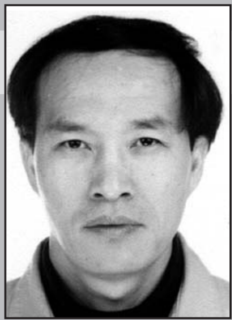

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# Artificial Societies for Integrated and Sustainable Development of Metropolitan Systems

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Over the past 15 years, China's urbanization has almost doubled, with approximately 31 percent of the population now living in one of the country's 660 cities or 19,000 towns. This rapid increase in metropolitan population and other urbanization activities has imposed a huge demand on Chinese metropolitan transportation systems, most of which weren't prepared for such development. For example, in 2003, the number of passenger vehicles increased by 85 percent, compared to an average of 1.5 percent in the rest of the world.[1] Additionally, 667,507 traffic accidents were reported, causing 104,372 deaths and 494,174 injuries and making traffic accidents the number-two cause of accidental deaths of children in China.[1]

Pollution is another transportation-related problem in China, contributing to over 90 percent of the total noise intensity and 60 percent carbon monoxide emissions, 50 percent nitrogen oxide emissions, and 30 percent hydrocarbon emissions in the metropolitan areas.[1] According to the UNDP China's National Human Development Report, in 2001 China had 16 of the world's top 20 most air-polluted cities.[2] Additionally, China has been reducing its land resource (developed lands) at a rate of 2 to 3 percent owing to transportation-infrastructure construction, further intensifying the pollution problem.[1]

Finally, weak and unreliable urban transportation systems have significantly increased the cost of logistic activities in China, currently at a level of 20 percent GDP. This is much higher than the average (10 percent) in developed countries.[1]

Although China has made significant efforts over the past two decades to solve its transportation problems, traffic congestion, pollution, accidents, and other related problems are only getting worse. So, a team of over 70 researchers from 10 universities and research institutes in China and the US is developing a framework of platforms based on concepts and methods in artificial societies and complex systems (see Figure 1). Our goal is to study integrated and sustainable development of metropolitan transportation, logistics, and ecosystems.

## Editor's Perspective

This issue's article is based on a discussion at the IEEE/CAS Workshop on Artificial Transportation Systems, held 25–26 April 2004 in Shanghai and on objectives of the Technical Committee on Artificial Transportation Systems (ATS), recently established by the IEEE Intelligent Transportation Systems Council. The ATS Technical Committee will develop standard techniques beyond computer simulations to analyze, evaluate, control, and manage transportation systems. The goal is to use concepts and methods in artificial and complex systems in ITS, and clearly artificial intelligence, life, and societies will play a key role in this new direction of ITS research.

Feel free to contact me if you have any comments about this department. I also seek contributions on the status of ITS projects worldwide and on innovative ideas and trends in future transportation systems. Contact me at feiyue@sie.arizona.edu.

*—Fei-Yue Wang*

## Research issues

Unfortunately, we can't solve transportation problems by focusing on transportation systems alone. Rather, we must consider the combined effects with other metropolitan systems. *Artificial systems*, based on artificial societies and agent-modeling technology, are effective tools for this purpose.[3]

Another issue is that no once-and-for-all solutions exist. Metropolitan transportation, logistics, and ecosystems are intrinsically open, dynamic, unpredictable, and complex in their behaviors and effects. We must adopt a management and control strategy for those systems based on continuous investigation and improvement and should use computational experiments with artificial systems to overcome the difficulty of experimenting with real systems.[4]

Finally, no optimal solutions exist. We must consider the sensitivity of so-called optimal solutions to their assumed ideal conditions and the unavoidable disparity between ideal and actual conditions. We should adapt our thinking to consider multiple effective solutions in dealing with urban development problems. In such cases, we should apply the


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concept of parallel systems, which consists of real and artificial systems and uses computational experiments and adaptive-control methods to seek adaptive, dynamic, and effective solutions.[5]

