“A Complex Systems Engineering Undertaking”

The Qian Xuesen School of Systems Engineering

"Systems engingeering is
my true lifelong pursuit"
“系统工程才是我一生追求的”

A BluePath Labs Report
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ABBREVIATIONS

C3I	Command, Control, Communications, and intelligence
CAE	Chinese Academy of Engineering
CAS	China Academy of Sciences
CAS	Complex Adaptive Systems
CASC	China Aerospace Science and Technology Corporation
CCP	Chinese Communist Party
CMC	Central Military Commission
DOD	Department of Defense
EC	Engineering Cybernetics
EDD	Equipment Development Department
FYP	Five-Year Plans
GAD	General Armament Department
INCOSE	International Council on Systems Engineering
KDD	Knowledge Discovery in Databases
MCF	Military-Civil Fusion
ODD	Overall Design Department
ORSA	Operations Research/Systems Analysis
PCMSE	Professional Committee of Military Systems Engineering
PERT	Program Evaluation Review Technique
SE	Systems Engineering
SESC	Systems Engineering Society of China
SFI	Santa Fe Institute

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Systems engineering is a method for research and analysis that holistically analyzes complex problems, such as building a spacecraft or an entire national defense program, by coordinating and optimizing components of the system such as individual work processes. This study is an early attempt to understand the Chinese school of systems engineering – most strongly associated with the ideas of Qian Xuesen [钱学森] – and the role of systems engineering-based principles in contemporary Chinese governance. It provides an overview of the origins, historical development, central theories, conceptual framework, and main applications of Chinese systems engineering. It also examines the theories driving CCP leaders' discourse surrounding systems thinking and system approaches, as well as the tools they have at their disposal to exercise holistic governance. The study is organized into two sections: Section 1 follows the arc of Qian's career as a systems scientist, highlighting his major contributions to the Chinese systems field, which have since become the foundational building blocks of the Chinese school of systems engineering. Section 2 examines the idea of social systems engineering and lays out its central theories, applications, and impact.

While Qian is the central figure in China's systems engineering field, he worked with many other scholars, and successive generations of scholars have continued the development of the field. Several of these systems scholars are mentioned here, but many others have been unfortunately left out due to the scope of this study. It is also worthwhile to note that, while most Chinese scholars regard the idea of a "Chinese school of systems engineering" and the "Qian Xuesen school" as virtually the same, occasionally important differences of opinion do exist. Some students of systems science appear to dislike Qian's inclusion of Marxist philosophy. Others question whether China needed to develop its own theoretical framework and school of thought, and still others prefer to treat the subject purely as a sub-field of mathematics. This study does not devote significant time to analyzing these differences of opinion since 1) They have yet to be developed into a coherent set of arguments; 2) the goal of this study is to understand the mainstream school of thought; and 3). Qian's theories and ideas are the ones that have had a profound impact on generations of CCP leaders.

Key Findings

This report lays out the Qian Xuesen (or Hsue-Shen Tsien) [钱学森] school of systems engineering (SE) and explores how its ideas have influenced contemporary governance in the People's Republic of China (PRC). Broadly speaking, SE is an interdisciplinary field that focuses on mapping an entire system's dynamics and constraints at the highest level, in order to better control it and achieve one's goals, whether in a missile system or in a policy program. Many Chinese systems scholars regard Qian, also widely revered as the father of China's nuclear and ballistic missile programs, as the founder of the Chinese school of systems engineering. The ideas about SE that Qian laid out over the course of his career view the field broadly, as an art, science, and technique for organizing and managing complex systems of any kind, including everything from economic policy to military strategy. Some key findings about this school of thought and its impact in the PRC are laid out below.

CHINESE LEADERS SINCE THE EARLY 1980s HAVE PUBLICALLY ADOPTED THE LANGUAGE OF SYSTEMS ENGINEERING, APPLYING IT TO ISSUES AS DIVERSE AS ECONOMIC POLICY AND MILITARY THEORY

Likening the design and execution of reforms and other key policy agendas to "complex systems engineering undertakings" has been a longstanding tradition of CCP leaders after Mao. Zhao Ziyang, Premier and Vice Chair and later Chairman of the CCP, referred to the idea in the early 1980s. Under Xi Jinping's tenure (2012-Present), concepts and terms informed by SE have been formalized in senior leaders' discourse on strategic issues to the extent that they appear as frequently as references to values like freedom and democracy appear in U.S. Presidents' rhetoric. Xi has repeatedly demanded CCP cadres to use "systems science, systems thinking, and systems approaches" to examine and solve problems, and upholding a "systems mindset" was identified as one of five fundamental principles to guide economic and social governance during the 14th Five-Year Plan (FYP) period and beyond.

CCP leaders see a systems approach to strategic planning and governance as an essential skillset and argue that these approaches have not only contributed to the success of China's strategic weapons development and the aerospace industry, but have also guided and informed Chinese practices in economic, social, and military management and development.

SYSTEMS ENGINEERING-INSPIRED LANGUAGE IN PRC POLITICAL DISCOURSE ORIGINATED FROM "THE CHINESE SCHOOL OF SYSTEMS ENGINEERING," FOUNDED BY QIAN XUESEN, A KEY FIGURE IN MODERN CHINESE PHYSICS, MATH, AND ENGINEERING

The Chinese school of SE traces its roots to Qian's work on engineering cybernetics in the 1950s. Its growth benefited from the lessons Qian learned in applying SE principles to the management of China's strategic weapons program between the mid-1950s to mid-1970s, as well as his extensive research into systems science in the 1980s and 90s. The following ideas form the building blocks of the Chinese school of SE:

- A broad understanding of SE as not only an engineering science, but an art, practice, and technique for organizing and managing complex systems of any kind that can be applied to economic, social, and military management.
- Organizations known as overall design departments [总体设计部] that work to apply the conceptual framework and methodology of systems engineering at the highest level.
- A conceptual framework that ties together diverse disciplines, including the science, theory, and philosophy of systems, and identifies their connections to Chinese cultural heritage and Marxist philosophy.
- A theory of open, complex, giant systems (OCGSs) and an emphasis on the importance of understanding them.
- A methodology called "meta-synthesis" or "meta-synthetic engineering" unites the holistic and reductionist approaches to analysis of systems, in addition to integrating empirical judgments and quantitative analysis in the analysis of OCGSs.

QIAN BELIEVED SOCIAL SYSTEMS ENGINEERING REPRESENTED BOTH AN ART AND A TECHNIQUE FOR MANAGING COMPLEX SOCIAL SYSTEMS, WHICH COULD SERVE AS A STATE GOVERNANCE TOOLKIT FOR PRC LEADERS THROUGH "TOP-LEVEL DESIGN"

In the 1970s, Qian developed a theory that saw the challenge of state governance as the organization and management of open, complex, giant systems, systems "with human beings as their main subsystems," characterized by the complexities and uncertainties of human psychology and behavior. He regarded "meta-synthesis," which values the empirical judgment of experts and quantitative analysis in equal measure, as the only suitable method for addressing "unknown [issues] with incomplete knowledge."

Qian designed a social engineering toolkit to enable top-down, holistic, and long-term decision-making for Chinese Party and state leaders, stressing that the application of this toolkit for political governance would only be successful in China. According to Qian's vision, with this social engineering toolkit, Chinese Party and state leaders can effectively macro-manage a wide variety of activities at the state level through a defined decision-making process that integrates empirical judgments and quantitative analysis based on a vast amount of information collected using an intelligence network and database. This policymaking process, carried out via an overall design department [总体设计部] acting as an advisory body staffed with senior experts, would enable systems-oriented, holistic, scientific planning at the highest level and minimize the negative impacts of bottom-up, uncoordinated, ad-hoc policymaking.

Qian's suggestions engendered the gradual adoption of social engineering-enabled "top-level design" as a philosophy of governance during Hu Jintao's tenure and eventually became a centerpiece of Xi Jinping's governing philosophy.

CHINESE SCIENTISTS, ENGINEERS, AND POLICYMAKERS CONTINUE EFFORTS TO FULLY REALIZE AND PUT INTO PRACTICE QIAN'S VISION AND IDEAS

Qian saw "meta-synthesis" as having enormous potential in intelligence collection and analysis, enabling the "activation" of data that might otherwise lie dormant. The Institute of

Automation of the Chinese Academy of Sciences and the Academy of Military Sciences, with support from CCP leadership, have since the 1990s made multiple attempts to develop a systems architecture that enables "meta-synthesis" to support military-strategic decision making. The goal has been to incorporate three different elements into such an architecture: artificial intelligence; command, control, communications, and intelligence (C3I); and virtual reality. Its development so far appears to have met with limited success, and little is known about the system's actual utilization and applications. However, a revival of similar efforts can be expected. CAS researchers indicated in 2021 that rapid advancements in network technologies and artificial intelligence over the past ten years necessitate a need to continue pursuing the concept.

NOTE ON TERMS AND CONCEPTS

The Chinese language contains several commonly used words that can be translated as "systems," including *tizhi* [体制], *zhidu* [制度], and *tixi* [体系] – each of which have subtle differences in meaning. Because this study primarily focuses on systems engineering [系统工程] and systems science [系统科学], both of which use the term *xitong* [系统] for "system," it is solely concerned with *xitong* systems. However, understanding how *xitong* differ from other systems in the Chinese language helps with understanding systems engineering theory and its place in discussions of contemporary Chinese governance.

Tixi in this context connotes something closer to a "system of systems," whereas *xitong* is flexible in scale and can also connote a smaller-scale, defined process, or even a device. *Tixi* are often composed of multiple *xitong*, for instance. Both *zhidu* and *tizhi* are often used to refer to human institutional arrangements and norms – both explicit and implicit – and would *not* be used to refer to systems in the engineering context. According to the *Cihai* [辞海],[21] a comprehensive and authoritative dictionary and encyclopedia of contemporary Mandarin Chinese, *zhidu* refers to "the sum of a series of habits, morals, laws, regulations, etc. that are unified and regulate social relations within a specific social scope in a certain historical period." *Tizhi* is less general, and is most often reserved for discussions when government entities are involved. According to the *Cihai*, *tizhi* is "a general term for "the systems, institutions, methods, forms, etc. involved in matters related to the institutional setup, leadership affiliation, and management authority of state organs, political party organizations, enterprises, and public institutions."[2]

Similar to the term *zhidu*, the true meaning of *tizhi* is often lost in translation. One of Xi Jinping's catchphrases, for example, is often translated as "new whole-of-nation system" *xinxing juguo tizhi* [新型举国体制],[24] but the term *tizhi* here is more akin to a form of governance, a system of social management that includes elements such as institutions, institutional norms, management structure and processes, and bureaucratic approaches, rather than simply a system.

Descriptions of education systems using these terms offer a useful example. An "education *tixi*" [教育体系] is the least broad in scope and refers to the structure of interconnected educational institutions.[1] An "education *zhidu*" [教育制度] refers to both the system (*tixi*) and management regulations of all educational organizations and institutions in a country.[2] While broader in scope than *tixi*, it is still bounded and relatively specific. An "education *xitong*" [教育系统] is an uncommon usage and probably the most broad and flexible of the three. It is used as a term to describe how the varied elements of the education *zhidu* relate to each other.[3] This flexibility is part of what distinguishes SE concepts; *xitong*'s sense of "systemness" is key to systems science more broadly.[i]

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[i] As defined by George E. Mobus and Michael C. Kalton in their 2015 textbook, *Principles of Systems Science*. George E Mobus and Michael C. Kalton, *Principles of Systems Science* (New York: Springer-Verlag, 2015).

XITONG SYSTEMS

A *xitong* system in the context of Chinese systems engineering theory can be defined in a myriad of ways, but the following definition offered by Qian and his coauthors in a landmark paper introducing the concept of systems engineering to the general public in 1978 represents an authoritative perspective on how to define *xitong* as discussed in this study:

> *"A system is an organic whole with specific functions. It is composed of a number of interacting and interdependent components. The "system" itself is part of a larger system to which it is subordinate. For example, the development of a strategic nuclear missile is the development of a complex system consisting of subsystems including the missile body, warhead, engine, guidance, telemetry, external ballistic measurement, and launch (systems); it may, in turn, be a component of a strategic defense weapons system consisting of a nuclear-powered submarine, a strategic bomber, and a strategic nuclear missile. Each subsystem of a missile is also composed of multiple devices. The warhead subsystem, for example, is composed of a fuse, safety, and thermonuclear devices; each device can be further divided into several electronic and mechanical components."*[4]

The language of *xitong* systems is still common in PRC leaders' discourse today. In late 2022, for example, a *People's Daily* article highlighted General Secretary Xi Jinping's exhortation to uphold "systems concepts" [系统观念], which (similar to the definition offered above) refers to a perspective that emphasizes how everything is "interdependent" [相互依存] and can only be understood properly by observing from a "comprehensive and systematic" [全面系统] perspective.[5] A 2023 *People's Daily* commentary similarly described improving the management of military affairs as a "complex systems engineering" [复杂系统工程] endeavor, noting that it must involve strengthening overall coordination, encouraging different departments and fields to cooperate more closely, and ensure that military governance is systematic.[6]

INTRODUCTION

"Those who fail to consider the full picture when strategizing are inadequate to the task of planning individual parts."
"不谋全局者，不足谋一域。"
— Xi Jinping

Systems engineering, broadly speaking, is an interdisciplinary field that focuses on mapping an entire system's dynamics and constraints in order to better control it. In contrast to reductive approaches that analyze components of a system in isolation, systems engineering aims to treat such systems – everything from biological ecosystems to transportation infrastructure – as wholes.

