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Meta-synthesis approach to complex system modeling

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Abstract

Meta-synthesis method is proposed to tackle with open complex giant system problems which cannot be effectively solved by traditional reductionism methods by a Chinese system scientist Qian, Xuesen (Tsien HsueShen) around the early 1990s. The method emphasizes the synthesis of collected information and knowledge of various kinds of experts, and combining quantitative methods with qualitative knowledge. Since then, continuous endeavors have been taken to put those ideas into practice. In this paper, firstly we review meta-synthesis approach and other research relevant to complex system modeling briefly. Then we discuss two main issues, model integration and opinion synthesis, which are often confronted when applying meta-synthesis approach, together with an exhibit of the development of an embryonic meta-synthetic support prototype. Such a demonstration shows how to model complex problems, such as macro-economic problems in Hall for Workshop on Meta-Synthetic Engineering with versatile resources in information collection, model integration and opinion synthesis. Finally, some future work is indicated.

Keywords: Decision support systems; Meta-synthesis; Complex system; Modeling

1. Introduction

Since the 1970s, difficulties confronted in dealing with modeling complex problems, especially in the areas of energy, environment, population, socioeconomic and sustainable development, etc. drove people to change their problem solving ways from simple mathematical modeling to considerations on those factors which had been neglected by quantitative modeling and towards a synthesis of models from different domains on a common problem along a system rethinking trend (Hafele and Basile, 1979; Tomlinson and Kiss, 1984; Flood and Jackson, 1991). Those endeavors reflect the limitations of analytical thinking dealing with human and organizational elements on system design and mathematical modeling for unstructured

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messy problems. Then a lot of new system approaches have been proposed, such as Ackoff's interactive planning, Checkland's soft system methodologies (SSM), Mason and Mitroff's strategic assumption surfacing and testing (SAST), etc. To be differentiated with those analytical modeling for problem solving which are regarded as hard system approaches, those approaches are referred as soft system approaches. Table 1 lists some comparisons between two categories of system approaches.

There are other sayings, like soft system analysis, soft operational research (OR), etc. which are also regarded as a same category as soft system approaches. Typical soft OR methods are discussed in Rosenhead and Mingers (2001), Mingers and Rosenhead (2004) and Keys (1991). Despite the differences between those soft approaches due to different origins and different applied domains, common grounds behind those approaches are of more attentions; the most salient feature of those approaches is for *problem structuring*, a basic but very difficult while a continuous goal and task for system analysts, modelers, strategic planners and decision makers. Decision support system (DSS) aims to provide effective support for solving unstructured, ill-structured or wicked problems for decision makers as its initial emergence in the late 1960s. Through more practice, people have gradually realized that for more effective support for problem solving, studying the concerned problem from different perspectives is a necessity for comprehensive definition of the problem, and one of the principal tasks in problem structuring process is how to synthesize those multiple and varied perspectives so as to handle more 'softer' information and broader concerns than mathematical models (Shim et al., 2002). Here the research on DSS and soft approaches are overlapped in the methods of problem structuring. System modeling is a dedicated activity of building model-based DSS while structuring process based on soft system approaches is itself a system modeling process.

Nowadays, tremendous progress in technology brings much influence to DSS study. In 2002, the major journal of DSS research, *Decision Support Systems*, published a special issue, "DSS: directions for the next decade" edited by Carlsson and Turban (2002). In witness of "an unparalleled digital revolution", the special issue studied the problems of those unimplemented goals of DSS and indicated directions for the next decade. Among those problems, "people problems", which may refer to human's limited capacity in cognition, subjective prejudice and world views, and belief in experts, are key reasons instead of technology-related problems. Those human problems may bring or increase uncertainties to decision making process. Even we suppose those uncertainties may change a structured problem into ill or unstructured problem, or a tame problem into a wicked problem.

It is not till present that people begin to pay attention to those human problems. Discussions on man–machine interaction, interactive modeling, etc. have already been undertaken with practice since 1980s (Fedra and Loucks, 1985; Loucks, 1992). The main feature of those discussions and practice is more emphasis on human roles in system modeling, as well as combination of human judgment (qualitative) and mathematical models (quantitative). Here we consider problem solving is equivalent to system modeling, as we regard the process of building a model of a system as

Table 1
A brief comparison between hard and soft system approaches

	Hard system approaches	Soft system approach
Assumption of observed system	Systematic world	Metaphor/systemic mind
Problem solving style	End–means	Participation/debate
Process goal	Optimization → satisfaction	Learning → satisfying
Acting focus	Goal-oriented	Process-oriented
Applying methods	Positive-empirical	Interpretive-exploratory
Acting philosophy	Do the thing *right*	Do the *right* thing

the process to define a problem and find its solutions. Despite those "people problems", human involvement or man–machine cooperative work is still among top foci for DSS researchers, which is also the focus of problem structuring process (Vidal, 2004).

In parallel to many western schools in approaches and methodologies for unstructured problem solving, eastern inquiry modes are studied and new system approaches have also been proposed based on comparisons between western and eastern system thoughts by oriental system scientists. Meta-synthesis approach (MSA) is one of those approaches proposed by a Chinese system scientist Xuesen Qian (HsueShen Tsien) to tackle with open complex giant system (OCGS) from the view of systems in the early 1990s (Qian et al., 1990; Qian, 2001). Here, we regard OCGS problems are ill-structured or wicked problems.

In this paper, we present our explorations in MSA and building a computerized embryonic prototype of MSA practicing platform. Firstly basic ideas of MSA and its practicing framework are reviewed. Relations between MSA and other oriental system approaches are discussed. Then a major project sponsored by National Natural Science Foundation of China (NSFC) for a demonstration of man–machine meta-synthetic support for macroeconomic decision making based on MSA is introduced. We present our study on some basic issues and methods for HWMSE implementation in that major project. Those main issues include model integration, opinion synthesis, macroeconomic modeling, etc.

Next meta-synthesis approach and its engineering practice framework are addressed.