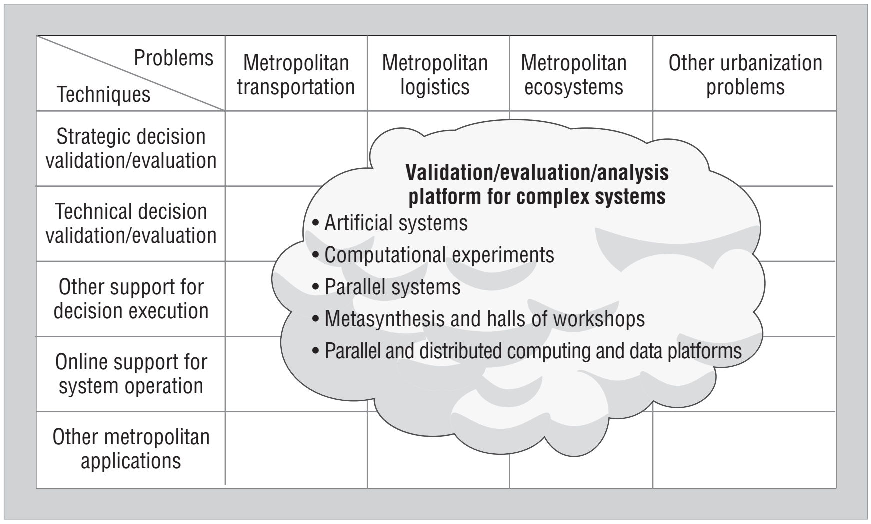


**Figure 1. A complex-systems platform for integrated and sustainable development of metropolitan transportation, logistics, and ecosystems.**

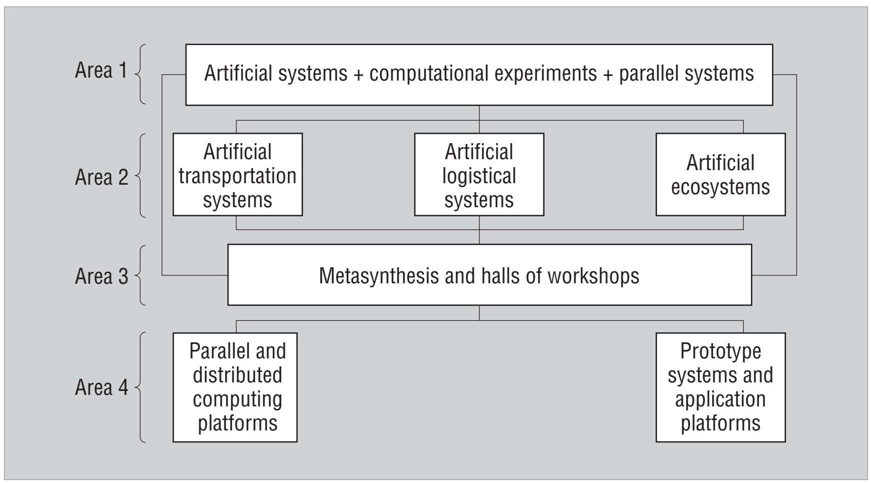


**Figure 2. Key issues and tasks for integrated, sustainable development of metropolitan systems using artificial systems.**

## Addressing the problems

Our team consists of researchers from systems engineering, computer science, transportation, logistics, operations research, plant science, economics, population studies, management science, and social studies. This effort represents an important application of artificial societies[6,7] and will further development of the activity-based TRANSIMS project[8] and artificial transportation systems.[9,10] Supported by the Knowledge Innovation Program of the Chinese Academy of Sciences and a pending grant from the Ministry of Science and Technology of China's National Key Fundamental Research Program (the 973 projects), we've already started work.

We're addressing several key problems, the first of which is the *modeling* problem. Effective methods for modeling and analyzing complex systems don't exist. We're inclined to be agreeable with simple objects or relationships—it's easy to reach an agreement over simple matters, but this isn't as easy with complicated matters. So, building agent models based on agreeable simple objects or relationships is useful. Then we can develop a bottom-up approach to "grow" complex systems and observe their behaviors through the interaction of simple but autonomous agents according to specified rules in given environments. We can use this approach to develop agent-based models that focus on behavior generation for integrated artificial systems for transportation, logistics, and ecosystems.

Second is the *experimenting* problem. Experimenting with complex systems is difficult—often even infeasible—especially when it involves human or societal subjects. So, artificial systems are helpful for computational experiments, which are a natural extension of computer simulations. Artificial systems and computational experiments are ideal tools to validate goals and objectives or evaluate strategies and decisions for coordinated and sustainable development of metropolitan transportation, logistics, and ecosystems.