While interest in systems engineering peaked long ago outside China,[7] within China, likening the design and execution of reforms and other key policy agendas to "complex systems-engineering undertakings" has been a longstanding tradition of CCP leaders. In a 2013 speech heralding one of the most extensive reform efforts in modern Chinese history, General Secretary Xi Jinping used the Qing Dynasty saying above to highlight a key component of his thinking: an integrated, high-level approach to policy.[8] In a fifty-minute address to the Third Plenary Session of the 18th Chinese Communist Party (CCP) Central Committee, Xi laid out in painstaking detail the rationale behind the decision to 'comprehensively deepen reform,' a massive undertaking which has since touched on every major area of Party and state governance, from social and economic issues to national defense.

According to Xi, "comprehensively deepening reform is a complex systems engineering undertaking [复杂的系统工程]" that requires a leadership mechanism at a higher level to exercise top-level design and coordination.[9] He stressed the importance of maintaining a holistic perspective and requested that CCP cadres let the "full picture" [全局] guide their thoughts and actions.[10] As Xi put it: "Comprehensively deepening reform is not one single program to reform a certain aspect or a certain sector, but a grand strategy concerning the entire endeavor [事业发展全局] of the Party and state."[11] According to Xi, reform carried out in one area will change the dynamics of other areas.[12] If reforms of various sectors or parts of government are not pursued deliberately and in a coordinated manner, he warned, then the measures taken in one area might inadvertently slow or block progress in other areas. As a result, the best approach is to strengthen "top-level design" [顶层设计] and "holistic planning" [整体谋划] through careful research into the connectedness [关联性], "systemness" [系统性] (introduced below in the note on terms and concepts), and feasibility of reform measures.

Under Xi's tenure, the term and its associated concepts have become even more ubiquitous in China's policy discourse on strategic issues. In 2013 Xu Qiliang [许其亮], then vice chairman of the Central Military Commission, described national defense and military reform as a "complex systems engineering undertaking."[13] Xi himself has also used the same term to describe the military-civil fusion (MCF) strategy in 2017 and demanded that CCP cadres use "systems science, systems thinking, and systems approaches" [系统科学、系统思维、系统方法] to examine and solve problems.[14] "Attaching greater importance to the systemness and the holistic and synergistic nature of reform" was written into the Party Constitution when it was amended in 2017.[15] A "systems mindset" [系统观念][ii] was identified as "a foundational way of thinking and way of working" [具有基础性的思想和工作方法] at the Fifth Plenary Session of the 19th Party Central Committee in November 2020 and was officially included as a fundamental principle to guide governance during the 14th Five-Year Plan (FYP) period and beyond.[16] Similar arguments and viewpoints have also been shared by leaders of state-owned aerospace conglomerates[17] and PLA Academy of Military Science researchers.[18]

The term *xitong* (systems) [系统] is unmistakably the common thread tying together these ideas. Collectively, they emphasize a need to analyze policy issues holistically and maintain a systems-oriented approach informed by principles of systems engineering. While these remarks and comments about promoting systems thinking might at first seem like nothing more than "Party speak," the systems-related nomenclature is rooted in a rich body of work produced by what is known as "the Chinese school of systems engineering" [系统工程中国学派]. Qian Xuesen (sometimes transliterated as Hsue-Shen Tsien) [钱学森], the father of China's nuclear and ballistic missile programs, is regarded as the founder of this school of systems engineering by many Chinese systems scholars.[iii] The Chinese school of systems engineering (SE) began with Qian's work on engineering cybernetics in the 1950s, and gradually expanded as Qian's career and research interests progressed between the 60s and 90s.

Among the central ideas of this school of thought is its broad interpretation of SE as more than just an engineering science and practice. The Chinese school of systems engineering views it as an art, science, and technique for organizing and managing complex systems of any kind. Furthermore, Qian, an aerospace engineer by training and a pragmatist with a strategic vision, did not confine himself to theoretical research alone. He had great ambitions for the application of the framework to critical roles in strategic planning, state governance, and China's overall socialist construction endeavor. In the late 1970s, Qian conceptualized the notion of social systems engineering [社会系统工程] as an extension of SE. This idea integrated his research on systems science with lessons learned from his experience in leading China's aerospace development, in order to create a top-down decision-making toolkit to assist with long-term strategic planning of economic, social, and military development.

Qian's vision and ideas, some of which have yet to be fully realized, have influenced generations of Chinese scientists, engineers, strategists, and policymakers. To this day, Qian Xuesen remains the only PRC scientist to have received the honorary title of "Scientist with Distinguished Contribution to the Nation" [国家杰出贡献科学家], conferred to him on 16 October 1991 at the Great Hall of the People in front of an audience of senior CCP officials that included Party Secretary Jiang Zemin.[19] At that ceremony, then CMC Vice Chairman Liu Huaqing [刘华清]

[ii] "观念" (*guannian*) can be translated as concepts, ideas, or views. As will be discussed in Section 2.4, the term "系统观念" (*xitong guannian*) used in this context has fairly broad connotations to mean a holistic mindset and approach informed by the principles of systems engineering and system science.

[iii] Virtually all scholarly work by Chinese systems thinkers on these topics reference Qian's work and legacy heavily, to the point that literature introducing systems science often reads like a biography of Qian.

read a decree signed by Jiang Zemin and Premier Li Peng that not only highlighted Qian's outstanding contribution to China's aerospace sector, but also fully acknowledged his achievement as a systems scientist and the far-reaching impact of his work in that area.

> *"Qian Xuesen's dedicated research on engineering cybernetics has since been developed into a complete set of system engineering theory, which has found wide applications in numerous fields from military operations, agriculture, forestry, to even social and economic development, and has played a crucial role in China's modernization endeavor."*[20]

Figure 1 Qian with Mao Zedong[21]

Figure 2 Qian with Deng Xiaoping[22]

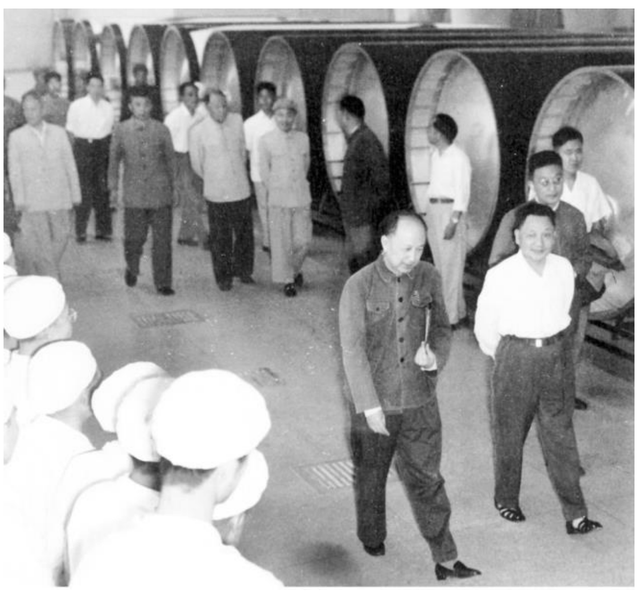

Figure 3 Qian with Jiang Zemin[23]

Figure 4 Qian with Hu Jintao[24]

Figure 5 Xi Jinping visits an exhibition on "People's Scientist Qian Xuesen" at the National Museum in Beijing[25]

SECTION 1. SHAPING THE CHINESE SCHOOL OF SYSTEMS ENGINEERING

This section is organized following the arc of Qian Xuesen's career as a systems scientist. It traces his milestone achievements, which have formed the central pillars of the Chinese school of SE. It outlines SE's main theories and methodologies, directing attention to the perspectives and approaches of Chinese scholars to consider their unique contributions.[iv]

Qian Xuesen's systems research was conducted intensively in two separate periods, first in the early 1950s and then from the mid-1970s onward. He developed an interest in the subject in the early 1950s while he was in the United States working on a book called *Engineering Cybernetics*, which introduced design principles for controlled and guided systems and effectively founded a new branch of engineering science.

After Qian returned to China, he took a two-decade-long hiatus from theoretical research and writing due to his involvement in China's strategic weapons development. However, the period between the mid-1950s to mid-1970s is still critical to the development of the Chinese school of SE, because Qian was able to apply his knowledge of SE and engineering cybernetics to the management of China's strategic weapons program. Qian's suggestions led to the creation of "overall design departments" [总体设计部], which played instrumental roles in the success of China's strategic weapons development.

Having stepped back from active involvement in weapons research and development in the late 1970s, Qian devoted the majority of his time to the development of the theories behind and applications of the Chinese school of systems engineering. Qian was also central to the popularization of SE and operations research, turning SE from an engineering concept known only inside the aerospace sector into a mainstream idea widely known to a general audience. He also significantly broadened the definition of SE to mean an art, a science, and a practice of organizing and managing complex systems of all kinds. This interpretation has since been adopted by generations of CCP leaders. In a parallel line of effort, Qian devised a theoretical framework to guide the development of systems science in China. This umbrella framework provided a baseline for understanding the structure and purpose of all the theoretical streams within systems science, as well as their connections to other branches of science, philosophy, and Chinese cultural heritage.

ENGINEERING CYBERNETICS AND INQUIRY INTO UNCERTAINTIES IN CONTROLLED SYSTEMS

After graduating from Shanghai Jiao Tong University in 1934, Qian Xuesen studied at the Massachusetts Institute of Technology on a Boxer Indemnity Scholarship[v] and then went on to complete his Ph.D. at the California Institute of Technology. Qian, by then a well-regarded scholar of aerodynamics and jet propulsion, was involved in U.S. aerospace technology development during WWII.[26] During the second Red Scare in the 1950s, Qian was accused of being sympathetic to communism and had his security clearance revoked. He was then put under partial house arrest

[iv] It should be noted that systems science is a massive, transdisciplinary domain of inquiry referred to by some scholars as a "universal science" or "metascience." It encompasses subject areas ranging from cybernetics and information theory to self (auto)-organization, emergence, and chaos-complexity theories. The purpose of this study is not to provide summaries or details about Chinese perspectives on these specific domains, but to outline how some of the mainstream Chinese thinkers approach the subject of systems science, so as to facilitate our understanding of the Chinese school of thought and practice.

[v] Established by President Theodore Roosevelt's administration in 1909.

under a delayed deportation order for five years.[27] He eventually made his way back to China in 1955 and was quickly recruited into China's nascent aerospace industry and military development programs, going on to become the founding father of the PRC's ballistic missile, nuclear weapons, and space programs.

Figure 6 Qian Xuesen pictured in Germany, 1945 with (from left) Hugh L. Dryden, Ludwig Prandtl, and Von Karman[28]

Qian first began research into the field of systems science during his years under house arrest in the United States, just as many new scientific fields were beginning to take shape in the post-War period. New fields of research, such as cybernetics, operations research, and information theory offered new paradigms to study the structure and function of systems. Qian, an aerospace engineer, saw the implications of the emergence of these new disciplines for the field of engineering. Taking inspiration from Norbert Weiner's[vi] 1948 book *Cybernetics or Control and Communication in the Animal and the Machine*, Qian authored *Engineering Cybernetics* [工程控制论] (*EC*), published in English in 1954.

The word "cybernetics" originally comes from the Greek κυβερνητική (*kybernētikḗ*), meaning "governance," or all that is pertinent to κυβερνάω, meaning "to steer, navigate or govern."

[vi] While Norbert Weiner is considered the founding figure of cybernetics, the field traces its history back to efforts to create automatic tracking systems to guide antiaircraft guns during WWII by researchers including not only Wiener but also John von Neumann and Claude Shannon. See George E. Mobus and Michael C. Kalton, *Principles of Systems Science* (New York: Springer-Verlag, 2015), 34.

The French physicist and mathematician André-Marie Ampère coined the word "*cybernetique"* in 1834 to mean the science of civil government, but the term was borrowed by Norbert Wiener to name a new science, which connects various domains of science, such as physiology, psychology, sociology, and engineering, based on the design concept of "feedback." As a broad field of science, cybernetics, which was translated into Chinese as control theory ["控制论"], has been defined in a myriad of ways by different scholars. According to Qian Xuesen, "Weiner's use of cybernetics" is primarily concerned with the "qualitative aspects of the interrelations among the various components of a system and the synthetic behavior of the complete mechanism." In contrast to Weiner's conceptualization, for Qian the purpose of engineering cybernetics, the subject of his book, was "to study those parts of the broad science of cybernetics which have direct engineering applications in designing controlled or guided systems." [29]

In the *Preface,* Qian made a clear distinction between the disciplines of engineering *science* and engineering *practice*. Engineering cybernetics, according to Qian, transcends engineering *practice*. It is an engineering *science* that abstracts a set of principles that can be applied across all engineering sectors. He wrote:

> *"A deeper and thus more important difference lies in the fact that engineering cybernetics is an engineering science, while servomechanisms engineering is an engineering practice. An engineering science aims to organize the design principles used in engineering practice into a discipline and thus to exhibit the similarities between different areas of engineering practice and to emphasize the power of fundamental concepts. In short, an engineering science is predominated by theoretical analysis and very often uses the tool of advanced mathematics."*[30]

In 18 chapters, Qian used a combination of basic and advanced mathematics to examine systems characterized by different behaviors (single vs. multiple inputs and outputs, linear vs. nonlinear, deterministic vs. stochastic), deriving a set of governing principles that can be directly applied to the engineering design of controlled or guided systems.[31] While *EC* was inspired by N. Wiener's theories, Chinese systems scholars regarded the book as showcasing remarkable originality and foresight. Renmin University scholar Miao Dongsheng [苗东升] noted that with *EC,* Qian was able to build a bridge connecting Weiner's largely philosophical discussions with real-world engineering practices.[32] In a journal article reflecting on the 60 years of history of Qian's engineering cybernetics, Zhiqiang Gao, a scholar of advanced control technologies with Cleveland State University, shared similar observations. According to Gao, *EC* occupied a unique space as a new branch of engineering science, managing to "clothe" Weiner's largely "bare bones" conceptions of cybernetics and create something that transcends engineering practices while remaining rooted in a deep understanding of them.[33]

Gao regards Qian as one among very few scholars who truly grasped the magnitude of cybernetics at the time, crediting Qian's background as an engineer, his training in advanced mathematics, and the fact that Qian was a "profound thinker."[34] In particular, Gao argued that Qian's insights on "dealing with uncertainties" in the design of control systems and his "disdain for empty mathematical exercises" set him apart from many systems thinkers of his time.[35]

According to Gao, *EC* represents an attempt to manage and cope with uncertainties in systems design. He pointed to Chapter 15 of *EC*, where Qian questioned the conventional assumption that "the properties and characteristics of the system to be controlled were always assumed to be known,"[vii] and noted the profoundness of Qian's observation. As Gao saw it, Qian's recognition of the "unknown dynamics of the controlled systems and unknown forces in their operating environments" put Qian significantly ahead of his time, as the problem of uncertainties in engineering design only drew significant attention decades later.[36][viii] As Gao put it, "the real challenge is to deal with what these equations do not describe."[37]

As will be discussed in Section 2.2, the insights Qian gained through writing *EC*, particularly with regard to uncertainties in complex systems, appear to have had a profound impact on his systems research, later influencing his approach to issues such as military simulations and his understanding of large, open, complex systems. Qian's career as a systems scholar focused heavily on dealing with uncertainties, a focus that was supported by a general distrust of approaches that oversimplified real-world conditions.