2. Meta-synthesis approach from qualitative hypothesis to quantitative validation

Analytical methods or reductionism are inappropriate or not enough to deal with those unstructured messy problems, which had been realized along system rethinking tide. Such a fact has also been recognized by Qian who began to concentrate on complex systems since the early 1980s (Qian et al., 1988). By studying the basic concept 'system' in system sciences, Qian gave his classification about system based on the complex level and openness of the system. Openness denotes energy, information, or material exchange with the outside world. The most complex system is open complex giant system (OCGS) where exists a large variety of subsystems with hierarchical structures and complex interrelations. There are exchanges in energy, information and materials between the system and external environments; the system is self-adaptive and evolutionary. Social system, human brain and body and geographical system are typical OCGSs. Traditional reduction approach is not suitable to deal with OCGS problems. Then Qian proposed meta-synthesis methodology by studying advances in system theory and relevant fields, and system engineering practices in China (Qian et al., 1990; Dai, 2002).

2.1. Meta-synthesis approach (MSA) and its engineering practice—HWMSE

The essential idea of meta-synthesis approach can be simplified as "confident hypothesis, rigorous validation", i.e. quantitative knowledge arises from qualitative understanding. The approach emphasizes to organically unite the expert group, data, all sorts of information, and the computer technology, and to unite scientific theory of various disciplines, and human experience and knowledge, for proposing hypothesis and quantitative validation.

MSA absorbed ideas from *meta-analysis*, a statistical method which aims to realize quantitative integration and analysis of the findings from all the empirical studies relevant to an issue and amenable to quantitative aggregation (Glass, 1976). Meta-analysis is regarded to do findings within one discipline or domain. Meta-synthesis is oriented to a synthesized work from multiple disciplines or domains. Such kind of cases appears widely in strategic planning, project assessment and evaluation, or roughly, complex problem solving. And the solutions do not remain on qualitative hypothesis, but towards verified and validated knowledge.

Based on the experiences on theoretical research and engineering practices in seminars, meta-synthesis approach, C^3I (Communications, Command, Control and Intelligence) system and war gaming, information and intelligence technologies, artificial intelligence, virtual reality, intelligent system, systematology, man–machine cooperated intelligent systems, and other new advanced technologies invented in the fifth industrial revolution, etc., Qian proposed the idea for constructing a Hall for Workshop on Meta-Synthetic Engineering (HWMSE) for practising meta-synthesis approach in 1992 (Wang et al., 1996). HWMSE aims to exceed the traditional DSS, which is mainly based on computer, by a man–machine hybrid system where people play principal roles to give judgment for strategic planning and decision analysis. Within the Hall, human experts make full use of advanced information technologies to achieve data, information and knowledge support for quantitative analysis; which reflects the cooperation and collaboration between human beings and machines while humans play active and decisive roles.

In comparison to traditional DSS framework, HWMSE is consisted of three systems: machine system, human experts system and knowledge system. Instead of a traditional DSS, machine system may refer to a networked system, such as the Internet. Moreover, it denotes functions or tasks which machines fulfill during problem-solving process, such as data storage, numerical computing and even modeling tools and methods, as referred as quantitative intelligence which are advantages of machines. Experts system mainly denotes groups of experts to emphasize human's principal role in HWMSE, which is ignored in a traditional DSS. Machine system helps people work. For strategic and critical problems, experts are selected according to indicators such as background, age, knowledge and experiences stored in experts system. Expert groups utilize experiences, intuition and human minds to apply thinking in terms of images in problem solving process, as denoted as qualitative intelligence. The more complex a problem is, the wider the set of experts' skills that are required to define the problem and find a feasible solution to the problem. Obviously, the experts system in HWMSE cannot be replaced by the expert system (ES) in artificial intelligence (AI). How to form a reasonable expert system which can provide effective information to customers about appropriate experts for problem solving is a critical issue for the construction of HWMSE. Knowledge system not only includes present knowledge such as domain knowledge, design rationale and problem-solving knowledge stored by books, digital media or both machine and experts systems, but also newly generated and validated knowledge produced within the Hall. Either experts system or machine system could be carrier of knowledge from knowledge system. With three systems, the Hall has abilities not only in collecting, storing, transferring, analyzing and synthesizing information and knowledge, but also for creating and generating new knowledge. The Hall is expected to expose the essence of meta-synthesis approach in pursuit of new ideas and knowledge and even wisdom which is beyond meta-analysis method. A generic framework about HWMSE is as shown in Fig. 1. From epistemological viewpoints, we suppose those activities reflect the conceptual process of knowing and doing during social practices (denoted by outer dotted boxes and arrowed lines). Applying MSA is to try to combine practical experiences (from social practice) with theoretical knowledge (stored in knowledge system or justified in HWMSE) and objective facts with subjective appreciation for problem solving in very complex situations.

Mainly, there are three kinds of meta-synthesis: (i) qualitative meta-synthesis; (ii) qualitative–quantitative meta-synthesis; (iii) meta-synthesis from qualitative hypothesis to quantitative validation (Yu and Tu, 2002). Each kind can be practiced and achieved in HWMSE. Qualitative meta-synthesis produces assumptions or hypotheses about the unstructured problems, i.e. to expose some qualitative relations or structures of the concerned problems. There are computerized tools, such as group support systems (GSS), support qualitative meta-synthesis, which is the origin of knowledge creation. The second kind of meta-synthesis means to conduct quantitative analysis based on qualitative assumptions acquired from the first kind of meta-synthesis. This kind of work is what system analysts and system engineering people do in their daily work and have already