Next is the *decision-making* problem. Through the interaction between real and artificial systems, we can construct parallel systems to perform computational experiments, test different strategies and decisions, and evaluate their effects for solving complex problems. Ideas and methods developed in adaptive-control systems can be used effectively in the framework of parallel systems for decision-making in complex systems. Furthermore, artificial systems, computational experiments, and parallel systems provide both data sources and proving grounds for decision support and analysis of complex systems using metasynthesis.[11] Fusing those methods offers a possible direction for establishing a computational framework for facilitating integrated, coordinated, and sustainable development of metropolitan systems under the principle of continuous investigation and improvement.

Finally, to solve the problems we've described, we must also address the *computing* problem. How can we best use new and advanced computing architectures and environments, especially networked computing such as grid computing and peer-to-peer computing?

To address these problems, the team has specified seven major tasks in four areas and assigned them to various team members (see Figure 2) for a five-year period. Figure 3 gives a roadmap for integrating those tasks into an effective, coherent framework for modeling, analysis, and management of complex systems.

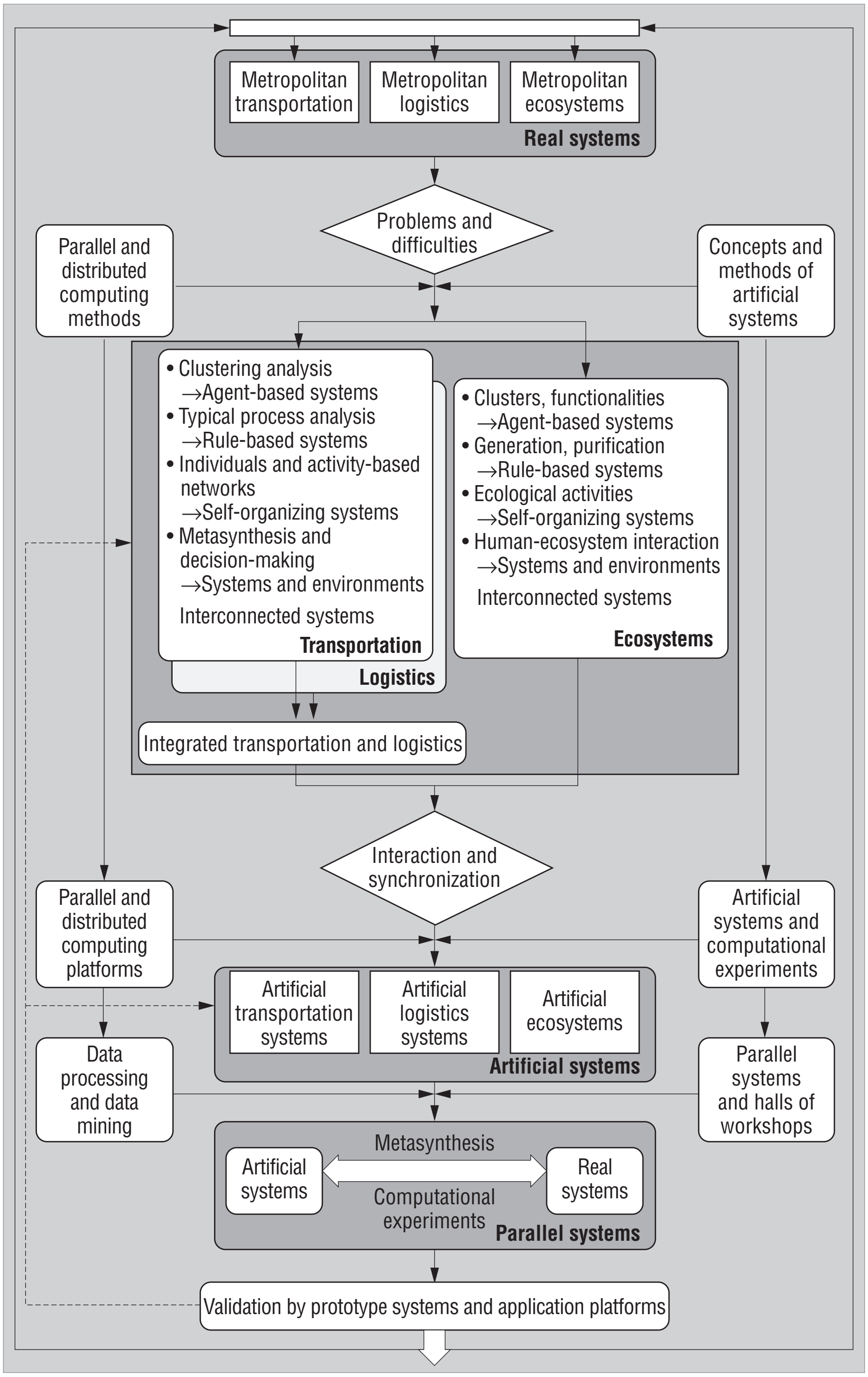


**Figure 3. Roadmap for integrated, sustainable development of metropolitan systems using artificial systems. (Dashed lines represent information that leads to modification in the directed box; solid lines represent other information or decision flows.)**

## Area 1: Artificial systems for real complex systems

The first area's goal is to establish a computational theory that uses artificial systems as alternatives to real complex systems for validating or evaluating computational experiments (see Figure 4) and for managing or controlling parallel systems (see Figure 5). Accomplishing this task involves three subtasks.

The first subtask is the agent-based modeling, design, analysis, and synthesis of artificial systems. This subtask will require

- Cellular automata and their generalization for modeling agents
- Linguistic dynamic systems for describing agent behaviors
- Multiresolution observation and analysis of agent behaviors
- Petri nets for specifying networking and cooperation among agents
- Computational-intelligence methods and game-theoretic strategies for decision-making by agents

The second subtask is to develop methods and procedures for computational experiments, which will require

- Transition of computer simulations to computational experiments
- Accelerated tests for pressure, limit, failures, or disasters
- Emergence-based observation and explanation for computational experiments
- Multiscale behavior analysis based on computational experiments
- Design, calibration, and verification of computational experiments