"Overall Design Departments" and China's Weapons Development Programs

After the publication of *EC*, Qian did not publish again on the topic for almost two decades. After his return to China in 1955, he assumed a critical role in the development of strategic weapon systems and China's defense industry more broadly. Even though Qian did not devote more time to in-depth research into systems science during that period, he nevertheless put many of his concepts into practice. A number of initiatives that Qian championed during this period laid the foundation for what later became the Chinese school of systems engineering.

Immediately upon his return to China, Qian, who had witnessed the flourishing of new fields like systems engineering and operations research/systems analysis (ORSA[ix]) in the U.S., made it a priority to propagate these new ideas and establish dedicated research organizations focused on them. Because Mao and other CCP leaders trusted Qian's authority and judgment, cybernetics and related fields were able to take root quickly in China, avoiding the negative reception they received in the Soviet Union, where they were labeled American "reactionary pseudoscience."[38] During the mid- to late-1950s, Qian's efforts directly resulted in the creation of the Operations Research Office [运筹学研究室] under both the Institute of Mechanics (iMech) [力学研究所] and the Academy of Mathematics [数学研究所] (Now Academy of Mathematics and

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[vii] According to Qian, the control design principles discussed prior to Chapter 15 rested on the assumption that the properties of a given system would remain unchanged. This was problematic because the properties of an engineered system could be altered by many factors, such as variations introduced in the manufacturing process, normal wear and tear, or a flight through icy conditions. "In short, the properties of an engineering system can never be known exactly prior to the instant of actual operation of the system," Qian warned. As a result, when "large, unpredictable variations of the system properties," the type of control design that is based upon the existing, or 'built-in,' knowledge of the properties of a system would sooner or later become unreliable, since the altered properties would render prior knowledge of the system useless. As a result, Qian introduced the principle of "continuously sensing and continuously measuring control systems" in which the properties of the controlled system are measured during the control process. See H. S. Tsien. *Engineering Cybernetics* (New York: McGraw-Hill, 1954): 214-215.

[viii] Recent arguments made by a group of U.S. systems scientists seem to corroborate Gao's point of view. Writing in 2018, Hillary Sillitto et al. noted a need to revisit and refresh the International Council on Systems Engineering's [INCOSE] definition of systems engineering, in part due to the fact that "uncertainty has become dominant in the landscape of systems engineering, and must be recognised and accepted in systems engineering decisions." See Hillary Sillitto et al., "A Fresh Look at Systems Engineering - What Is It, How Should It Work?," *INSIGHT* 21 (October 1, 2018): 44–51, https://doi.org/10.1002/inst.12211.

[ix] This abbreviation is taken from OPERATIONS RESEARCH/SYSTEMS ANALYSIS (ORSA): Fundamental Principles, Techniques, and Applications, The Army Logistics University, October 2011, https://www.fa49.army.mil/pdfs/ORSA_Book.pdf.

Systems Science) of the Chinese Academy of Sciences.[39] Soon after he also established the PRC's first military operations research [军事运筹学] institute (called the Operations Research Division [作战研究处]) under the Ministry of National Defense's Fifth Academy, the birthplace of the PRC's missile and aerospace industry.[40] These organizations played instrumental roles in cultivating the first generation of systems researchers in China. One of these individuals was Xu Guozhi [许国志], an engineer and mathematician who received his Ph.D. from the University of Kansas, who coincidentally had been on the same ship to China as Qian.[41] During the voyage they discussed their shared interest in operations research. Later, Xu headed the Operations Research Office under iMech.

More significant developments took place in the early 1960s. Qian took the failed launch of the DF-2 medium-range ballistic missile on 21 March 1962 as further proof of the necessity of promoting SE principles across China's nascent aerospace sector. According to Tu Yuanji [涂元季], a former General Armaments Department researcher who served as Qian's secretary in the 1980s, many scientists and engineers assigned to work on the aerospace weapons programs had never even seen a missile before or received any training in SE, and therefore had trouble fully grasping the need to coordinate the individual design and manufacturing processes or ensure that they worked together as a system.[42] A common misconception, therefore, was viewing the engineering of a complex weapons system as a simple task of dividing it into discrete components which could then be assembled. Almost two decades after Qian stepped down from active weapons research and development, in 1978 he and his coauthors, Xu Guozhi and Wang Shouyun [王寿云][x], reflected on this period of history. They wrote:[43]

> *"A missile weapon system is one of the most complex engineering systems of modern times and can be successfully developed only by the concerted efforts of thousands of people. The basic problem facing the development of such a complex engineering system is how to translate the relatively general initial development requirements into the specific tasks to be undertaken by thousands of participants, and how to eventually synthesize these efforts, within a short R&D development cycle, into a technologically sound, cost-effective, coordinated, and operational system that will eventually become an effective part of an even larger system to which it subordinates."*

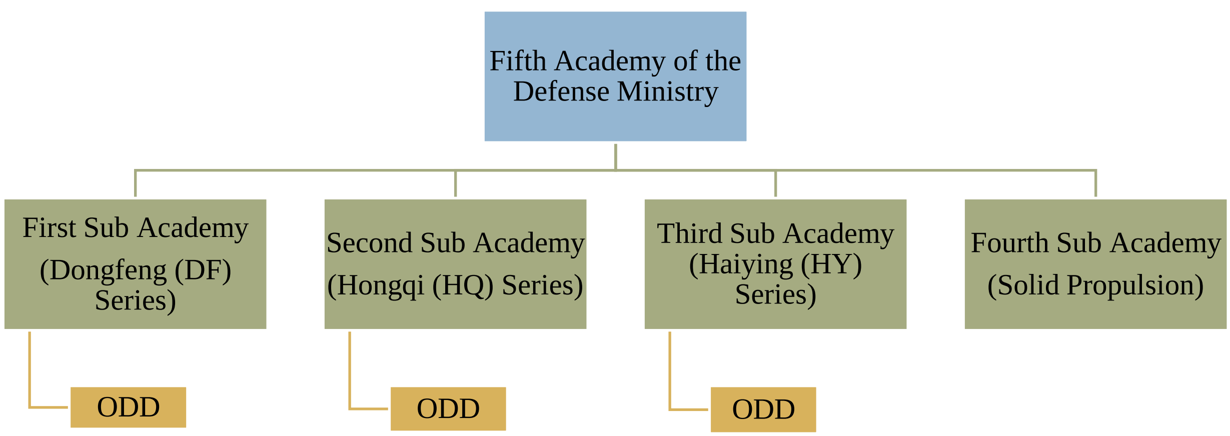
Taking inspiration from his observations of the management of the Manhattan Project and the Apollo Program (both of which were complex systems engineering undertakings involving tens of thousands of personnel), Qian became convinced that the complexity of weapon systems design and manufacturing required a holistic approach.[44] His views on management processes were also inspired by the Program Evaluation Review Technique (PERT), part of the Polaris submarine-launched ballistic missile program.[45]

[x] Wang was an expert in military SE [军事系统工程] and battle simulations [作战模拟]. Note that the translation 'battle simulations' is used for this term throughout the paper. This translation was provided by Qian Xuesen in 1979. 作战 is often translated as combat or operational (as in operations simulations) in similar contexts. It is unclear why this translation was chosen by Qian but is used throughout this paper to preserve his original intent. See "Military Systems Engineering" [军事系统工程], Speech given to the PLA headquarters staff, 24 July 1979, www.lib.xjtu.edu.cn/lib75/qxs/lxtgch/40.htm

With support from Zhou Enlai and Nie Rongzhen [聂荣臻], Qian devised a model that applied SE principles to the management of the Chinese aerospace program. This model has several essential components. These included a "designer system" [设计师系统] to coordinate and integrate the design needs of the overall system and various subsystems; two lines of command separating design, research, and development from administrative tasks; a science and technology committee where senior experts could serve as advisors and offer input; and the adoption of both modeling and simulation techniques and an information management system.[46]

In this SE-informed aerospace management model, Qian attached particular importance to the creation of an organization he termed the "Overall Design Department" (ODD) [总体设计部] (also sometimes translated as "Department of Integrative Systems Design" (DISD)) to exercise centralized command over the design and development of weapon systems.[xi] Based on his suggestion, overall design departments were established in the three sub-Academies (see Figure 7) of the Fifth Academy of the Ministry of National Defense to lead the design of the overall systems architecture of the three main missile series.[xii]

Figure 7 Sub Academies under the Ministry of National Defense's Fifth Academy[47]



In their 1978 article, Qian et al. gave a detailed account of the functions of ODDs and explained how critical they were to the success of China's aerospace weapons development. In terms of their function, ODDs are described as being responsible for designing the "'overall' system [系统的总体], the 'overall scheme' [总体方案] of the system, and the 'technological pathway' [技术途径] for whole system development."[48] An ODD is composed of "technical

[xi] "总体设计" can be translated a number of ways. "Overall design" is chosen because Qian used this expression multiple times in a paper he coauthored in the early 1990s. In that paper, Qian et al. discussed the "the scheme of overall planning of the design and manufacture" and talked about "overall analysis, overall design, overall coordination and overall plan." See Qian Xuesen, Yu Jingyuan, and Da Ruwei, "A New Discipline of Science—The Study of Open Complex Giant System and Its Methodology." *Chinese Journal of Systems Engineering and Electronics* 4, no 2 (1993): 2-12.
[xii] Notably, even though China's aerospace research, development, and industrial complex has gone through multiple rounds of reforms, the current organizational set-up in China's state-owned aerospace defense corporations such as CASC and CASIC retained this important feature, where overall design departments [总体设计部/总体部] (or Research Institutes) can be found under research academies responsible for systems integration.

personnel whose collective expertise covers all aspects of the system to be engineered, and led by experts with a broad reserve of knowledge [知识面比较宽广]."[49] Furthermore, ODDs generally do not undertake the design of specific components; however, they are indispensable units that oversee technological development in an integrative sense [技术抓总].[50] An ODD operates by the following systems-based principles: [51]

- It approaches the design of the system in question as part of a larger system to which it is subordinate, and all technological requirements are first considered from the viewpoint of achieving technological coordination with the larger system.
- It sees the system in question as an organic integration of several subsystems, and the technological requirements of each subsystem are first considered from the viewpoint of achieving technological coordination with the whole system;
- It devises solutions to resolve conflicting design technological requirements between the various subsystems and between subsystems and the larger system.

An ODD is both an entity and a methodology, which, according to Qian and his coauthors, perfectly symbolizes the principles of systems engineering, with universal significance for the management of systems of all types. According to Tu Yuanji, Qian believed that an ODD's work, if done well, could bring about a concept articulated in his book *Engineering Cybernetics*: the formation of a reliable system using less reliable components.[52] ODDs are a centralized decision-making mechanism based on the practice of democratic centralism, in which debate is encouraged prior to making the decision, but participants are expected to support the final decision once made. Qian saw them as critical in preventing failures that could result from the then-prevalent reductionist approach to weapon design and manufacturing, which involved breaking processes down into smaller components rather than viewing them as an integrated whole.[53] Former Director of the China Academy of Aerospace Systems Science and Engineering [中国航天系统科学与工程研究院] (CASC 12th Academy) Xue Huifeng [薛惠锋] once revealed in an interview that Qian believed that the highly systematic "top-level design" enabled by ODD was the real secret behind the ability of China's aerospace industry to develop so rapidly.[54]

"Systems Engineering—A Technique for Organization and Management"

In the late 1970s, Qian, then Deputy Director of the Committee for National Defense and Technology [国防科学技术委员会副主任], stepped down from the frontline of strategic weapons research and development and shifted his focus to the development of the systems engineering field in China. According to Qian's own account, his efforts in this area were largely driven by a request he received from Premier Zhou Enlai, who had asked Qian to consider applying the lessons learned from leading China's aerospace weapons program, including SE-informed management practices and the ODD, to other aspects of national development.[xiii][55]

[xiii] In Qian's own account, he felt indebted to Zhou who went to great lengths to protect him during the Cultural Revolution and acknowledged that without Zhou he probably would not have survived that period. See "Qian Xuesen: Premier Zhou Assigned Me to Work on Missiles" [钱学森: 周总理让我搞导弹], Zhou Enlai Memorial Website, accessed November 2021, http://zhouenlai.people.cn/n1/2018/0223/c409117-

In September 1978, Qian, along with Xu Guozhi and Wang Shouyun, published a landmark article titled "Systems Engineering—A Technique for Organization and Management" [组织管理的技术—系统科学], which comprehensively introduced systems engineering to the general public, using plain language and easy-to-understand examples.[56] In this article, Qian et al. made the case that in order to achieve the Four Modernizations[xiv], China not only needed to develop science and technology, but also required parallel improvement in organization and management skills.[57] Systems engineering and systems thinking, they argued, were crucial to both. With the broadest base of audiences in mind, Qian et al. first explained what a "system" entails and illustrated their innate complexity using a strategic nuclear missile as an example, while simultaneously noting that "systems" and SE should not be merely confined to the field of engineering. They noted that at the time, the term "system" was used frequently in daily communications, but it was not common to consciously register a factory, an enterprise, or a government agency as a system. A shift in mindset was in order, therefore, to recognize that "systems" (they used *xitong* and *tixi* interchangeably) exist in all shapes and forms in society.[58]

When conceptualizing systems this way, SE thus can be understood as an art, science, and practice of organizing and managing the six core elements in "systems" of any kind: people, materials, equipment, finances [财务], tasks [任务], and information. Qian et al. also noted that the key principles of SE already permeated the public psyche, as evidenced by a long list of frequently used terms and concepts in the Chinese language meaning "overall planning and all-around consideration" such as *tongchou jiangu* [统筹兼顾], *quanmian guihua* [全面规划], and *jubu fucong quanju*[xv] [局部服从全局].[59] They argued it was necessary to transform the spontaneous applications of SE principles into scientific, conscious decisions.

