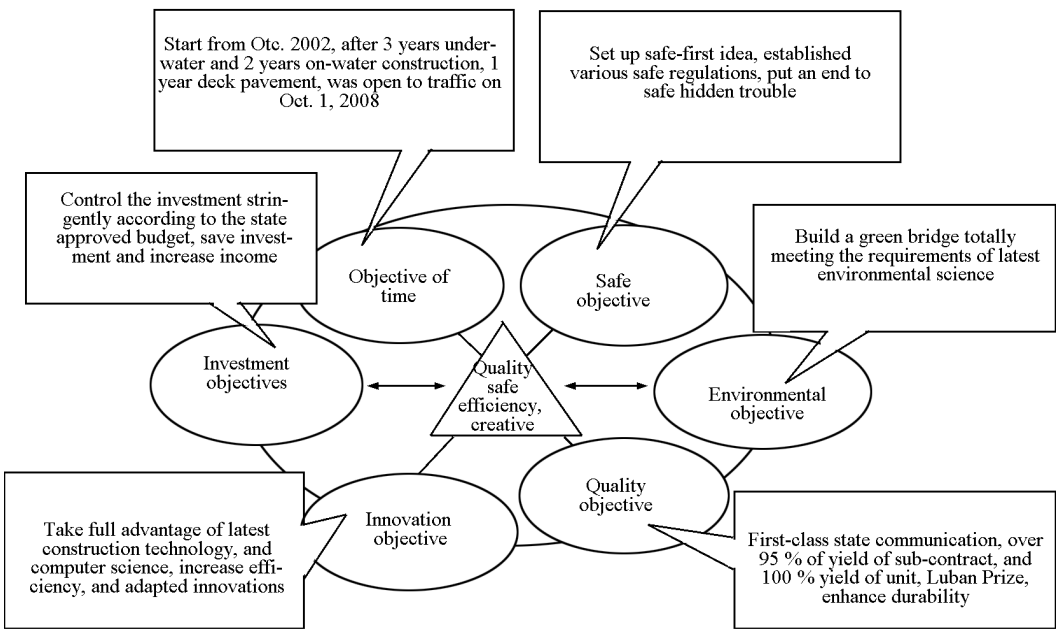

Fig. 5 Overall objective of Sutong Bridge

3.4 Choose strategy—the behavior art under the guideline of objectives system

The chief of Prussian Army in 19th century, Von Moltke has said that "strategy is just a set of expedient measure. It is much more profound and profuse; it is utilization of knowledge in practical life, a special guideline in changing environment, a behavior art under rigor situation...". That is why the guideline deduced from expedient measure and its system does not have any strategic value.

When constructors come into planning phrase, everything seems easy now; planning is just a design process of sub-system. What the policy-makers do is to design a combination of serial activities. But in a specific circumstance or a disturbance from environment, every moment can have only one action that brings out the difficult in choice and policy-making. The more complex and multi of activities, the choice and policy-making is harder to make, and more time is consumed.

As regard of this question, H. A. Simon put it in

his system hierarchy principle theory, "... a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem."[7] The most common method to this question is to break down the policy-making questions, break them down into sub-questions, and every sub-question is described by its sub-objective, and be solved basing on sub-objective. All the sub-objectives can be achieved by various lower level activities, functions, and behaviors. Therefore, large complex construction like Sutong Bridge's planning formed multi-levelled planning system, the more complex of the construction, the more the level of activities will be. In the lower level of planning, the planning appeared like detailed operation planning. In higher level of policy-making, the planning has strategic guideline.

However, this hierarchy principle eases the difficulty of policy-making, but the question is not solved at all. Making policy-making easier by decreasing the activities (cause rigidness and limit its adaptability) or increasing the activities diversity by increasing the difficult of policy-making (will increase the complexity significantly and cause waste of resources), this can be anything but a dynamic balance.

Usually, a construction has multi-technique, solutions, route to choose. This choice is defined by requesters' values; in other words, to achieve maximum output and good social, economic and environment benefit with minimum investment, achieve meta-synthesis and optimization of multi-objective.

The task of planning is to find, design and determine a route from initial condition to final objective, or design a practical and operable program for participants. Generally speaking, there are over two feasible routes or program, it is a strategic question to choose which one as formal action plan. This is a rational decision question and a behavior art under guideline of objective as well.

Sutong Bridge drew lessons from other successful bridge constructions, thought over the overall objectives, after repeated proof, then formed Overall Outline of Construction of Sutong Bridge. In order to make the construction run smoothly and successfully, annual planning and seasonal planning are designed basing on outline and actual construction process. They broke the plans down into city level, sub-contract level, and readjust them in time according to the processing, relocate the resource reasonably. The provincial and municipal headquarter can direct the construction via advanced PC information technology which can provide detailed dynamic data. Provincial headquarter released 10-day report thrice per month to inform all the participants and stakeholders. During the completing sprint phrase, the commanding department adapts daily construction report with daily dynamic data to acknowledge the processing; what is more, they adapted countdown control in last phrase.

4 Conclusions

Meta-synthesis management is an organization and management complex system basing on meta-synthetic methodology. It is development of management thoughts and theory, and development of systems engineering. In fact, meta-synthesis management is theory and technology on complex system.

Meta-synthesis' theoretical base is complex system theory; and its methodology is meta-synthesis, its practical value is to teach the manager how to design management organization, defined management strategy, and enhance the site management level etc.

However, complex system theory and meta-synthesis theory is still growing, the meta-synthesis management theory is not ripe and sophisticated. Sutong Bridge had many instructive attempts and exploration. This paper described this theoretical thinking and summarizing-up; there is much room in deepening and perfecting it.

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The construction of the Sutong Bridge standard cantilever was from November 10, 2006 to May 29, 2007, lifting the standard beams for a total of 80 times which lasted nearly 7 months. The advanced crane systems achieved the hoisting operations of mechanization, automation and digitalization which has greatly reduced the labor intensity of the workers, improved the work efficiency and ensured the safety of the construction.

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