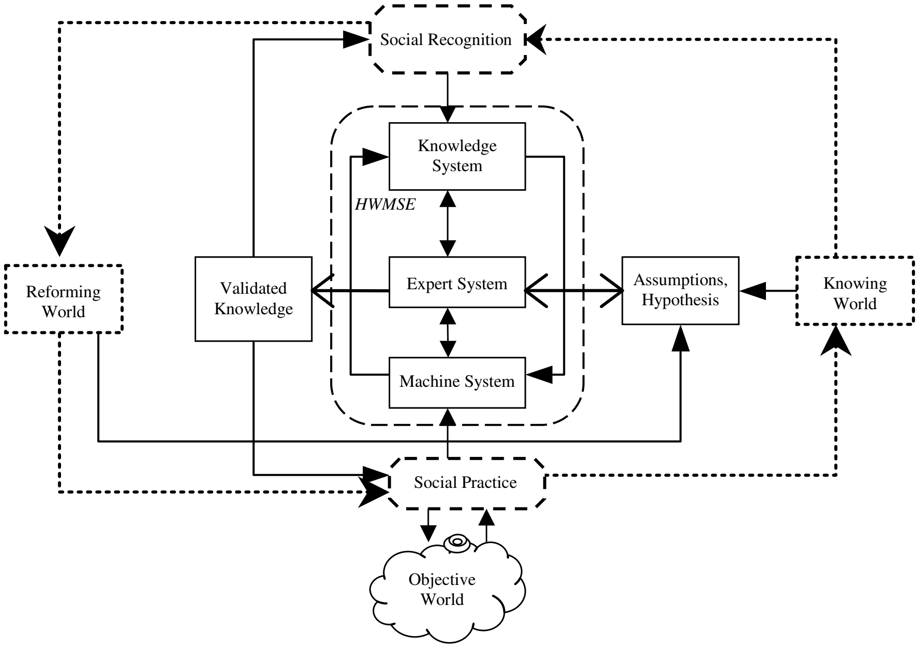

Fig. 1. Generic framework of hall for workshop of meta-synthetic engineering.

been studied widely and deeply, and supported by most DSS and expert systems from AI field (Wierzbicki et al., 2000). The third kind of meta-synthesis is to validate the results from the second one. If the validation is successful, solutions toward original unstructured problem are acquired. If not, new perspectives need to be explored by three kinds of meta-synthesis for another structuring process. HWMSE is a place for implementation of three kinds of meta-synthesis where resolutions about unstructured issues are captured with a series of structured approximation by meta-synthesis approach (Yu and Zhou, 2002).

Here lie many arguments about MSA and HWMSE in comparison to system methodologies and soft OR methods in the western. Since MSA is still under further exploration and there is not a perfect demonstration about HWMSE, we just say that MSA is one of those methodologies for complex systems modeling proposed by oriental system scientists, who absorb the oriental system thought which emphasizes on systemic thinking, holism and the oneness between heaven and human beings, and take a systemic approach to tackle with unstructured problems. Next we make some simple comparisons between two oriental system approaches for complex system modeling.

2.2. Oriental system approaches

Along system rethinking trend in the western, oriental system thinking, eastern modes of inquiry and oriental ancient philosophies have been also noticed due to their intuitively systemic ideas and emphasis in human relationships. Pressman (1992) compared both western and eastern system methodologies from the view of inquiry mode. In his comparisons, each methodology is taken in the context of the assumptions of the other. Finally, a synthesis which tries to maximize the refinement of potential of each, coordinate them into an ever-deepening process of refinement that approaches to a theoretically "complete" account of all possible phenomena.

On the other hand, oriental researchers also explore their own methodologies to deal with system complexities or thinking about system of science and technology. In late 1980s, a Japanese system scientist Sawaragi proposed *Shinayakana* system approach. *Shinayakana* is an adjective in Japanese, means something between hard and soft or both. The main point of the approach is how to use methods or tools to manage ill-defined systems and to develop well-defined system with emphasis in *honesty* in modeling, *harmony* within the group and *humanity* in system designing. As a matter of course, *Shinayakana* approach put more concerns on human roles in system modeling. The approach had been applied to a computerized support system for environmental planning at Tokyo Bay (Sawaragi et al., 1990). This oriental approach is gradually evolved into an approach to knowledge creation framework, which consists of five systems, *intelligence*, *imagination*, *involvement*, *integration* and *intervention* as shown in Fig. 2 (Nakamori, 2000).

Both MSA and *Shinayakana* approach are proposed by oriental system scientists who aim to find effective methodologies to deal with complex systems problems or those "people problems". HWMSE is a place for engineering practice of MSA, and also for knowledge creation and wisdom emergence; while *i*-System is for scientific knowledge creation. By Fig. 1's framework, we know three components of HWMSE and basic epistemological activities about confident hypothesis and rigorous validation; while the working process to achieve three kinds of meta-synthesis achieved through three systems in HWMSE is still very vague and lacks concrete steps or mechanisms about knowledge creation and wisdom emergence. The *i*-System provides a general framework, which has more specific components for generation of assumptions (imagination), social practice (involvement), validation of knowledge (intelligence), knowing of issues (intervention) and systemizing of validated knowledge (integration). The hierarchical structures and emergent characteristic have been indicated or even studied among OCGS or *i*-System, while further research is still needed to bridge the gap between conceptual model and practical implementation in both frameworks. Gu and Tang (2001) proposed meta-synthetic knowledge system for complex problem solving which assimilates the common grounds of both frameworks.

There is a great variety of system approaches that can be applied to different problematic situations. The suitability of an approach is depending on the actual real-life situation, cultural background and the way how the approach is applied.