The final subtask is to consider a theory and methods for parallel systems, which will involve

- Developing a framework of parallel systems and protocols and processes of interaction between real and artificial systems
- Validating and evaluating strategies and decisions using parallel systems
- Installing internal feedback mechanisms for control and adaptation
- Performing perturbation analysis and ordinal optimization for effective operation based on parallel systems
- Identifying behavior patterns using computational experiments and parallel systems

## Area 2: Artificial systems for metropolitan transportation, logistics, and ecosystems

Using artificial systems to study complex systems is a natural extension of computer simulations as computational power grows. To maintain coherence and achieve integration of different artificial systems for transportation, logistics, and ecosystems, the systems use and share common agent models. Figure 6 presents the major components for artificial systems.

This area involves three tasks. The first task is designing, constructing, and analyzing artificial transportation systems, which will require

- Using agent models to model traffic behaviors in terms of selecting trips, destinations, times, means, and routes
- Having interaction between transportation and social systems, economic systems, population, resources, environments, and information
- Estimating and analyzing transportation capacities in different situations
- Validating and evaluating transportation strategies and decisions using computational experiments and parallel systems
- Using artificial transportation systems to create a standardized performance-evaluation procedure for traffic management and control systems

The second task is designing, constructing, and analyzing artificial logistical systems, which will require

- Using agent models and their calibration for logistical activities
- Creating self-organizing and learning artificial systems based on supply chains and service chains for logistical operations
- Performing emergence-based observation of logistical behaviors and their interaction with transportation systems
- Validating and evaluating logistical strategies and decisions using computational experiments and parallel systems
- Using artificial logistical systems to create a standardized performance-evaluation procedure for logistical management and control systems

The third task is designing, constructing, and analyzing artificial ecosystems, which will require

- Using agent models for plant growth and plant-environment interaction
- Regulating ecosystems and transportation systems and ensuring proper interaction between them
- Estimating and analyzing the ecosystems' carrying capacities in terms of population, transportation, and logistical development
- Sampling and generating synthetic human population and plant distribution
- Validating and evaluating ecological strategies and decisions using computational experiments and parallel systems