According to Qian et al., framing systems in this way also made it easy to identify the various branches of SE.[60] For example, the art of managing the engineering of a complex weapons system is engineering SE [工程系统工程]; the techniques used to manage the administrative tasks of state agencies should be called administrative SE [行政系统工程]; the art of organizing and commanding combat operations falls under military SE [军事系统工程]; and the organization of logistics work belongs to logistics SE [后勤系统工程]. In a speech he delivered the following year, Qian further expanded the scope of SE to include a total of fourteen branches, such as information systems engineering [信息系统工程], economic systems engineering [经济系统工程], and social (systems) engineering [社会(系统)工程] (see Section 2.1).[61]

Qian's broad interpretation of SE and his ambitions for the discipline from the 1970s showed great foresight, and anticipated by several decades the definition adopted by the

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29830987.html; "Zhou Enlai and Qian Xuesen in the Development of Chinese Missile and Space Technology" " [中国导弹航天科技发展中的周恩来和钱学森], News of the Communist Party of China, accessed November 2021, http://cpc.people.com.cn/GB/64162/64172/85037/85038/6997579.html

[xiv] The Four Modernizations [四个现代化] were post-Mao efforts to rejuvenate China's economy through modernization of industry, agriculture, defense and science & technology championed by Deng beginning in 1977.

[xv] There are a large number of expressions associated with the character "局" (*ju*) that are frequently used to refer to the overall situation in a strategic context. "棋局" (*qiju*) describes the state of the game board in chess or Go; "全局" (*quanju*) emphasizes the entire board, therefore is frequently used to mean the overall strategic picture; "大局" (*daju*) means the big picture; "局部" (*jubu*) means parts or a localized situation within the overall picture; These words form an array of combinations that stress the same idea, and that is to approach a problem holistically and think deeply about the interrelatedness of the various moving parts.

International Council on Systems Engineering (INCOSE) in 2014. Prior to 2014, INCOSE's definition of SE reflected a fairly narrow outlook on what a system is and what SE is intended to do.[xvi] As some scholars have pointed out, the old definition was based on a "command and control paradigm" and is primarily designed to solve specific problems in single systems.[62] It was not until the release of the *Vision 2025* in 2014 that INCOSE began to consider broadening its interpretation of SE. Drivers for this change include the need to acknowledge the increasing complexity and interconnectedness of modern systems, as well as to account for the fact that societal and naturally-occurring systems are increasingly part of SE work.[63]

Qian's framing of SE has had a strong impact on multiple generations of senior CCP leaders, who have readily adopted Qian's broad interpretation of SE as an art and science for managing large, complex undertakings. According to Qian's own account, Premier Zhao Ziyang [赵紫阳] was perhaps the first to describe reforms in SE terms when he remarked at the 1987 13th CCP National Congress that "reform is a grand systems engineering undertaking" [改革是一项伟大的系统工程].[64] Jiang Zemin [江泽民] used the same language to describe Party building.[65] During Hu Jintao's [胡锦涛] tenure, the references to SE became more ubiquitous. Hu Jintao and Wen Jiabao used the term "a systems engineering undertaking" to describe a raft of policy issues and initiatives, from implementing the scientific concept of development, building a harmonious society, and strengthening governing skills to building an innovative country, preventing and treating SARS, and strategically adjusting agricultural and rural economic structures.[66] The incumbent Party Secretary Xi Jinping continued this tradition. So far, he has applied the term to several important policy agendas, including the comprehensive deepening of reform, the promotion of military-civil fusion, comprehensive law-based governance, innovation-driven development, and the implementation of the free-trade zone strategy.[67]

Qian's advocacy for SE also led to the establishment of a robust network of diverse organizations studying the subject in China. His 1978 article with Xu Guozhi and Wang Shouyun, along with the arrival of a "springtime for science" [科学的春天], excited many scientists there. Dai Ruwei [戴汝为], an expert in cybernetics, automation and artificial intelligence, recalled a time during which "even in the cafeteria during lunch, the conversations centered on systems engineering, a brand-new topic at that time."[68] Yu Jingyuan, another aerospace, cybernetics, and SE expert who worked with Qian for many years, commented that "at that time, systems engineering theory was being developed abroad, but the overseas academic community was divided and no consensus has been formed; in China, it was a new concept to most. Qian's article gave systems engineering a proper stage to grow academically."[69]

According to Tu Yuanji, Qian's proposals led directly to the establishment of the Systems Engineering Society of China (SESC) [中国系统工程学会] in 1980.[70] By 1987, SESC had accrued

[xvi] The INCOSE SE Handbook (INCOSE, 2015) defined SE as "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem." The revised definition considers SE "a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods. We use the terms 'engineering' and 'engineered' in their widest sense: 'the action of working artfully to bring something about'. 'Engineered systems' may be composed of any or all of people, products, services, information, processes, and natural elements." For more on this, see Hillary Sillitto et al., "A Fresh Look at Systems Engineering - What Is It, How Should It Work?," *INSIGHT* 21 (October 1, 2018): 44–51, https://doi.org/10.1002/inst.12211; See "Systems Engineering," INCOSE, accessed November 2021, https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition

over 80 member organizations and affiliates,[71] including organizations as diverse as the Fourth Bureau of the Ministry of State Security, various research academies affiliated with the PLA and the Commission for Science, Technology and Industry for National Defense (COSTIND) [国防科学技术工业委员会], China's top research universities, and sector-specific organizations such as the Industrial and Commercial Bank of China [中国工商银行]. Institutions such as PLA research academies, civilian universities, public research institutes, and other organizations also began offering SE courses.[72]

Three additional SESC professional committees were created in the 1980s, including one on societal and economic systems engineering in 1982, one on fuzzy mathematics and fuzzy systems engineering in 1983,[xvii] and another on information systems engineering in 1987 (currently housed at the PLA Naval Research Academy). In the following years and decades, more than 29 professional committees would be created under SESC.[xviii] These developments represented an impressive growth in the space of less than ten years, considering Dai and Yu's aforementioned comments about how systems engineering was a brand-new subject to most in 1978.

MILITARY SYSTEMS ENGINEERING

Qian was particularly instrumental in championing military SE. In a talk to the PLA headquarters staff [解放军总部机关] on 24 July 1979, he drew on examples of foreign experiences with systems engineering in warfare to expound on the concept and applications of military SE and argue for their application in China.[73] According to Qian, the command of warfare, more than any other human social activities and practices, requires the adoption of a 'full picture mindset' [全局观念] and a holistic mindset [整体观念] to effectively leverage the 'parts' [局部] to achieve the best outcome of the 'whole' [全局].[74] "This is the essence of systems engineering," he remarked.[75] Used in this sense, he told his audience, the term "engineering" was restored to its original meaning, that of activities executed to serve military purposes. Accordingly, he argued "military SE" should be interpreted as the art of organizing and managing military matters, rather than as an engineering practice.

As a first step in developing military SE in the PLA, Qian advised PLA leaders to fully leverage the power of ORSA and computer technology in order to apply them to battle simulations, military decision making, weapons development planning, logistics, and the development of modern command systems.[76] He also offered the following suggestions to advance the field of military SE and ORSA in the PLA:[77]

- Military SE professionals should be placed within the General Staff Department and headquarters Departments at all levels; logistics SE professionals should be given positions in the General Logistics Department and logistics departments at all levels.

[xvii] Fuzzy mathematics refers to a branch of mathematical theory that addresses categories with unclear boundaries; essentially, it is an approach to handling ambiguous data in computation. It has found applications in fields like linguistics and disease diagnosis. Fuzzy systems engineering applies developments in fuzzy mathematics to help systems engineers deal with ambiguity in the data on which their systems rely. Nadia Nedjah and Luiza de Macedo Mourelle, *Fuzzy Systems Engineering* (New York: Springer, 2005).

[xviii] For the full list, see "Contact Information of Each Branch of the Society," accessed November 2021, http://www.sesc.org.cn/htm/column/column68_0.htm

- An organization should be created with responsibility for the systematic collection of combat data to serve as the basis for combat simulations and war games.
- Research organizations for military SE and other theories with implications for military SE should be set up within the AMS and various research academies subordinate to the services and branches.
- Courses on military SE should be offered in other PLA academic institutions, in addition to the one already established at the National University of Defense Technology. Mandatory courses should include areas of military science such as the science of strategy [战略学], the science of campaigns [战役学], the science of tactics [战术学], the science of military organization and institutional arrangements [军制学], and military geography [军事地理].

Qian's talk preceded a period in which several important SE research entities, some of which are still active today, were created. The General Staff Department established a subordinate operations research/systems analysis (ORSA) Office [作战运筹分析研究室] in 1980.[78] It was later renamed the Institute of Military Operations Research and Analysis [军事运筹分析研究所],[79] which remained active until at least 2011.[80] The Professional Committee of Military Systems Engineering (PCMSE) [军事系统工程专业委员会], a sub-committee of SESC specializing in defense ORSA, was established soon after in 1981.[81] The SESC's website indicates this committee still exists, and it is responsible for publishing one of the first core journals of military science in China, a quarterly publication named *Military Operations Research and Systems Engineering* [军事运筹与系统工程].[82] Today, this journal regularly publishes topics on ORSA theory and methodology, combat simulation and emulation, intelligent decision making, command automation, information systems and informatization, etc., and remains one of the most influential journals on ORSA in China. Another important organization in the military SE research space, the Beijing Systems Engineering Research Institute [北京系统工程研究所], was also created in 1986 under COSTIND. This organization was later made subordinate to the PLA General Armament Department, which was abolished as part of major reforms to the PLA in 2016.[83]

These organizations were founded during the infancy of systems engineering science in China, and over the ensuing decades they and their civilian counterparts expanded the field substantially.[84] In China, interest in systems engineering remains strong in general as well as for military applications. On 17 April 2018, for example, AMS's Systems Engineering Research Institute [军事科学院系统工程研究院] and CASC's China Academy of Aerospace Systems Science and Engineering [中国航天系统科学与工程研究院] (CASC 12th Academy) together unveiled a "Qian Xuesen Military Systems Engineering Research Institute [钱学森军事系统工程研究院] in front of an audience of over 200 representatives from the PLA and the defense industrial base.[85] Leaders from the Chinese Academy of Engineering (CAE), the CMC Equipment Development Department, the CMC Science and Technology Committee, and the CMC Strategic Planning Office attended the opening ceremony. Reportedly, this institute will operate under the dual leadership of AMS and CASC to "comprehensively use Qian Xuesen's systems engineering ideas, give full play to the unique advantages of both parties in the field of systems engineering, actively explore MCF-enabled collaborative innovation, and carry out joint research on major military and civilian projects."[86] Speaking at the ceremony, Li Feng [李峰], CASC's chief engineer, expressed the hope that the new institute will make good use Qian Xuesen's system engineering ideas to "design, take control of, and decisively win the future and provide high-quality intellectual support for building a world-class military and winning modern wars."[xix]

Figure 8 Qian Xuesen Military Systems Engineering Research Institute Inauguration[87]

FROM SYSTEMS ENGINEERING TO SYSTEMS SCIENCE

Beginning in 1978, as Qian worked to broaden the definition of SE and popularize the concept to a wider audience, he also contemplated the establishment of a new branch of science called systems science [系统科学] to extract new and more profound understandings of systems from SE and other systems research. To mobilize efforts and build consensus, Qian delivered a talk titled "Vigorously Develop Systems Engineering and Establish a Framework for Systems Science as Early as Possible" at the Beijing Symposium on Systems Engineering in October 1979.[88] In this speech, he explained why it was necessary for the Chinese systems field to establish a new discipline for more in-depth systems research and made it clear that systems science should be considered as its own category of science alongside the natural sciences, mathematics, and social sciences.[89]

According to Qian, SE as a discipline is ultimately aimed at solving real-world problems, relying on the language of mathematics and modern technologies such as computers to quantitatively analyze the relationships of any systems in question.[90] However, SE did not represent an end point for gaining understanding into the inner workings of complex systems; research into the shared features, structures, and dynamics across different types of systems could

[xix] The original Chinese is "设计未来、掌控未来、决胜未来，为建设世界一流军队、打赢现代化战争提供高质量的智力支持."