As meta-synthesis method was proposed, some projects had been undertaken to test the ideas in both civil and military areas such as sustainable development, macroeconomics, defense system analysis and large project evaluation in recent 10 years (Hu, 2002; Yu and Tu, 2002; Gu and Tang, 2003a). However, satisfying and convincing results have not gained yet. Lack of support from both technology and further relevant theoretical research is among those reasons. Breaking advances in information technologies (IT) in recent years,

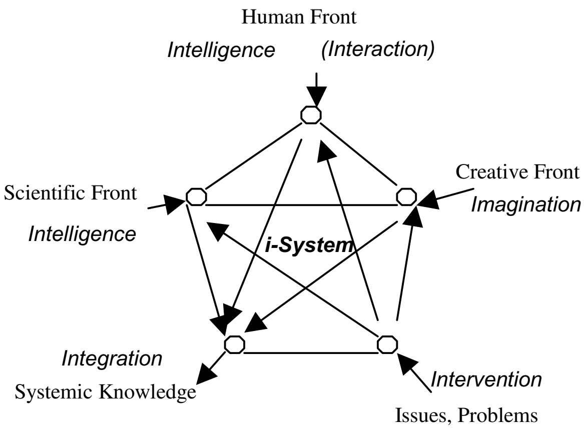

Fig. 2. The framework of *i*-System.

especially networking and distributed computing technologies turned many past imaginations into reality and then provides powerful support to past bottleneck problems. On the other hand, lots of achievements of the approaches with similar ideas to meta-synthesis method had been obtained. Some of them had even transferred into commercial products. Then NSFC approved a 4-year major project for the implementation of a pilot prototype for HWMSE for macroeconomic decision-making in 1999. Over 60 researchers from 14 research institutes or universities are involved and organized into four groups or subprojects for better management by NSFC: Group 1. HWMSE platform; Group 2. Macroeconomic modeling; Group 3. Meta-synthesis and systematology research; Group 4. Knowledge discovery and data mining (KDD), and cognitive modeling of macroeconomic decision-making. There is another group in charge of integrative system design. In this paper, Group 3's work is mainly introduced.

The principal goal of this major project is to exhibit the power of HWMSE in macroeconomic decision support. Before we present main work of Group 3, whose tasks are to propose basic solutions towards main issues and methods supported for whole system design and implementation, some basic topics which are key to HWMSE implementation and meta-synthesis approach itself are of a brief review.

3. Some topics in MSA research

Even during project application period, the leading investigators and advisors of the project proposed two questions for Group 3 people. (1) How to integrate opinions from experts especially when those opinions are so different and conflicted during debates? Referred as *opinion synthesis issue*; (2) How to integrate available models or methods to construct new models for unknown problems? Referred as *model integration issue*. Actually, both issues perplex researchers on meta-synthesis approach and HWMSE during past decade. Either is confronted during different phases in Simon's model about decision-making process (Simon, 1960). As a matter of fact, opinion synthesis can be regarded as perspective synthesis, since it is assumed that different groups of experts hold different ideas about the concerned problems and those different ideas are basis to develop different perspectives whose integrative scenario constructs a system model. In this section, up-to-date research relevant to both issues with regard to meta-synthesis approach is reviewed.

3.1. Model integration

Modeling is a pervasive activity which manifests itself in nearly every discipline. Different people develop various models for various problems or systems. Effective decision support calls for integration of different models about different components so as to construct a comprehensive scenario about a larger system. The potential significance of research findings in model management extends well beyond the sphere of operations research and management sciences or any other patently model-based fields (Krishnan and Chari, 2000). Model integration is regarded as an extension of model management; while the former extends the scope of the latter, especially in practice as a result of increasing complexities which had been continually perplexed people along the socioeconomic and environmental development. Dolk and Kottemann (1993) addressed four perspectives of model integration, definitional and procedural, organizational and implementational. Definitional perspective is on model representation and corresponds to schema integration while procedural integration is about model manipulation and corresponds to process synchronization. Most theoretical research work focused on technical perspectives while fewer discussions about organizational issues are seen than those about technical issues. There are three main schools of model representation: structured modeling (Geoffrion, 1987), logic modeling (Kimbrough and Lee, 1988; Bhargava and Kimbrough, 1993) and graph grammars (Jones, 1990; Jones, 1993).

Geoffrion (1996) gave his distinction between what might be called *deep* integration and *functional* integration in correspondence to *definitional* and *procedural* integration, and suggested 10 possible types based on a four-level hierarchy of model abstraction: *model instance*, *model class*, *modeling paradigm*, and *modeling tradition* (Geoffrion, 1989). Based on those, Makowski (this issue) develops structured modeling technology (SMT) which can provide modular tools for structured modeling.

The integrated modeling environments (IME) facilitate the process of model integration. DecisionNet and DOME (Distributed Object-based Modeling and Evaluation) are two typical examples (Bhargava et al., 1997; Pahng et al., 1998). Advances in software engineering and distributed artificial intelligence and the quick development of Internet technology invigorate model integration research.

Tang (2001) summarized three approaches, top-down, bottom-up (or distributed) and systemic approach toward implementation of model integration. By top-down approach, a comprehensive model about the concerned problem should be clarified so as to decompose the problem efficiently. Top-down architecture reflects a centralized mechanism to divide-and-conquer for problem-solving. A generic, common sense framework is pertinent for the concerned problem during the implementing model integration. Ontological engineering contributes much. Bottom-up approach reflects *distributed* and *decentralized* activities during implementing model integration and management. Such kind of approach overcomes the limitations in model resources for integration and expands the scope of integration activities, especially when it is hard to acquire a standard architecture for integration. *Distributed* model integration might have two distinct forms: distributed modelers with access to centralized resources (data or models for integration), or distributed modelers with distributed resources. *Decentralized* means that the coordination between modelers is not centrally controlled. However, applying bottom-up approach still needs some higher-level framework. The third approach is systems thinking towards the concerned problem itself, i.e. systemic approach. Bhargava and Krishnan (1993) indicate four issues worth deep thinking: (a) *cognitive issues*; (b) *language issues*; (c) *system issues*; and (d) *empirical issues*. Issues (a) and (d) actually belong to "people problems" and are beyond current concerns of the theoretical methods about model integration. It had been realized that resolving those kinds of issues could not be quickly achieved; instead, a learning process usually happened. Those three approaches reflect the evolutions of perspective towards model integration, from process-oriented to problem-oriented, and from analytical thinking to synthetic thinking. More and more social and organizational factors have been considered in modeling process. There is a great deal of discussions on model-based decision support from systemic approaches (Wierzbicki et al., 2000). Collaboration, especially for dealing with those subjective factors has been gradually becoming an important focus during integration. In this point, ways of model integration is based on results of opinion synthesis.

Research on opinion synthesis issue is mainly around two areas. One is the method for synthesis; the other is approach to synthesizing process.