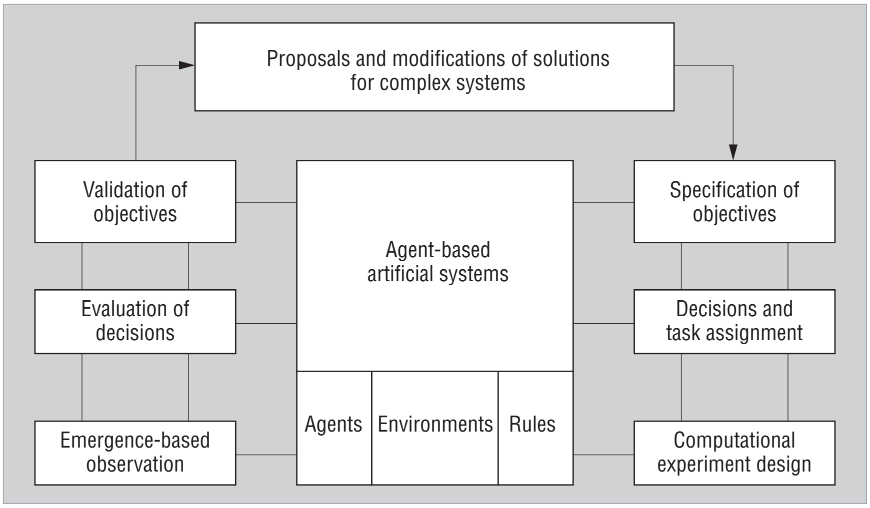


**Figure 4. Computational experiments for behavior analysis and decision evaluation of complex systems.**

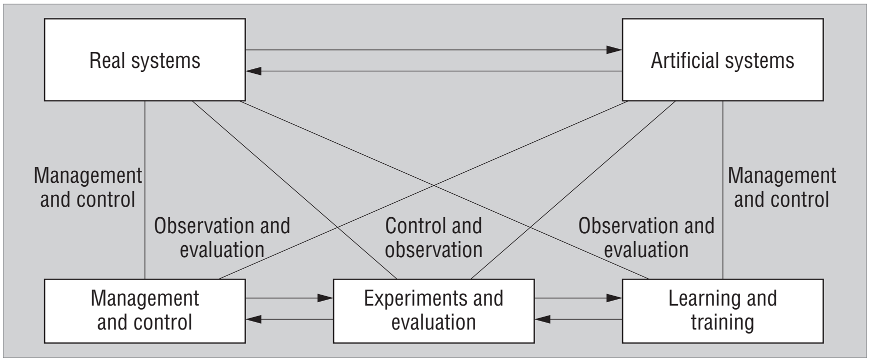


**Figure 5. Parallel systems for management and control of complex systems.**

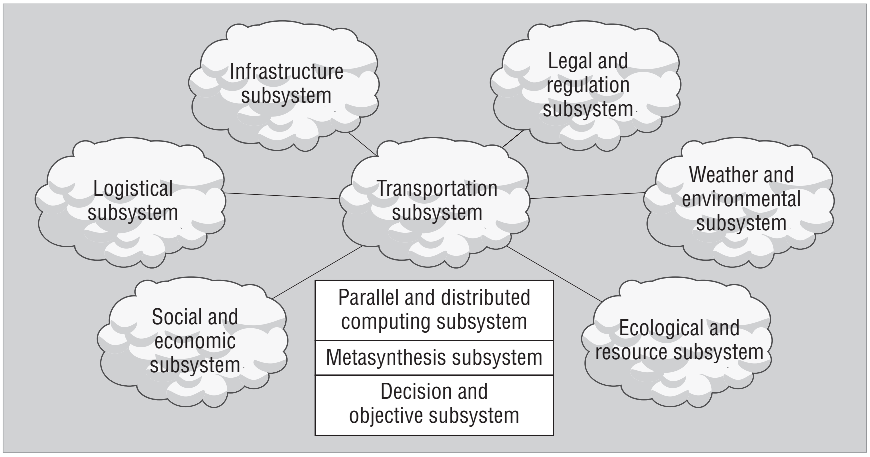


**Figure 6. Integrated artificial systems for transportation, logistics, and ecosystems.**

### Area 3: Metasynthesis and halls of workshops

Metasynthesis and halls of workshops are methods and tools proposed and developed in the late 1980s by a research group led by Hsue-Shen Tsien, the founder of engineering cybernetics[11] and the Chinese Space Program, and Ru-Wei Dai for dealing with