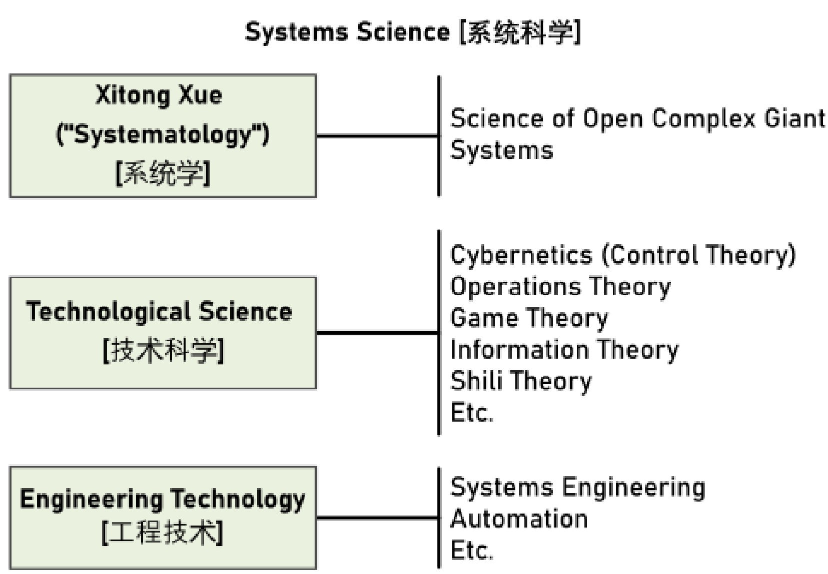
potentially reveal new patterns that were not previously understood.[91] The new knowledge gained through systems research in turn could shed light on real-world problems and guide actions.

Systems science was then also a nascent area of research outside of China. Scholars abroad were pondering similar thoughts and calling for a more coherent way to organize the various theoretical streams within the systems field and unify the widely dispersed literature of systems research.[92] Qian believed that Chinese scholars in this field should approach systems engineering and systems science from the standpoints of Marxism-Leninism, Mao Zedong Thought, and China's reality.[93] He urged the fledgling Chinese systems field to work together to identify a unique path forward. "We cannot just blindly follow foreign scholars; we should strive to understand what they cannot, clarify whatever they are unclear about, and seek to make sure our arguments are consistent with general principles," he remarked.[94]

A Framework for Systems Science

Qian's framework for the newer field of systems science is arranged by level of abstraction, with *Xitong Xue* [系统学] (systematology) at the top, followed by *Technological Science* [技术科学] and *Engineering Technologies* [工程技术]. When this framework was being developed in the early 1980s, Qian assessed that the disciplines he outlined at the two lower levels already had the large bases of supporting institutions and trained experts necessary for their healthy development, but perceived a lack of dedicated research and inquiry into the fundamental principles of how complex systems work that inform all engineering sciences across boundaries.[95] *Xitong Xue* was thus intended to fill this gap.[96] Figure 9 below illustrates these three levels of Qian's vision for systems science.

Figure 9 Qian's three-level conception of systems science



Xitong Xue is a field that studies the behavior and features of entire complex systems. *Xitong Xue*, translated at one point by Yu Jingyuan as "systematology," can be understood as the "science of systems" to differentiate it from the larger discipline of systems science, which also includes the study of both dynamics within those systems and methods for modifying those systems.[97] However, it does not appear that the Chinese systems science community has an agreed-upon translation for the term. To avoid any confusion, the pinyin form is retained throughout this study because *Xitong Xue* (along with *Xitong Lun* and *Xitong Guan*) is considered a concept unique to the Chinese school (see Appendix 1 for a list of *xitong* terms discussed in this paper and their translations).

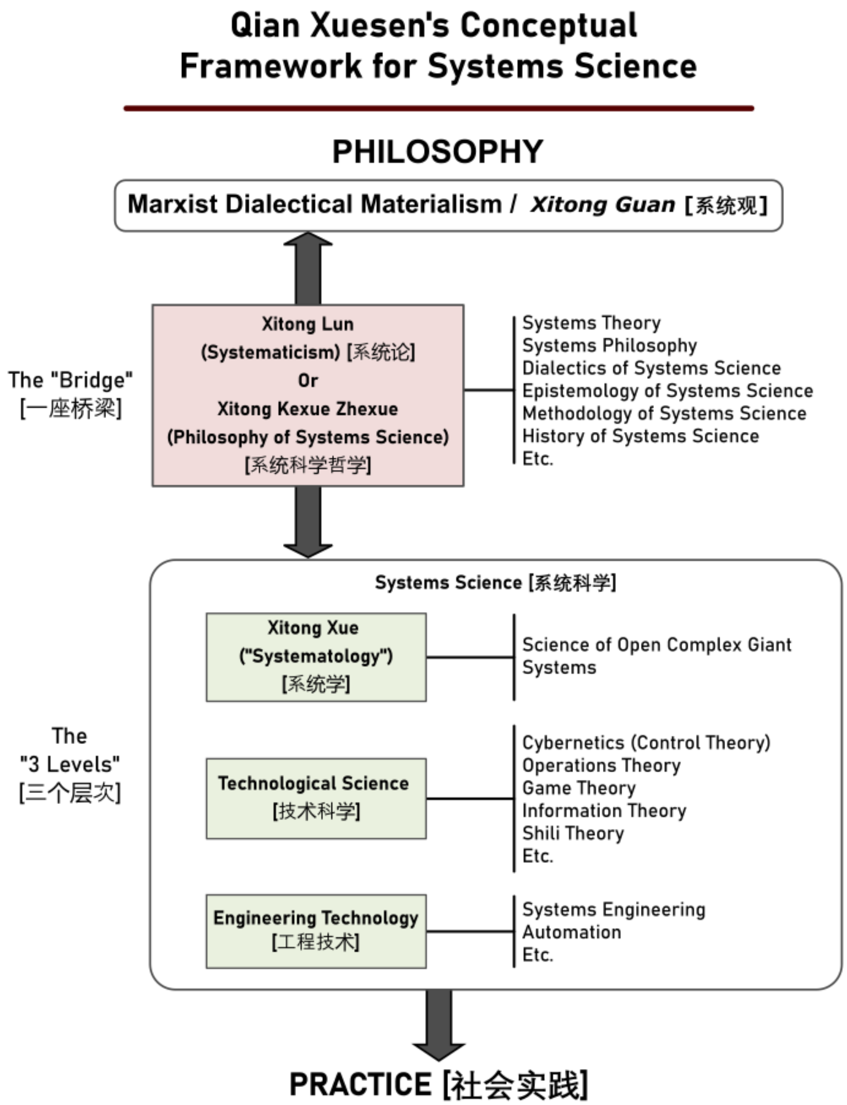
The second component of systems science is an interdisciplinary field Qian called *Technological Science*, which he noted included a wide range of subject areas, including information theory [信息学], cybernetics/control theory [控制学], operations theory [运筹学], game theory [博弈学], and other emerging fields in the same category. Given the nature of disciplines that he put under this category, Qian's *Technological Science* is an interdisciplinary domain similar to what has been variously named by scholars outside of China as "formal sciences," "mathematical" sciences, or the "sciences of complexity."[98]

Engineering Technologies are those that can be directly applied to transform the world [指导实践]. Examples include the various branches of systems engineering as Qian defined them and a wide range of technologies such as automation [自动化技术].

As a first step in developing this new discipline, Qian suggested Chinese scholars systematically collect, analyze, and abstract insights from the written works of influential systems thinkers on the sciences of complexity. He pointed to several existing literatures as sources of inspiration, including Austrian Biologist Ludwig von Bertalanffy's general system theory [一般系统论], Ilya Prigogine's work on dissipative structures, Chinese Mathematician Liao Shantao's work on systems of differential equations and obstruction sets, as well as other published work on information theory, computation theory, bifurcation theory, and other emerging new theories.[99] Qian himself also contributed to the existing body of research through his work on Open, Complex, Giant Systems (discussed in Section 2.2).

After finalizing this three-level framework of system science, Qian Xuesen conceptualized a "bridge," a vast domain of inquiry that analyzes systems science through a philosophical lens and connects it to Marxist dialectics. In general, this bridge embraces a materialist philosophy that emphasizes the importance of real-world conditions and the presence of contradictions within things. The complete conceptual guide that integrated Qian's systems science framework eventually became known as the "three levels and one bridge" framework [三个层次一座桥梁]. Multiple variations of this framework exist, with slight differences in visualizations and some minor details. Figure 10 below provides an illustration of this framework based on Miao Dongsheng's *Essentials of Systems Science*.[100]

Figure 10 Qian's conceptual framework for systems science



The conception of this framework marked a milestone in Qian's school of systems thought, showcasing his foresight and originality as a systems thinker. As American systems scientist John Warfield pointed out in 2003, in the West, the field of systems science in the 2000s was still "in a formative stage," having neither a framework for understanding all of the content of systems science, nor a corpus of foundational and theoretical work, nor a methodology providing a defined process.[101] A similar attempt to map out and visualize the vast domain of systems science in Western scholarship can be found in the works of Andreas Hieronymi from 2013, which provided visual maps to understand the many diversified perspectives, theories, and methods within the field of systems science,[102] and of the works of George E. Mobus and Michael C. Kalton,[103] who published what they referred to as the first introductory textbook of systems science in 2015.

A full comparison of the Chinese school of systems science versus the international perspectives on the field is outside the scope of this study. However, Chinese scholars have highlighted several elements of Qian's framework—most notably *Xitong Guan*, *Xitong Lun*, and *Xitong Xue* (the focus of Section 2.2), that they consider unique Chinese contributions to the field.

Xitong Guan, or the Philosophy of Systems

According to Qian, in due time, the entire body of knowledge generated from systems science could be abstracted to create a branch of philosophy he called *Xitong Guan* [系统观],[xx] which would eventually become an integral part of dialectical materialism. Qian saw dialectical materialism and other Marxist teachings as providing the highest form of guidance on systems science.[xxi] He was particularly impressed with Friedrich Engels's exposition on phase transitions and believed that it is necessary to understand systems science through the lens of contradiction, phase transitions, and interrelations in a constant state of change. In his 1979 speech, Qian expounded:[104]

> *"Outside of China, some people like to talk about 'systems' in systems engineering as if they were a new discovery of the 20th century or a unique creation of modern science and technology. From our point of view, we naturally cannot agree with this, because the notions of the dialectical unity of the part and the whole, as well as the development and evolution of the internal contradiction of things——considered common sense under dialectical materialism—capture the very essence of 'systems'."*

However, Qian also pointed out that the development of *Xitong Guan* was predicated on a rich understanding of systems science; therefore, the most pressing task was to develop *Xitong Lun* and *Xitong Xue*.

Xitong Lun, or the Theory of Systems

Qian initially proposed naming the "bridge" (between systems science and dialectical materialism) *Xitong Lun* [系统论], but had concerns about the term being confused with Bertalanffy's general system theory. Qian and other leading Chinese systems scholars, such as Tsinghua University professor and systems science expert Wei Hongsen [魏宏森] and Renmin University Professor Miao Dongsheng [苗东升], argue that the *Xitong Lun* they envisioned is a much broader and deeper domain of inquiry than Bertalanffy's General System Theory.[105] They also argue that it is uniquely Chinese, and that it differs significantly from Hungarian philosopher Ervin László's systems philosophy.[xxii]

Wei Hongsen proposed using "Systematicism" as the English translation of *Xitong Lun* in perhaps the most groundbreaking study in this field, his 1995 book *Xitong Lun—Xitong Kexue Zhexue*, coauthored with Zeng Guoping [曾国屏] (see images below).[106] In his 2010 book *Essentials of Systems Science*, Miao Dongsheng favored "Philosophy of Systems Science" *Xitong*

[xx] *Guan* ["观"] is sometimes translated as outlook, approach, or concept, but in this context a more appropriate translation is philosophy.

[xxi] It is difficult to determine whether Qian Xuesen's self-identification with Marxism reflects his actual beliefs or if adopting Marxist rhetoric was instead politically expedient to improve receptiveness of his ideas and distance himself from purely Western ideas.

[xxii] Miao Dongsheng, *Essentials of Systems Science*, 9. László's 1972 book, *Introduction to Systems Philosophy* (New York: Harper Torchbooks), was the first to describe the discipline of systems philosophy.

Kexue Zhexue [系统科学哲学] (another term coined by Qian) for its broad connotation that encompasses a large number of disciplines[xxiii] under this domain inquiry.[107]

Figure 11 Wei Hongsen's Xitong Lun[108]

SYSTEMATICISM

Wei Hongsen　Zeng Guoping

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Qian also wanted *Xitong Lun* to incorporate elements from Chinese culture such as holistic thinking.[109] Other Chinese scholars of systems have similarly argued that Chinese people are in an advantageous position to study and advance systems science and make unique contributions, thanks to China's traditions of holism.[110] They point out that systems thinking as a mode of inquiry mirrors ancient Chinese philosophical works from over 2,000 years ago. They note that holistic, integrative, and systems thinking permeates ancient writings such as the *I Ching*, the Taoist classic *Tao Te Ching*, and the *Art of War*, as well as the practice of traditional Chinese medicine.[111] Both literature and practice explored the physical realm and mental phenomenon from a holistic and dynamic point of view, emphasizing the discovery of interrelatedness and connectedness.[112]

Building the Discipline of Systems Science

While Qian's ideas were prescient and systems science elsewhere in the world has grown and matured, it appears that the Chinese systems field has not been able to make significant progress in advancing this framework beyond Qian's initial efforts. When Chinese scholars celebrated the 15th anniversary of the founding of the SESC in 1995, they noted that a comprehensive set of theories that truly reflects a unique Chinese perspective on systems science

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[xxiii] For example, systems science dialectics, epistemology, methodology, to the history of systems science, systems science and technological revolution, systems science and society, and many other disciplinary areas

– as Qian had hoped for – has yet to be developed.[113] Writing in 2010, Miao Dongsheng echoed this sentiment. He noted that some Chinese systems researchers were unable to fully grasp Qian's theories and ideas, and thus often either resort to proposing erroneous ideas and theories that Qian had refuted or proposing new ideas that actually inhibit real progress.[114]

Meanwhile, the growth of the international systems field, along with a growing awareness of the implications of systems research, appears to validate Qian's original intention when he created this framework. As noted throughout Section 1, Qian had anticipated that breakthroughs in a qualitative understanding of the features and behavior of complex systems could lead to paradigm shifts with far-reaching consequences, particularly with regard to military strategies and the art of warfare. Western scholars such as Antoine J. Bousquet have examined this "intimate symbiosis between science and warfare" and how breakthroughs in systems science led to new theories and practices of warfare.[115] The U.S. Department of Defense has placed great emphasis on leveraging new theories and ideas out of the field of systems science—from cybernetics and chaos theory to complexity science—to the design of new warfighting concepts. There has also been new research that discusses ways to leverage complexity in great-power competitions.[116] Given the ramifications, the nexus between Chinese systems research and military theories and the cooperation between the Chinese systems field, particularly with regard to *Xitong Xue, Xitong Lun*, and *Xitong Guan,* and the military think tanks such as the AMS, are worth watching closely.