3.2. Synthesis of perspectives

About synthesis method, an important field is multiple criteria decision analysis and group decision research. Artificial intelligence is also an important relevant field. Zhang and Zhang (1999) present how to synthesize the results from distributed expert systems. During 1997–2002, Japan Society for the Promotion of Science sponsored a major project titled "Science of Synthesis", whose goal is in pursuit of a methodology of collaborative synthesis by artificial intelligence where ontology engineering is applied for synthesis of knowledge. The main application is on the design and production of industrial product (Mizoguchi et al., 1999).

Intensive research on synthesis is also taken in medicine and social sciences. A research project is carried out titled "analytic techniques for qualitative meta-synthesis" (2000–2005) in USA (Sandelowski et al., 1997). Suri (2000) reviewed both strengths and weaknesses of four contemporary methods of research synthesis, traditional narrative reviews, meta-analysis, best-evidence syntheses, and qualitative research syntheses, and argues that a comprehensive research synthesis should include quantitative as well as qualitative research findings. The process of synthesizing research should be inductive and interpretive rather than a rigid set of procedures and techniques. Such kind of assertion is beyond the original ideas of meta-analysis.

Lots of similar research and practice as meta-synthesis have been undertaking within some specific fields in recent decade. Global change, sustainable development and geographical systems are active areas for meta-synthesis practice. Gu and Tang (2003a) present some examples. Since the mid of 1990s, combination of quantitative modeling and qualitative expert judgment during system modeling is more and more emphasized together with more demand in computerized support for applying those synthesis methods.

3.3. Computerized support for synthesis

The process of synthesis of different perspectives mainly refers to process of synthesis of data, information, models, knowledge, and even wisdom. Such a working process is usually undertaken via a series of group activities, such as communications, collaborations and conclusion or consensus. During a synthesis process, new knowledge is expected to be created for resolution of issues.

Computerized support tools for those activities are mainly for group work, such as group DSS, groupware, computer mediated communication (CMC) system, computer supported cooperative work (CSCW), etc. which are one of DSS trend (Shim et al., 2002). Actually, group support systems (GSS) replaced GDSS since the mid of 1990s because of more emphases on communications and information sharing among group work. Most products with knowledge management brands also belong to this category. While there is another category of support tools for group work, i.e. for argumentation and sensing-making for problem structuring. Lots of tools had already been explored, such as Dialog Mapping (gIbIS based, QuestMap) (Conklin et al., 2001), Decision Explorer and Group Explorer based on Strategic Options Development and Analysis (SODA) (Eden and Ackermann, 2001), Wisdom (Pidd et al., 2003) and Augmented Informative Discussion Environment (AIDE) (Mase et al., 1998). Those tools are all based on specific mental models about group thinking or decision making.

The trend of DSS reflects that decision-making is becoming "more *pluralistic* and less hierarchical, determined not so much by position in the organizational hierarchy but much by the *argumentative* and *evidential* value" (Carlsson and Turban, 2002), which is also supported by the new decision paradigm for DSS proposed by Courtney (2001) (Fig. 3).

The mental model which lies at the heart of the process could be "either personally or collectively", "determines what is examined and what perspectives are developed". The development of perspectives also leads to the update of the mental models. More widely, we understand the mental model as cognitive models which are expected to be studied in our NSFC project. The salient feature of Courtney's paradigm in comparison to traditional decision models in a DSS context, is the development of multiple perspectives during problem formulation phases, where technical (T), organizational (O) and personal (P) perspectives are suggested by Mitroff and Linstone (1993). Moreover, ethical and aesthetic factors are also taken into consideration. Here we think other necessary perspectives, such situational or contextual perspectives also need to be considered.

Next we present part of our research results for the NSFC major project.

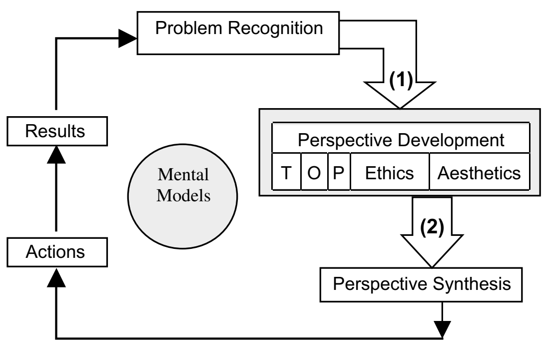

Fig. 3. Decision paradigm for DSS (Courtney, 2001).

4. Man–machine meta-synthetic support for macro economic decision making

By the original design of the project, it is expected to develop effective support for macro economy decision making. Since macroeconomic system is an open giant complex system, MSA is applied. The concerned system involves a number of factors, attributes and aspects, therefore different models have been developed to deal with different facets of the system under different purposes.

4.1. Modeling about macro economic problems

According to the modeling principles proposed by Ackoff and Sasieni (1968), we divide modeling activities in the project into six categories:

I. Modeling by mechanism, such as econometric models which predict the whole year operation of national economy (Ma et al., 1999; Zhou, 2003).
II. Modeling by analogy, such as case based reasoning for financial crisis awareness (Wei et al., 2001).
III. Modeling by rule. This category refers to multi-agent simulation (MAS) using complex adaptive system theory which is useful to analyze collective characteristics based on individual behaviors (Chen et al., 2000). Such kind of rule-based modeling may also be regarded as a means to test some assumptions, to design and examine what will be happened.
IV. Modeling by data, such as various statistic models, Bayesian network model, neural network (NN) model, and reconstructability analysis (RA) model (Tian et al., 2002; Guo and Tang, 2001; Shu, 2000).
V. Modeling by evolutionary scenario, such as evolutionary model (Di and Li, 1998; Fang and Chen, 2003; Shen et al., 2002). Evolutionary modeling is useful in finding the complexity. Such kind of models is to investigate and explore the economic complexity, such as chaos and fractal.
VI. Modeling by learning, such as those knowledge discovery and data-mining models (Tian et al., 2001).