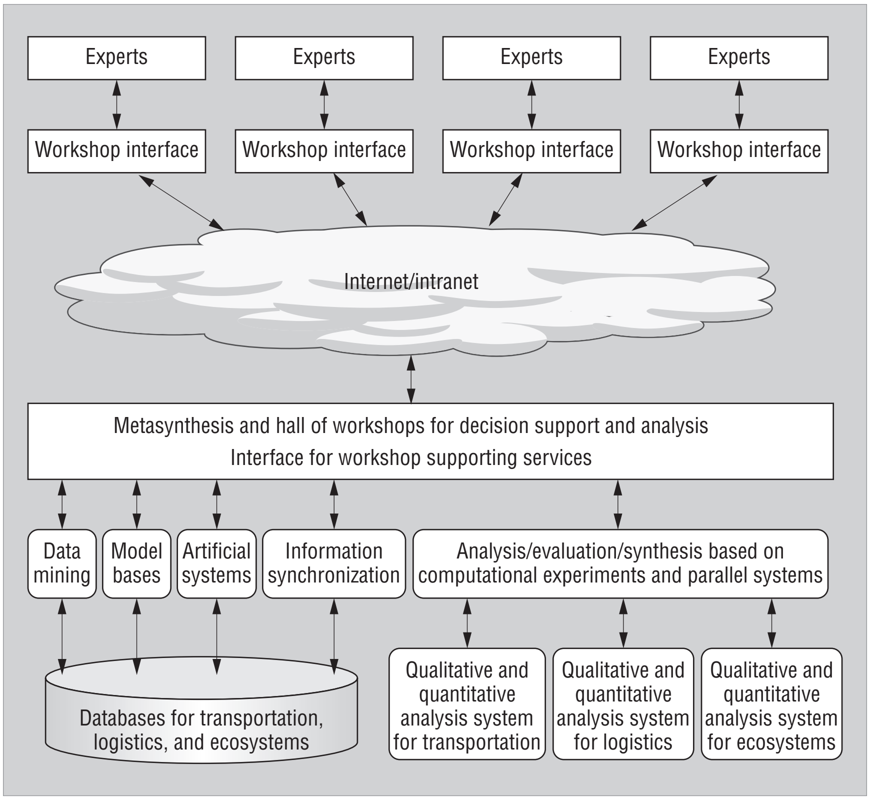


**Figure 7. Metasynthesis and halls of workshops for decision support and analysis of metropolitan systems.**

open, complex, and huge systems.[11,12] This area's task is to use artificial systems, computational experiments, and parallel systems to develop application-specific metasynthesis and halls of workshops for decision support and analysis of metropolitan transportation, logistics, and ecosystems (see Figure 7). This task will require

- Human-machine interaction-based metasynthesis for decision support and analysis
- Architectures and strategies of halls of workshops for decision support and analysis
- Workflows of halls of workshops for decision-making support
- Software support and network environment for halls of workshops
- An integrated validation and evaluation environment based on metasynthesis, computational experiments, and parallel systems

### Area 4: Computing platforms and prototypes

Powerful, effective computing and data-processing platforms are essential to the success of this team endeavor. The final two tasks are to develop two types of computing platforms: a grid-computing platform for management and control, and a peer-to-peer platform for research and development. Prototype systems and field applications in three major cities (Shanghai, Shenzhen, and Jinan) will be conducted to validate and evaluate the theory and framework developed in this project.

The platform for managing and controlling parallel systems will require

- Open computing architectures and processes for artificial systems and their parallel and distributed models
- Petri nets for specifying and modeling parallel and distributed computing processes of artificial systems
- Data management, mining, fusion, and reduction for artificial systems
- Effective parallel and distributed algorithms and synchronization methods for computational experiments, parallel systems, and halls of workshops
- Computing environments, tools, and intelligent user interfaces for computational experiments, parallel systems, and halls of workshops

The platform for creating prototype systems and applications will require

- Prototype systems for field applications in Shanghai, Shenzhen, and Jinan
- An integrated control and management platform for traffic systems
- An integrated scheduling and management platform for logistical systems
- An integrated analysis and management platform for ecosystems
- Validation and evaluation of field testing and applications

By fusing field-specific knowledge from the disciplines of individual researchers, we aim to use a multidisciplinary approach to reevaluate R&D strategies in transportation, logistics, and ecosystems. We also plan to establish a computational theory and framework with artificial systems, computational experiments, parallel systems, and metasynthesis for decision support and analysis of complex systems in general, and for integrated, coordinated, and sustainable development of metropolitan transportation, logistics, and ecosystems in specific. Eventually, we hope to develop a computational framework that lets us model, analyze, and synthesize complex urban and metropolitan social systems from qualitative validation to quantitative evaluation.

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