Section 2. Designing the Social Engineering Toolkit

Section 1 traced the Chinese school of SE from its conception in the 1950s to its maturation as a school of thought and the adoption of Qian's initial conceptual framework in the 1980s. This section turns attention to a parallel line of effort Qian started in the late 1970s to engage his SE theory and knowledge in the service of the nation: his work on social engineering [社会工程].

As explained in Section 1.3, Qian developed a broad understanding of SE as an art and technique for organizing and managing complex systems in the 1970s. Around the same time, alongside his theoretical research into systems science, Qian conceptualized the notion of social engineering as an art and technique for managing complex social systems. [xxiv] Qian's efforts in this area led to the formation of a theory on "open, complex, giant systems" that sought to gain understanding of the form and functions of social systems, as well as an accompanying methodology for approaching systems of this type. Based on these new discoveries, Qian designed a social engineering toolkit and recommended it to senior Party and state leaders, while at the same time advocating for a pivot in their philosophy of governance from the previous uncoordinated and often ad-hoc policymaking practice to a systems-oriented, holistic, scientific approach conducted at the highest level. Through this process, Qian demonstrated how to apply knowledge of complex systems to real-world practice. This social engineering-enabled top-level design approach gained traction during the Hu Jintao era and eventually became a centerpiece of Xi Jinping's governing philosophy.

Social Systems Engineering for Socialist Construction

After Qian's landmark 1978 article, which comprehensively introduced SE to the public, Qian, along with coauthor Wu Jiapei [乌家培], published a follow-on article in 1979 titled "Social Engineering—A Technique for Organizing and Managing Socialist Construction" [组织管理社会主义建设的技术—社会工程]. In this article, Qian and Wu further broadened the notion of a system to be engineered to include "an entire society" [整个社会] or "an entire nation" [整个国家] as examples of a "giant system" [巨系统] that could be the target of SE.[117] After providing a brief introduction to the essential elements of what social engineering could achieve in the 1979 article, Qian worked to refine the idea and its associated methodologies, writing or coauthoring thirty-five news and journal articles centered around this subject between 1979 and 1987.[118]

Just as Qian regarded SE as an art and science for organizing and managing complex systems to achieve desired outcomes, he considered social engineering as a toolkit critical to the success of state-level macro-governance [国家的宏观管理]. State governance, he argued, must be approached holistically, balancing the imperatives of "the production of material wealth, the creation of spiritual wealth [精神财富], the emerging sectors such as the service industry, government administration, upholding the rule of law, managing international relations, national defense, and environmental protection."[119]

[xxiv] The Chinese term "社会工程" can also be translated as societal engineering, which perhaps better conveys the idea of SE being applied to a complex, giant system that is a society. However, Qian himself used the terms "social systems engineering" and "social engineering" in a 1990 paper written in English, and the latter is closest to a literal translation, so it is used here.

Moreover, in a speech in 1987, Qian argued that the task of managing a complex, giant social system at this scale would become increasingly challenging in a world poised to undergo rapid social changes due to advances in science and technology and shifts in the global strategic situation.[120] To achieve effective governance of a complex system in a rapidly changing world, Qian contended that many of the existing haphazard, reactionary, and unscientific policymaking processes must be transformed.[121] Qian described the SE thinking and approach behind the launch of a satellite to illustrate why "crossing the river by touching the stones" [摸着石头过河] (a hallmark governing philosophy of the Deng Xiaoping era) was problematic: in a satellite launch, all the important calculations and the systems design must be completed along with contingency plans before the launch.[122] If these steps are carried out according to the philosophy of "crossing the river by touching the stones," "we wouldn't even be able to locate the satellite once launched."[123]

Instead, Qian argued, what the Party and state leaders needed was a social engineering toolkit that allows them to holistically take into consideration the various moving pieces and arrive at scientifically sound policy decisions.[124] According to Qian, development in a socialist country comes with its own unique set of challenges and opportunities, with one of the most important opportunities being its ability to design and implement long-term development plans. With help from social engineering, he suggested, China's political system was well-positioned to carry out long-term planning on a national scale and ensure its long-term success. By contrast, he contended that applying SE to long-term state-level planning simply "cannot be done" in capitalist countries despite the fact that SE is widely adopted in commercial enterprises in their systems. Successful adoption of SE as an enterprise management solution cannot be transferred to the state management level, he explained, due to capitalist systems' inability to form a consensus on a set of national goals.[125]

In their 1979 article, Qian and Wu pointed out that China's successful implementation of long-term plans hinges on the following factors:[126]

- The implementation needs to be able to reach a state of dynamic balance, adjusting for real-world conditions, new situations, and emergent "imbalances."
- Party and state leaders must have well-established channels to obtain accurate and timely intelligence in order to make informed decisions.
- Near the end of each implementation period, there needs to be a proper way of assessing its implementation to make future adjustments.

Instead of the trial-and-error approach, Qian reasoned, a top-down decision-making mechanism enabled by the social engineering toolkit would be necessary throughout the planning and implementation cycle. Designed according to sound SE principles, this toolkit would enable much more scientific policy decision making, with much lower margins of error.[127] Qian regarded the following elements as essential for inclusion in the social engineering toolkit for Chinese policymakers in order to achieve the desired outcomes:

- An intelligence network and database [情报网和情报资料数据库] tracking economic activities, daily life activities, scientific and technological developments, and other important aspects of economic and social life.[xxv][128] Intelligence is regarded as critical in social engineering. Qian and Wu suggested building a giant database to automatically collect important statistics, with linkages to the national and international communications networks.[129]

- Supercomputers to process the vast amount of information collected.[130]
- The creation of overall design departments [总体设计部] in top Party and state agencies, similar to the ones created in China's aerospace industry, staffed with a diverse group of experts to propose policies and conduct analysis from a holistic perspective in support of the central leadership's top-level policy design.[131] The ODDs would follow a decision-making process based on a combination of empirical judgments and quantitative analysis.
- Advancement in systems theories such as cybernetics and ORSA, and new research into the inner workings of complex, giant systems.[132]

Of course, when Qian formulated his social engineering theories in the 1980s and 1990s, many of these elements, including networked databases capable of storing vast amounts of information and the supercomputers to process the data, were only in nascent stages of development. While Qian likely anticipated that the technology infrastructure enabling this toolkit would take time and significant investment to develop and mature, he nevertheless directed his attention to the field of *Xitong Xue* to uncover the inner workings of complex, giant systems to inform management practices.[133] As explained in Section 1.4, Qian saw a deep understanding of the fundamental laws of complex systems as the prerequisite for designing methodologies to manage these systems. In other words, he believed that in order to manage complex, giant social systems, one must understand the form and functions of the system in question. His research led to a theory on what he and his coauthors Yu Jingyuan and Dai Ruwei [戴汝为] call "open, complex, giant systems" (OCGS) and an accompanying methodology they proposed for analyzing these types of systems.

SOCIETY AS AN OPEN, COMPLEX, GIANT SYSTEM

In their 1990[xxvi] paper "A New Discipline of Science—The Study of Open Complex Giant System and Its Methodology," Qian et al. shared a framework for understanding the various types of systems and discussed the best analytical methods for studying these different types of systems (see Table 1). While this paper represented an important milestone in the development of Chinese *Xitong Xue*, it was light on pure scientific discussions on the nature of systems and focused heavily on applications rather than pure scientific and theoretical discussions. The focus of the paper was

[xxv] Some researchers, including Samantha Hoffman, have argued that Qian was a major figure in the shaping of the Chinese brand of social management theories, which have influenced the CCP's approach to managing state security. See Samantha R. Hoffman. "Programming China: the Communist Party's autonomic approach to managing state security." (PhD diss., University of Nottingham, 2017), http://eprints.nottingham.ac.uk/48547/

[xxvi] Even though the version in wide circulation was from 1993, multiple Chinese scholars noted that this article was first published in the January 1990 issue of *Nature Magazine*, although they were not able to locate the original publication. See Wang Shouyun [王寿云], "Some Understanding of Comrade Qian Xuesen's Thoughts on Systems Science" [对钱学森同志系统科学思想的一点理解], *System Engineering—Theory and Practice* [系统工程理论与实践] no. 5 (September 1992): 7; Wang Danli [王丹力], Zheng Nan [郑楠], Liu Chenglin [刘成林], "Hall for workshop of metasynthetic engineering: the origin, development status and future" [综合集成研讨厅体系起源、发展现状与趋势], *Acta Automatica Sinica* [自动化学报], 47, no.8 (August 2021): 1822−1839 doi: 10.16383/j.aas.c210062

on introducing what Qian et al. termed “open, complex, giant systems (OCGSs), which are “complex giant systems with human beings as their main subsystems.”[134] Here, ‘open’ and ‘complex’ have fairly broad connotations: [135]

> *“‘Openness’ denotes energy, information, or material exchange with the outside world. To be more exact, (1) the system and its subsystems exchange information with the outside world; (2) the subsystems acquire knowledge by learning. A human being is a complex giant system. Society takes an enormous quantity of such complex giant systems as its subsystem. The complexity of such systems can be outlined as: (1) between the subsystems there are many modes of communication; (2) subsystems are of many varieties; (3) the subsystems have different ways of expressing and acquiring knowledge; (4) the structure of the subsystems changes with evolution, so the structure of the system is in a state of flux.”*

In a lecture Qian delivered the following year, he pointed to an additional important characteristic of OCGSs, arguing that OCGSs have many unobserved, undetected, or simply unknown layers between the subsystems and the larger system of systems.[136] Qian et al. argued that these features differentiate an OCGS from simple systems or simple giant systems, and that therefore existing analytical tools, such as the reductionist approach or statistical analysis, no longer apply. There are two main reasons they argue these tools no longer apply. First of all, because OCGSs are complex giant systems with human beings as their main subsystems, the analytic tool must be able to account for complexity in human behavior. Qian et al. gave game theory as an example, noting that because it tends to oversimplify the “complications and uncertainty of human psychology and behaviour,” and when applied to OCGSs, game theory would reduce the analysis down to that of simple systems.[137] Other tools, such as system dynamics or self-organization theory, are equally inadequate due to similar limitations.[138] Secondly, quantitative analysis alone, valuable as it may be, is insufficient in dealing with OCGSs. Yu Jingyuan, one of the coauthors, revealed in a paper from 2001 that while Qian was encouraged by the progress made in this area from the Complex Adaptive Systems movement originating from the Santa Fe Institute (SFI) in the mid-1980s, he was skeptical of its utility in analyzing OCGSs.[139] According to Qian and Yu, the movement and SFI approach, which places a dominant emphasis on computer simulations as a research tool, is a welcome addition but would still be inadequate in dealing with OCGSs. Yu even went so far as to argue that any problem that can be solved by machines alone will naturally not fall under the realm of complexity.[140]

Table 1 Qian et al.'s classification of systems

Qian et al.'s Classification of Systems[xxvii][141]			
Systems	**Criteria**	**Example**	**Proposed Analytical Methods**
Simple systems	"Simple system denotes their comprising relatively fewer subsystems with simpler interrelations."	"A measuring instrument"	"No matter which it is, small or large, such a simple system can be studied, starting from the interaction of the subsystems, then directly synthesizing the dynamic function of the complete system. This can be called the direct method. At most, a large computer or a supercomputer is needed to process such a system."
Large systems	"If the number of subsystems is comparatively large (e.g., a hundred)."	"A manufacturing plant"	
Simple Giant System	"If the number of the subsystems is extremely large (e.g., thousands to trillions)" and "if the variety of the subsystems is not too diffuse (several, or tens of different kinds), and their interrelation is not too complex."	"A laser system"	Statistical analysis where "giant system consisting of billions of elements is generalized by statistical methods with details neglected." Examples include Prigogine's theory of Dissipative Structure or Haken's Synergetics.[xxviii]
Complex Giant Systems	"If there is a large variety of subsystems with hierarchical structure and complex interrelations"	The human nervous system, a geographical system (including ecological system), a social system, etc.[xxix]	Meta-Synthetic Engineering
Open Complex Giant Systems	Complex Giant Systems "with human beings as their main subsystems."		

Notably, the arguments in this paper again echo the core principle that has been a consistent part of Qian's systems thinking since *EC*, and that is the need to not only acknowledge the existence of uncertainties, but to also make room for them in the analytical toolkit (see Section 1.1). Qian had, from the very beginning, been wary of the tendency to regard quantitative data and analysis as the ultimate solution for solving problems involving complex systems with human elements. According to Wang Shouyun's account, during his research into systems science in the 1980s, Qian was also became deeply influenced by the Lanchester(-Osipov) theory of combat,

[xxvii] This paper was written in English. All text in quotation marks is directly quoted from the original material.