Modeling by learning here is still based on data, while it emphasizes a higher level work to expose the hidden knowledge embedded in large amount of data. It also emphasizes human involvement, so as to absorb experts' knowledge to improve modeling process.

A variety of models reflect different perspectives towards macro economy system. Then how to undertake the synthesis of perspectives by Courtney's paradigm? Currently, the fulfillment of such kind of tasks is by expert meeting or group discussions held in HWMSE. A flowchart to apply MSA in HWMSE is as shown in Fig. 4.

Different styles of meetings are adopted to implement three kinds of meta-synthesis. At first, an expert meeting is held synchronously to practice qualitative meta-synthesis, as indicated as Synchronous Stage I. At this stage, experts are expected to propose different viewpoints or ideas towards discussed issued under time pressure, and finally some qualitative assumptions are formed and scenarios are depicted for further analysis. Then enter into a stage where developing quantitative modeling based on qualitative assumptions. Such kind of analytical activities are taken asynchronously, which means less time pressure to modelers. As different groups of experts finish respective modeling based on their preferred scenarios, the meta-synthesis from qualitative understanding to quantitative validation is applied at another round of synchronous meeting

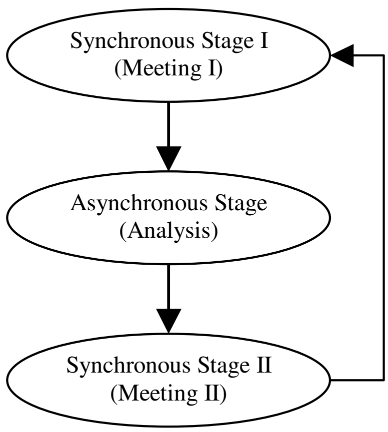

Fig. 4. Working process by MSA.

denoted as Synchronous Stage II. Next we explain the whole working process stage by stage.

4.2. Synchronous group work for qualitative assumptions

During the first synchronous stage, attentions are paid to identify the concerned problems or issues. Expert meeting is convened for collecting experts' opinions towards problem recognition. Here, divergent thinking is applied to acquirement of different opinions to expose different perspectives about what is concerned, indicated as (1) in Fig. 3.

Brainstorming is the most frequently used tool for group divergent thinking which can aggregate ideas as many as possible toward concerned problems. Through brainstorming sessions within HWMSE, as different opinions are collected, convergent thinking is applied to aggregate opinions which are condensed to some assumptions and scenarios. Before any sessions, the assistant (human) or facilitator provide basic data, information, knowledge and cases related to what are discussed within the session to help experts to propose their opinions sound. Besides, participants utilize the resources and facilities to acquire extra information and cases for their individual or group thinking. To facilitate such kind of discussion, computerized support tools for group work can be applied, such as commercial products branded as groupware, GSS, and CSCW, etc. Argumentation tools can also be used for idea generation. In Group 3's work of the major project, tools for group work to support those group activities are developed, such as *electronic common brain* (ECB) designed by Xi'an Jiaotong University (Cheng et al., 2001) and *group argumentation environment* (GAE) designed by Institute of Systems Science (Tang and Liu, 2002; Liu and Tang, 2003). Both tools provide more support to group work in comparison to general groupware. In ECB, where Toulmin argument framework (Mitroff et al., 1982) is applied to structure group arguments and decision tasks, the utterance by each participant is stored according to the predefined grammar. Thus a framework of all opinions is generated for share and retrieval, which serves as a shared memory, not only for the expert group in the sessions, but as a case base of the discussions on the concerned issue. GAE goes another way. It aims to support idea generation or creative solutions for messy issues, thus it is mainly for divergent thinking. Like most e-chats tools, GAE list all participants' utterances as plain texts. Moreover, all collective information, mainly utterances and keywords by each participant who attends the same session of one topic are processed by dual-scaling method and results are visualized at a two-dimension space for better understanding. Such kind of visualization aims to help participants review past conversations, initiate their creative associations and find common grounds about the concerned issue (Mase et al., 1998). Visualized analysis for argumentation process is expected to help initiate creative ideas toward some structure of unknown or complex problems during a divergent thinking process where experts express their opinions freely while simultaneously affected by others' ideas, and then are expected to acquire new understandings about the discussed issue beyond their original views. Cognitive studies had given some proof that idea sharing in groups can be productive and may be an important means for enhancing creativity and innovation in organizations with some procedure techniques, like limiting verbal interaction and exchanging ideas by writing or typing on computers, to overcome the limitations of interactive brainstorming and facilitate group members carefully process and response the ideas exchanged in the group (Paulus and Yang, 2000). The interactions within groups actually create a field or atmosphere for knowledge creation or even wisdom emergence for problem solving.

Table 2 lists input, tasks, tools and output of the working process in Synchronous Stage I. For Group 3 people in this major project, the principal tasks are to demonstrate feasibility and accessibility of MSA to complex problem solving. Therefore some tests have been taken. In order to facilitate a whole test, some commercial products are also adopted, such as SkyMark's PathMaker which has been applied to some tests (Gu and Tang, 2003b).

Through group divergent and convergent work, some assumptions or hypotheses are formulated

Table 2
Work in Synchronous Stage I

Input	Tasks	Tools	Output
Data	Divergent thinking (idea generation)	ECB	Hypothesis
Information	Convergent thinking (qualitative meta-synthesis)	GAE	Assumptions
Knowledge		PathMaker	Scenarios
Cases		etc.	Decisions
Expert backgrounds			

and scenarios about the issue are expected to be acquired. Then we enter into Asynchronous Stage for qualitative-quantitative meta-synthesis.

4.3. Asynchronous Stage for quantitative modeling

Synchronous and asynchronous activities are relative with regard to time pressure for those activities. Expert meeting for some qualitative consensus may take only several days, or even several hours; while it takes much longer for quantitative modeling. In Section 4.1 different modeling strategies on macro economy are depicted. Those modeling work reflects some characteristics about modeling on macro economy:

(i) Combination between static and dynamic modeling, e.g. econometric modeling vs. evolutionary modeling;
(ii) Combination of white box models and black box models, e.g. econometric models vs. data-driven models;
(iii) Combination of macro models and micro models, e.g. econometric and evolutionary modeling vs. MAS modeling.