[xxviii] Hermann Haken, a specialist in laser physics, is also credited with establishing the interdisciplinary science of synergetics, which focuses on explaining self-organization in non-equilibrium systems. See, *e.g.*, his book *The Science of Structure: Synergetics* (Van Nostrand Reinhold Company, 1984).

[xxix] These systems are referred to Complex Adaptive Systems (CAS) and fall under the field of complexity theory in the United States.

which shaped his semi-empirical semi-scientific/theoretical [半经验半理论] approach to war games and simulations.[xxx142] Reflecting on his conversations with Qian on this subject, Wang wrote:[143]

> *"When one seeks to analyze complex behaviors using quantitative methods, it is easy to focus on the mathematical logic and ignore the subtle empirical implications and explanations. It is important to understand that such mathematical models may seem to be backed by sound theories* [理论性强]*, but in actuality could be quite far-fetched and detached from reality. It is thus better to acknowledge the theoretical inadequacy at the beginning of the modeling process and remedy the inadequacy by the inclusion of empirical judgments* [经验判断]*. ... Such an approach to system modeling enhances and expands upon the modeler's judgment* [判断力] *and is very important."*

Wang thus concluded that the credibility of the mathematical model—an abstraction of a problem to its essential characteristics—rests on two premises: 1) the sound internal logic of the mathematical analysis and 2) sound empirical judgment that connects the model with real-world conditions.[144]

The Meta-synthesis Approach

Given the uncertainty, unknowns, and the unpredictable nature of open, complex, giant systems, studying OCGSs often involves explaining the "unknown with incomplete knowledge."[145] To address these issues, Qian et. al proposed what they described as the only feasible methodology, an approach called "meta-synthesis" [综合集成方法论], or "meta-synthetic engineering method," which integrates empirical judgments and quantitative analysis and, according to Qian, represents a unity of holism and reductionism.[146] Meta-synthesis derives "quantitative knowledge from qualitative understanding," and is carried out through the interaction of three subsystems: an expert system [专家体系], a knowledge system [知识体系], and a machine system [机器体系], which together constitute a complex giant system in and of itself.[147] Based on their 1990 paper and on subsequent articles by other Chinese systems scholars, "meta-synthetic engineering" is a cyclical process composed of three important steps.

- Step 1: A problem or a policy issue will first be studied by a group of policy experts, SMEs, and systems scientists, who will examine the problem using systems thinking to 1) clarify the crux of the problem; 2) make qualitative assessments (empirical hypotheses) and propose the best course of action to solve the problem; 3) place the problem in a systems engineering context, determine its boundaries and specify the "state variables, environment variables, control variables (policy variables) and output

[xxx] Wang was a full corps-grade officer [正军职] and member of the Standing Committee of the Science and Technology Commission of COSTIND. A pioneer in PLA battle simulations [作战模拟] research, he frequently collaborated with Qian on various research projects. According to Wang, he took Qian's suggestions and applied the semi-empirical semi-scientific/theoretical approach to complex confrontation sets [处理复杂对阵问题] in Chapter Three of his book 1984 book *Modern Battle Simulations* [现代作战模拟].

variables (observation variables)." According to Qian et al., this step is of prime importance.

- Step 2: The second step involves the use of mathematical models to conceptualize and construct systems based on the list of variables specified in step one. The validity of the empirical hypotheses is then tested by computer simulations, and system analysis is performed.
- Step 3: The quantitative results obtained in step two are deliberated by the expert group to determine if the course of action chosen is plausible. If found implausible, the model will be modified, the parameters adjusted, and a new model will be generated. This process will be repeated until the expert group reaches a consensus on a feasible course of action.

As Yu Jingyuan later noted in 2007, it is crucial to grasp the cyclical nature of the process. Problems involving complex giant systems are usually unstructured problems. The meta-synthesis approach is essential in using a structured sequence to approximate an unstructured problem.[148] Qian et al. also repeatedly emphasized the importance of empirical input. Despite the important role machines play in the process, it regards the empirical judgements of the expert group as instrumental to reaching a credible outcome and a feasible solution. As they put it, "Men guide and decide the key points, machines carry out the repetitive and tedious work."[149]

Figure 12 Diagram showing meta-synthesis[150]

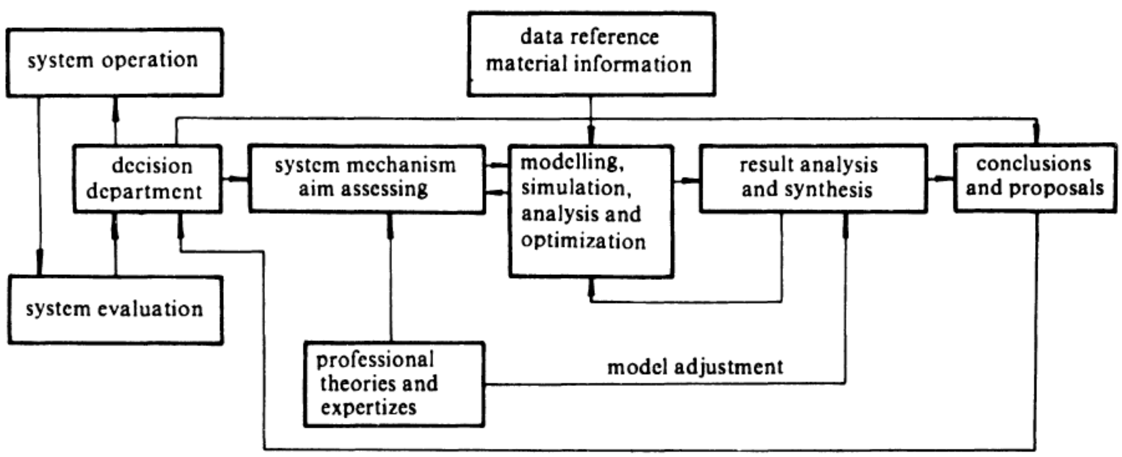

Fig. 1 Application of meta–systhetic engineering

Finally, according to Qian et al., meta-synthesis would enable the "activation" [激活] of data and information which might otherwise lie dormant.[151] The process is designed so that the organic combination of the three parts can give rise to a highly intelligent system, which not only performs the functions of collecting, storing, transmitting, retrieving, analyzing, and integrating information and knowledge, but more importantly, it also generates new knowledge that can be further utilized to develop theories as well as to tackle practical issues from a holistic perspective.[152] Qian noted that the "activation" of information achieved through meta-synthesis, which he proposed calling "information inspiritment,"[xxxi] is of prime importance to intelligence work, which is not only concerned with the *collection* of information and data, but also with finding ways to "activate" the data collected.

"Hall for Workshop of Meta-synthetic Engineering" (HWME)

The systems architecture enabling meta-synthesis was proposed by Qian in 1992. Widely translated by Chinese researchers as "hall for workshop of meta-synthetic engineering (HWME)" [从定性到定量的综合集成研讨厅], it was envisioned by Qian as a virtual environment where experts can hold seminar discussions and conduct meta-synthesis by leveraging a platform that connects to a command, control, communications and intelligence (C3I) architecture and incorporates elements of emerging technologies such as artificial intelligence and virtual reality.[153]

Since the early 1990s, Chinese researchers have developed several variations of system architectures for HWME, particularly with regard to military and economic decision making. In an August 2021 paper published in *ACTA Automatica Sinica* [自动化学报], three CAS-affiliated researchers who specialize in complex systems management, pattern recognition, and artificial intelligence traced the evolution of these attempts and recent developments.[154] According to the CAS researchers, the first attempt was made between 1992 to 1996 with funding from the segment of the "863 Program" that supported the development of intelligent computer systems.[155] The research efforts, led by Yu Jingyuan, Dai Ruwei, and Feng Shan [冯珊], focused on the development of an intelligent system to assist macroeconomic decision-making. Building on these early efforts, the National Natural Science Foundation of China (NSFC) launched a large-scale research project in 1999 led by Dai Ruwei to construct a HWME for macro-economic policymaking.[xxxii][156] The conceived integrated system consists of three parts exactly as Qian proposed: a "machine system" composed of computers and information infrastructures such as information networks and multimedia technologies; an "expert system" composed of economists, sociologists, natural scientists, engineers, and technicians; and a "knowledge system" for acquiring and processing information.[157] To develop an HWME prototype, the NSFC research project centered on four main topics:[158]

1. A prototype for the human-machine integrated meta-synthesis system and its environmental architecture [人机结合综合集成体系雏形及其支撑环境的研制]
2. Macroeconomic information and modeling system and its functions [宏观经济信息、模型体系及其功能研究]
3. Meta-synthesis and *Xitong Xue* that support macroeconomic decision making [支持宏观经济决策综合集成方法体系与系统学研究]
4. Cognitive and knowledge discovery technology related to macroeconomic decision making [与宏观经济决策有关的认知与知识发现技术(KDD)研究]

[xxxi] Qian's original Chinese-language article used this phrase in English to convey his point. He disliked the term "data fusion" (which he also used in English), as it fails to convey the idea of transforming a large amount of dormant information into actionable "live" intelligence.

[xxxii] In an interview from 2005, Dai proposed an alternate name for the system which he called "Cyberspace for Workshop of Metasynthetic Engineering (CWME)." See "Academician Dai Ruwei Discusses HWME: a Major Original Research Achievement based on the Science of Complexity" [戴汝为院士谈"综合集成研讨厅":复杂性科学的原创性重大成果], 28 April 2005, https://news.uestc.edu.cn/?n=UestcNews.Front.Document.ArticlePage&Id=17340

The project was undertaken by more than ten universities and research institutes in China, including CAS's Institute of Automation [自动化研究所], the Institute of System Sciences, the Institute of Psychology [心理研究所], the 710 Research Institute of the China Aerospace Corporation,[xxxiii] the Beijing Systems Engineering Research Institute [北京系统工程研究所], and the Department of Computer Science of Tsinghua University.[159] In their 2021 paper, the CAS researchers characterized the HWME prototype as a moderate success. They noted that: [160]

- The prototype was demonstrated at a workshop for complex systems modeling held by the International Institute for Applied Systems Analysis (IIASA) in 2003 and drew significant attention from the international audience.
- Between 2003 and 2005, multiple senior Party and state officials watched demonstrations of the HWME prototype and judged that the system had "basically taken shape" [基本成型] and recommended its promotion in relevant national departments.
- When the project concluded in 2004, the review panel "unanimously agreed that the system had basically reached an operable level" [基本达到了可操作的水平] and recommended its application to relevant national departments.

Around 2006, Dai Ruwei and his team at CAS's Institute of Automation launched a joint program with AMS to develop the systems architecture for an "HWME for strategic decision making" [战略决策综合集成研讨系统], extending the methodology's reach into military strategic decision making for the first time. The core functions of this system have been outlined by CAS researchers as follows:

[xxxiii] Now under CASC.

Table 2 Strategic decision making HWME client[161]

Strategic Decision Making HWME Client [战略决策综合集成研讨客户端]		
Seminar Hall		E-meeting
		Comments and Input Function
		In-depth Discussion
		Host Controls
Tools Supporting Decision Making	Tools for Strategic Research	Index system design and calculation [指标体系设计与计算] Strategic intent coordination [战略意图协调] Strategic power comparison [战略力量对比]
	Tools for Analyzing Expert Panel Opinions	Strategic Action Plan Evaluation [战略行动方案评价] Questionnaire
	Tools for Decision Making	AHP questionnaire Pairwise comparison [成对比较法] Scheme generation framework [方案生成框架] Problem tree decomposition [问题树分解]
Intelligent data analysis [智能数据分析]		Collaborative editing of action plans [方案协同编辑]
		Statistical analysis of military data [军事数据统计分析]
		Analysis of operational capability [作战能力分析]
		Analysis of strike plans [打击方案分析]
Administrative functions [秘书功能]		Meeting organizing and note-taking [会议整理与记录]
		Real-time adjustment and editing of seminar discussions [研讨流程实时调整与编辑]
		Management of resources and documents [资源、文档关联]
Management Functions [管理功能]		Discussion organization [研讨管理]
		Agenda setting [单元、议程设置]
		Document, model, tool management [文档、模型、工具管理]
		Expert information management [专家信息管理]

While little is known about the system's actual utilization and applications, the Institute of Automation claimed in 2008 that the "HWME for strategic decision making" has been applied to wargames [推演] concerning multiple major military-strategic issues [若干重大军事战略问题].[162] Notably, when Hu Jintao visited AMS to celebrate its 50th anniversary on 21 March 2008, he paid a visit to the Joint Operations Research and Experimentation Center [联合作战研究实验中心] and watched a demonstration of said system. Hu commented that the system and the meta-synthesis methodology hold great significance for many of the important issues of the day and expressed anticipation for the system to play its rightful role in due time.[163]

CCP leadership has so far supported the development of the HWME systems architecture, but its development has met with limited success. This slow progress may be due to the fact that many of the underpinning technologies for an HWME envisioned by Qian were only in their nascent stages of development when he conceived the idea. However, its time appears to have come. As CAS researchers noted in their 2021 paper, rapid advancements in network technologies and artificial intelligence over the past ten years necessitate a need to revisit the HWME concept. Given the authors' close affiliation with the Institute of Automation and its State Key Laboratory for Management and Control of Complex Systems [复杂系统管理与控制国家重点实验室], it is highly likely that the Institute of Automation will continue to lead efforts in this area.