Versatile models describe different perspectives of macro economy running based on qualitative assumptions, hypotheses and scenarios gained in Stage I (Table 3). Those models are developed by different groups located in different places. A distributed integration strategy is applied (Hu and Wang, 2001). Such an integrative framework is similar as DecisionNet (Bhargava et al., 1997), which is a collection of decision analytical tools, aims to improve the usability, interoperability and reusability of decision technologies by exploiting those strengths of Web technologies.

Experts run those models to test those assumptions. Here the habitual domains of experts may affect their utilizing those available models (Yu, 1995). The intuition and tacit knowledge are expected to be synthesized with qualitative models (Makowski and Wierzbicki, 2003). The aggregation and collection of tacit knowledge during this stage is an important step to form modeling paradigm for the concerned issues (here are macro economic modeling). As different results have been acquired by different modeling which reflects different perspectives toward macro economy, we enter into the Synchronous Stage II for synthesis.

4.4. Synchronous group work for quantitative validation of synthesized perspectives from qualitative hypothesis

In this stage, experts, managers and decision makers attend meeting for validation of models. They join together to express opinions about the results from Asynchronous Stage. They may change the parameters and the structures of models or to propose some new models, or even change the assumptions and scenarios which are inconvincible for some participants, who may just suspect some results achieved in Asynchronous Stage. The main work in this stage is to reach consensus or compromise toward the concerned issues, indicated as (2) in Fig. 3.

In this stage, group convergent thinking and group decision making is applied. Methods for convergence are widely used. Besides those common ways for convergence, such as voting, analytical hierarchy process (AHP) and nominal group technique (NGT), some other methods are also developed, such as possibly satisfying method (Wang, 1982) and meta-synthesis system recon-

Table 3
Quantitative modeling during Asynchronous Stage

Input	Tasks	Models or tools	Output
Data, Information	Modeling by mechanism	Econometric model	Economic indicators
Knowledge, Cases	Modeling by data	Time series, Bayesian network, NN, RA	Alternatives
Experiences, Intuition	Modeling by rules	SWARM	Individually justified hypothesis
	Modeling by cases	Case-based reasoning	
Hypothesis, Assumptions	Modeling by evolutionary scenarios	SWARM, dynamic system, complexity research (chaos and fractal)	
Scenarios	Modeling by learning	Knowledge discovery and data mining	
	Model integration	Integrated modeling environment	

Table 4
Work in Synchronous Stage II

Input	Tasks	Tools	Output
Data	Model validation	Meta-synthetic RA	Validated knowledge
Information	Consensus building	Possibly satisfying approach	Decisions
Knowledge		AHP, NGT	Consensus/Compromise
Cases		ECB	
Experiences		PathMaker	
Intuition		Expert Choice	
Economic indicators		etc.	
Alternatives			
Individually validated hypothesis			

struction model which accepts expert knowledge to improve the behaviors of reconstructability (Shu, 2000). Table 4 lists the possible work undertaken in Synchronous Stage II, where Expert Choice (AHP) and PathMaker are commercial tools for consensus building.

Above depicts how to apply MSA to macro economy modeling. Those activities are undertaken within HWMSE. Next we discuss how HWMSE supports those activities.

4.5. Supports for meeting held in HWMSE

According to the simple working process of MSA as shown in Fig. 4, expert meetings are held during different working stages. Fig. 5 shows a possible framework of users (participants) and resources available for seminars and workshops held in HWMSE. Those resources and participants are from three component systems of HWMSE.

Human expert system consists of a variety of expert bases. Meeting organizers get basic information, such as age, knowledge background, working experiences, etc. from expert bases so as to select appropriate experts and facilitators to construct a feasible group for effective argumentation. Facilitators help to coordinate the meeting process to follow the predefined agenda. Obviously, the updating of expert bases is one of important tasks for human expert system.

To support those expert meetings, machine system provides necessary data and relevant information about the concerned topics besides communication facilities and cooperative tools for expert group work, such as various groupware tools, like CSCW, ECB and GAE. For example, in the discussion of gross domestic product (GDP) growth trend, the required history data and operating data of national economy can be accessed from data base. Relevant information can also be gained from Internet or relevant portals. Besides, some cases about historic events, like Asian financial crisis, which have been processed and stored in case base, can be browsed by human experts for comparisons. Moreover, software agents (also called intelligent agents) which take care of

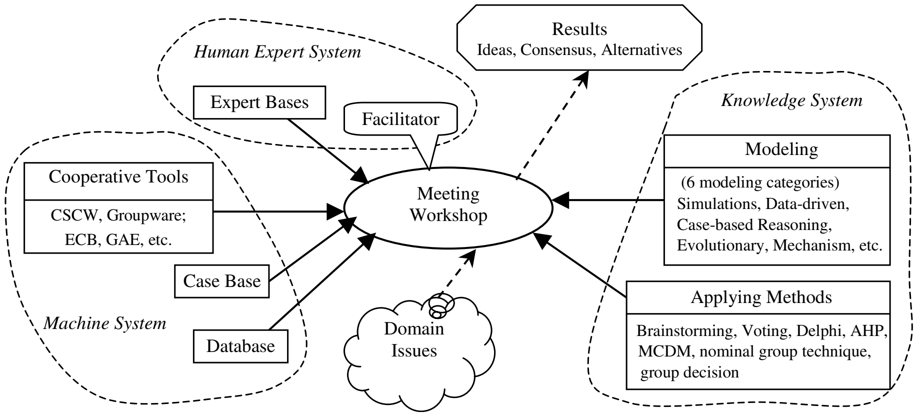

Fig. 5. Resources within HWMSE for a meeting.

searching, screening, sifting and filtering of data, information and knowledge provide customized help for facilitator and human experts. All those collaboration tools, databases, case bases and external accessible information plus customized services in machine system are one kind of quantitative intelligence support for human experts.