Systems Mindset, Holistic Planning, and Top-Level Design

The conception of the OCGS theory and the meta-synthesis methodology in the early 1990s significantly enhanced Qian's social engineering theory. In his vision, Chinese Party and state leaders can effectively macro-manage a wide variety of activities at the state level (an open, complex, giant system) through a defined decision-making process (meta-synthetic engineering) that integrates empirical judgments and quantitative analysis (meta-synthesis) based on a vast amount of information collected via an intelligence network and database. This policymaking process, carried out via an overall design department [总体设计部] acting as an advisory body staffed with senior experts, would enable systems-oriented, holistic, scientific planning at the highest level and minimize the negative impacts from the prior bottom-up, uncoordinated, ad-hoc policymaking practice. As Qian et al. stated in their 1990 article:[164]

> *"All this shows that the one-track mind and piecemeal reform just does not work. Reform needs overall analysis, overall design, overall coordination, and overall plan. This is the realistic significance of the social systems engineering to the reform and opening policy in China."*

Yu Jingyuan formally put forth the suggestion to create an ODD for national economic development [国民经济总体设计部] at the First Session of the Eighth National Committee of the Chinese People's Political Consultative Conference (CPPCC) held in 1993. [165] Yu remarked during the conference that China had entered a stage in its economic reform when it was critical to approach key issues and policy agendas in a holistic, coordinated fashion, not only in terms of coordination between the various mechanisms, rules and regulations, and policies, but also coordination between its economic policies and development in politics, science, and technology, etc. Noting that ODDs are a unique Chinese creation, different from the Western "think tanks," Yu stated that this ODD, a decision-making advisory body, would apply Qian's meta-synthesis analysis approach and social systems engineering techniques to conduct "overall analysis, overall design, overall planning, and overall coordination" on major issues to devise policies and that are feasible and actionable. According to AMS scholar You Guangrong [游光荣], Qian at one point proposed the establishment of five ODDs:[166]

- An ODD under the Party Central Committee, which would be responsible for putting forward the central requirements and overall development plans for politics, economy, culture, and national defense.
- An ODD under the Standing Committee of the National People's Congress (NPC) in charge of designing national mid- and long-term development plans especially concerned with the "socialist material civilization construction" [社会主义物质文明建设]. Once approved by the NPC, the mid- to long-term plans would be used as a basis for review of the State Council's five-year plans and annual plans.
- An ODD under the State Council. Its main responsibility would be to propose five-year plans and annual plans in accordance with the national medium and long-term plans, as well as making necessary adjustments during the implementation process.
- The fourth ODD would be mainly concerned with the ideological or cultural aspect of national development, also known as the "socialist spiritual civilization construction" [社会主义精神文明建设].
- The fifth ODD would handle international relations and diplomatic strategies.

While Qian and Yu's suggestions were intended for the Jiang Zemin administration, it is unclear how receptive Jiang was to the idea of pivoting from a "trial and error" approach to the "overall design" approach via the creation of an ODD. However, "top-level design" as a philosophy of governance clearly gained traction during Hu Jintao's tenure. Hu personally communicated to Qian Xuesen that he was deeply influenced by Qian's SE theories when he called on Qian on 20 January 2008.[167] Hu stated that he was first exposed to Qian's work in the early 1980s when he was studying at the Central Party School. Hu found Qian's report "very innovative" [很有创见] for underscoring the importance of "grasping the whole" [从整体上加以把握] and considering all elements and factors when dealing with complex problems. Hu revealed to Qian that his scientific development concept [科学发展], which emphasizes comprehensive, coordinated, and sustainable development, was designed to reflect the principle of *tongchou jiangu* (referring to overall planning and all-around consideration, as discussed in Section 1.3).

In October 2010 at the Fifth Plenary Session of the 17th CCP Central Committee, Hu Jintao put forward for the first time the idea of needing to attach greater importance to "top-level design and overall planning" [顶层设计和总体规划] in matters related to reform.[168] Hu did not give a precise definition for the term "top-level design," but commentaries and analysis on this subject published in the following year strongly echoed many of Qian's and Yu's arguments. For example, an article by Gao Shangquan [高尚全], then honorary president [名誉会长] of the China Society of Economic Reform who had previously served as deputy director of State Commission for Economic Restructuring [国家经济体制改革委员会], and a separate article by Deng Yuwen [邓

聿文], then deputy editor of *Study Times*, both mentioned that Hu's top-level design concept represented a break from the "crossing the river by touching the stones" philosophy of Deng's era.[169] According to Gao, China's economic reform had entered the "deep water zone" [深水区], where many complex issues and problems intertwine to the point that it became difficult to clearly delineate whether the nature of a problem is economic, political, or social. The complexity of the mission thus required overall design and overall coordination at the highest level, carried out by a coordinating body responsible for the overall design and coordination, Gao noted. In Deng Yuwen's article, he mentioned that Liu He [刘鹤], who was a key person behind the drafting of the 12th Five Year Plan, expressed similar viewpoints.[170]

Hu Jintao's intention to pivot to "top-level design" was also evidenced by the creation of the PLA Strategic Planning Department [解放军战略规划部], under the General Staff Department, on 22 November 2011. The Strategic Planning Department, whose mandate Xinhua summarized as "being responsible for the PLA's 'top-level design'" [负责全军"顶层设计"],[171] was to take charge of, among other missions, "drafting force construction and military development plans, putting forward suggestions on the overall direction and macro-management of strategic military resources [军队战略资源], and coordinating and resolving inter-departmental and interdisciplinary issues."[172] Xinhua's description of the department's mandate suggests that Qian's overall design department [总体设计部] idea has been adopted and experimented with and that the organizations being created (which appear to be functionally ODDs, if not necessarily in name) can take various shapes and forms.

The influence of SE and systems thinking is also evident in Hu's military thought, a key element of which was the requirement to transform from element-based military thinking [要素型军事思维] to systems-oriented military thinking [体系化军事思维].[173] For example, focusing on the element of a single commander's capabilities as the cause of a battlefield victory would ignore the system around him or her that was equally (if not more) crucial to that victorious outcome. Deputy Dean of AMS Liu Jixian [刘继贤] commented in 2007 that element-based military thinking, a product of the agricultural and industrial ages, lacked consideration for the overall picture.[174] Systems-oriented military thinking is the mindset required to build an informationized military. The essence of systems-oriented military thinking is to apply the "large system" perspective ["大系统"的观点] to military issues and scientifically organize force building and military activities.[175]

The "top-level design" philosophy and approach, which gathered momentum during the latter half of Hu's tenure, took center stage after Xi Jinping took over as the paramount leader of China in 2012. Xi made the most forceful case for "top-level design" when he addressed the Third Plenary Session of the 18th Chinese Communist Party (CCP) Central Committee in November 2013 in Beijing, prior to launching one of the most extensive rounds of reforms in PRC history. Xi stated:[176]

> *"The comprehensive deepening of reforms requires strengthening top-level design and overall planning, and strengthening the interconnectedness* [关联性], *systemness* [系统性], *and feasibility of various reform measures. We often*

say that we must be bold in our approach and steady in our steps [胆子要大、步子要稳]. *Taking steady steps means we should exercise all-around consideration, conduct comprehensive analysis, and achieve scientific decision-making. Economic, political, cultural, social, and ecological reforms are closely linked and integrated with party building reforms. Reforms in any single domain will affect others and therefore require close coordination. If the reform measures in these domains are uncoordinated, it will be difficult to comprehensively deepen reforms. Even if implemented, the effectiveness will be greatly reduced."*

"Comprehensively deepening reforms is a complex systems-engineering undertaking," Xi said, as he announced the creation of the Central Leading Small Group (LSG) for Comprehensively Deepening Reforms.[177] This LSG would be responsible for the "overall design" [总体设计], overall planning and coordination [统筹协调], and holistic advancement [整体推进] over all matters related to this round of reforms and their implementation.

As some foreign observers have noted, Xi, likely aware of the significance of his departure from the methodology and philosophy of reform during the Deng Xiaoping era, has attempted a reconciliation, at least in theory, by highlighting a need for both "top-level design" and "crossing the river by feeling the stones" in accordance with dialectics.[178] Despite the rhetoric, however, Xi's subsequent centralization of power and other policy moves signaled his clear preference for the former. Arguably, Xi has, to an extent, realized Qian's vision of creating overall design departments [总体设计部] at the highest level to lead China's socialist construction endeavor through the strengthening and creation of the various LSGs and central commissions in charge of decision making over the most important strategic issues.

Xi Jinping has also extended the emphasis placed on systems thinking, holistic approaches, and top-level design to the discussion of other important policy priorities. Systems science-associated concepts permeate Xi's speeches on a variety of important issues.[179] When speaking to the Central Commission for Military-Civil Fusion Development on 22 September 2017, Xi stressed a need for the application of systems science, systems thinking, and systems methods to understanding and solving problems.[180] When outlining his vision and requirements for the 14th Five-Year Plan (2021-2025) period on 3 November 2020, Xi stated that systems planning and strategizing [系统谋划] carried out by the Party Central Committee enabled the advancement of every Party and state endeavor in a holistic manner with historic achievements, concluding that "a systems mindset is a foundational way of thinking and working throughout this process."[181] When discussing the holistic national security concept [总体国家安全观] at the 26th collective study session of the 19th Politburo on 11 December 2020, Xi underscored the importance of adhering to systems thinking, of integrating national security into the entire process of all aspects of Party and state work, and of planning and strategizing in a holistic manner alongside economic and social development.[182]

"Upholding a systems mindset" was officially identified as one of five fundamental principles to guide economic and social governance during the 14th Five-Year Plan (FYP) period and beyond at the Fifth Plenary Session of the 19th Party Central Committee in November 2020.[183]

In a People's Daily article published the following month, Zhan Chengfu [詹成付], deputy director of the Ministry of Civil Affairs [民政部], traced the theoretical origin of this seemingly simple phrase, noting that the phrase embodies a rich foundation deeply rooted in China's experience in the past four decades.[184] According to Zhan, “upholding a systems mindset” entails a need to:

- Gain an understanding of any subject in question from a holistic standpoint, considering the full picture and the interconnectedness of the various elements
- Uncover the fundamental laws behind said subject, create order, and achieve the optimization of the entire system
- Approach economic and social issues through the analytical lens of open, complex systems and the meta-synthesis methodology

CONCLUSION

This paper has introduced the building blocks of the Chinese school of systems engineering, some of that school's unique perspectives, and the roles its theories and methodologies have played in China's defense R&D, as well as economic, social, and military development. After four decades of development, the central concepts of this school can be summarized as follows:

- A conceptual framework ('Three Levels, One Bridge') that unites the various disciplines within systems science and identifies its relation to Marxist dialectics
- A systems philosophy (*Xitong Guan/Xitong Kexue Zhexue*) that informs practice
- A theory of open, complex, giant systems with humans as the subsystems, which constituted the main body of knowledge of *Xitong Xue*
- A methodology (meta-synthesis) that unifies holism and reductionism, and a defined process and systems architecture (meta-synthetic engineering and HWME) through which to apply the methodology
- A central purpose: to support the socialist construction endeavor
- A broad understanding of SE as more than just an engineering science and practice, but an art, science, and technique for organizing and managing complex systems of any kind
- A type of organization borne out of the success of China's aerospace industry – an overall design department – that was designed to apply the conceptual framework and methodology to achieve the central goals at hand

Qian's death in 2009 did not presage a decline in the influence and vitality of this school. In the past few decades, Chinese systems engineering has continued to develop and retained its influence among senior CCP officials. Interest in Qian Xuesen's theories and systems science remains high. Qian's legacy as father of China's missile and nuclear programs would have no doubt ensured his place in modern Chinese history, even without his contributions to systems science. This latter role, the one that he most wished to be remembered for, will likely prove to be the more impactful legacy due to its centrality to Chinese concepts of governance. The path that China is taking is already arguably the most important story of the 21st century, and, by China's leaders' own admission, Qian's ideas are right at the heart of their thinking.

Of course, the adoption of SE principles and systems thinking in management is by no means an idea unique to China. In the United States, the Department of Defense, the defense sector at large, and various businesses have been incorporating solutions and approaches informed by SE and systems science for decades. However, thanks to Qian, SE concepts and approaches have been recognized and promoted to a much wider audience by senior Chinese leaders for decades. The prevalence of references to the concepts of systems thinking, systems engineering, and "systemness" in Chinese leaders' public expressions of policy puts it on par with the way that U.S. leaders might reference values such as "freedom" and "democracy." In acknowledging and describing key policy agendas and strategies as "complex systems engineering undertakings," CCP leaders take a step in a direction that reflects one of the most salient points of Qian's teachings, that is, the need to recognize and accommodate complexity, uncertainty, and aspects of reality that equations do not describe.

A systems approach to strategic planning, decision-making, and governance has also been regarded as an essential skill set of CCP cadres. Even if not every official can fully appreciate or readily apply Qian's theories and methodologies, what has been demanded of them is the maintenance of an integrative mindset to see problems and issues as involving complex systems intricately connected with long-term consequences.

For all China's immense structural, geographic, economic, and social challenges, at a theoretical level, Qian's contribution was to set China up for success in long-term epochal competition. While a systems mindset alone is insufficient in winning long-term strategic competitions, it is a good starting point, and one that China's strategic opponents should have in their arsenals so as not to be misled by siloed, narrow approaches to policy and other myopic, reductionist approaches.

Appendix 1

Chinese	Pinyin Romanization	Translations adopted in this paper	Other translations provided by Chinese scholars
系统	*Xitong*	Systems	
系统性	*Xitong xing*	systemness	
系统工程	*Xitong gongcheng*	Systems engineering (SE)	
系统科学	*Xitong kexue*	Systems science	
系统论 (Qian Xuesen)	*Xitong lun*	Theory of Systems	"Systematicism"
一般系统论 (Ludwig von Bertalanffy)	*Yiban xitong lun*	General Systems Theory	
系统观	*Xitong guan*	Philosophy of Systems	
系统学	*Xitong xue*	Science of systems	"systematology"
系统科学哲学	*Xitong kexue zhexue*	Philosophy of systems science	
系统观念	*Xitong guannian*	Systems mindset	
系统思维	*Xitong siwei*	Systems thinking	
系统方法	*Xitong fangfa*	Systems approach	

ENDNOTES

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