On the other hand, quantitative methods or models for quantitative analysis also provide quantitative intelligent support. The "Modeling" component in knowledge system in Fig. 5 denotes to those 6 categories of modeling work as depicted in Section 4.1. The "Applying Methods" component refers to decision analysis methods, such as multi-criteria decision making (MCDM) methods, Delphi and nominal group techniques, etc. Moreover, it denotes to a context or template where applied procedural techniques to implement those methods. Both models and methods are for analytical and synthetic work. If an expert meeting is held for a convergent decision process, then synthetic methods like voting, Delphi, AHP, etc. may be used to acquire some consensus toward concerned issues. If a seminar is held just for idea generation about a messy problem, then brainstorming template may be applied. Meetings can be held synchronously or asynchronously based on different tasks and requirements. As a matter of course, both formalized and computerized models and methods belong to machine system. As they are applied to specific issues based on specified or even new perspectives given by human experts in tackling with the concerned issues or testing those qualitative hypotheses, the whole context of application reflect knowing of the issues or even lead to produce new knowledge, which involves human experiences and intuition, and represents qualitative intelligence support for human experts. In this point, they are classified into knowledge system.

Through the working process as shown in Fig. 4 and with help of available resources from three systems in HWMSE, humans (experts, decision makers) can acquire ideas, alternatives or consensus about the concerned issues, as indicated as a flow by dotted line in Fig. 5.

Both Cao and Dai (2003) and Hu (2002) discussed the techniques for system implementation of HWMSE while further research is still required, especially for a seamless integration of all resources contributed by different groups in the major project. Tang and Gu (2002) proposed framework on building HWMSE for this project based on systems thinking and had applied to the integration of research results in Group 3.

5. Validation

In order to verify the methodology and the developed software a number of tests and case studies have been developed. In September of 2003 a dedicated session was organized with participation of European, US, Canadian and Japanese experts in model-based decision support at the International Institute for Applied Systems Analysis (IIASA). The case study used for the demonstration was "how to evaluate China GDP growth with the impact of SARS by meta-synthesis approach". In this test we had collected a lot of different information including data and facts, opinions and comments, estimates and forecasts, etc. from Internet and other sources related to SARS and China economy during April to August of 2003. The commercial software tool for cooperative group work, PathMaker, was applied to facilitate the working process. Some of our own tools or models, such as the econometric models provided by Beijing Institute of Information and Control (BIIC), neural network models by Tsinghua University, reconstructability analytical model and GAE by Institute of Systems Science, were also linked with PathMaker. The models ran at different computers to test distributed modeling. For the econometric models, calculations were taken under three assumptions about the economic development trend and SARS impacts respectively and 9 scenarios were acquired for group discussions. In the end of the special session, experts summarized the positive evaluation and gave recommendations for future work.

6. Concluding remarks

In this paper, meta-synthesis approach and hall for workshop of meta-synthetic engineering (HWMSE) are addressed. Proposed by Qian and his colleagues, meta-synthesis approach is for dealing with open giant complex system where traditional reductionism methods do not work. Moreover, MSA is regarded to deal with unstructured messy problems. DSS aims for unstructured problems while HWMSE can fulfill all functions of DSS with more emphasis on knowledge creation and creative activities based on intuition and wisdom emerged via communications and collaborations between experts during the meetings or discussions/debates held in HWMSE.

Main ideas of Group 3 of NSFC major project, to implement a prototype of HWMSE for macro economy decision making, are presented. We focus on basic solutions towards main issues and methods including model integration, opinion synthesis, macroeconomic modeling, etc. For macroeconomic system modeling, besides econometric models, several other kinds of approaches, such as multi-agent simulation, evolutionary modeling and reconstructability analysis are studied and relevant models are developed. To achieve the ideas of HWMSE, more attentions are given to computerized support for group activities, especially for group thinking, group argumentation and group decision making. Several computerized environments support those group activities are developed, such as *Electronic Common Brain* and *Group Argumentation Environment*, which can serve as distributed discussion rooms within the Hall. Various models can be regarded as resources for experts' discussion and debates within the Hall.

Obviously, our current on-going work only exposes some strengths of HWMSE support for complex problem solving. Lots of explorations need to be undertaken. For example, how to provide effective support for idea generation or knowledge creation and even wisdom emergence? Further research is barely needed to acquire more mental models for both individuals and group. That can also be sensed from the practical organizing of the major NSFC project where actually lacked a research unit on knowledge system for HWMSE.

Recently, relevant research on knowledge creation is very hot. Several approaches to knowledge creation have been proposed; one of which is the organizational knowledge creating theory where emphasizing the role of a right "*ba*" during knowledge creation process (Nonaka and Takeuchi, 1995). *Ba* is defined as a platform where knowledge is created, shared, associated and exploited; the most important aspect of *ba* is "interaction". The knowledge-creating process is also the process of creating *ba*, which means to create a boundary of new interaction (Nonaka and Nishiguchi, 2001). Gibbons et al. (1994) adopt a similar perspective about knowledge creation (production) and propose two modes about knowledge production, while Mode 2 knowledge embraces the "transdisciplinary social and economic context" and is produced in the application context. As a test bed of MSA, HWMSE may be regarded as a *ba* for knowledge creation and wisdom emergence or Mode 2 knowledge production within a metasynthetic context.

Meta-synthesis approach aims to knowledge creation and wisdom emergence which is essential for creative solutions of unstructured complex issues. We have started research supporting the creation of '*ba*' for knowledge emergence. It is necessary to study the cognitive process about group work, to study man–machine (people-Web) environment for group knowledge creation. Moreover, mechanism of formulation of group for knowledge creation needs to be studied.

By review of DSS development, it is found that Simon's decision making framework has always been referred while early technologies work had already been discarded due to continuous revolutions in information technologies. Qian had proposed that the basis for MSA and HWMSE is cognitive science or noetic science (Wang et al., 1996). Problem structuring approaches, including those soft OR and system approaches, belong to the theoretical part of MSA studies and are worth more concerns.

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