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Introduction

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China's defense industry has been introducing new weapon systems at a faster rate than at any other time in its history. From new fighter aircraft to new rocket launchers to new types of information systems, China's once moribund defense industry can now manufacture increasingly capable weapons and equipment. Indeed, the U.S. Defense Department assesses that China's defense industry is as capable as Russia and the European Union in some technology areas.

A critical component of China's weapons programs is its research, development, and acquisition (RDA) system. To better understand how China brings weapons programs to fruition from conception to fielding, the University of California Institute on Global Conflict and Cooperation (IGCC) in July 2013 held the conference "Understanding the Structure, Process, and Performance of the Chinese Defense Research, Development, and Acquisition System," its fourth annual inquiry into China's defense industry.

For the purposes of this conference, RDA was defined as actions taken by developers to transform internal and external resources into weapon systems. A country's RDA system is likely to include decision-making and planning processes, organizational structure, technical capabilities, manufacturing know-how, and the implementation and management of the research and development of technology, components, and systems. Analysis of a country's RDA process can provide insights into the length of time a country takes to complete weapons systems, identify RDA milestones or activities and standards of practice, and can serve to highlight deviations in the time between milestones and in standards of practice.

The twelve research briefs in this collection are divided into three sections. The first provides analysis of global RDA processes, the role of high-risk/high-reward technology development organizations, and a comparative look at global fighter aircraft development timelines. The second section examines cross-cutting issues in the Chinese RDA system. A final section provides briefs of six Chinese RDA case studies.

This collection also contains a section of charts and diagrams that provide up-to-date and relevant information into key aspects of the Chinese defense economy and China's broader national science and technology enterprise.

GLOBAL ISSUES IN DEFENSE RESEARCH, DEVELOPMENT, AND ACQUISITION

Several of the briefs address global issues in RDA and their implications for China's weapons development. Writing on changing trends in global RDA processes, Maggie Marcum and Aliaksandr Milshyn conclude that changes in requirements for future warfare will require defense planners to focus on a broad range of RDA activities, including force planning, articulation of requirements, integration of advanced technologies and systems, and changes in defense budgets that may change acquisition processes.

Marcum, in her paper comparing development timelines for U.S., European, Chinese, and Russian fighter aircraft, assesses that China's fighter development programs lag some 20 years behind western technology developments, but appear to be closing the gap in terms of capabilities and manufacturing know-

how. For example, the United States and Russia took an average of 12 years from study to delivery of their fourth-generation systems while the Chinese fourth-generation J-10 has taken 25 years to develop. The timeline for fielding China's fifth-generation fighters, however, appears to be more in line with other countries. It is likely that it will take most developers about 25 years to conceptualize and deliver a fifth-generation fighter because of the complexity of the technologies and components.

Marcum also examined the role of high-risk/high-reward organizations such as the U.S. Defense Advanced Research Projects Agency (DARPA) in fostering innovation. She finds that although most defense acquisition leaders and experts point to the system established by DARPA as the most efficient means to stimulate high-risk/high-reward research, no other countries have adopted a similar structure or process.

CROSS-CUTTING ISSUES IN THE CHINESE RESEARCH, DEVELOPMENT, AND ACQUISITION SYSTEM

A second set of research briefs covers cross-cutting issues in China's RDA system. Kate Walsh, in her brief on China's RDA system and the quality of linkages within it, assesses that China's ongoing defense industrial reforms have resulted in more rapid development and modestly innovative products in recent years. Yet China's defense industrial processes have followed the more traditional, linear, industrial-age development model, which is likely to limit the type of innovation realized. She concludes that as China continues its pursuit of military-civilian integration and focuses

on shifting to a system-of-systems development model more conducive to the information age, we are likely to see significant changes in China’s approach to—and potentially advances in—defense innovation.

In their brief on the role of the General Armament Department (GAD) and the State Administration for Science, Technology, and Industry for National Defense (SASTIND) in the RDA process, Susan Puska et al. develop a seven-step defense life cycle management model for “cradle to grave” analysis of Chinese military modernization programs and projects. The model provides a systemic approach to examine key players at each step of the process, and to assess systemic challenges and strengths of the RDA process driving China’s military modernization. They find that GAD’s inability to effectively oversee the development of military weapons and equipment leads to persistent problems in quality control and a mismatch between defense production and military user requirements. These shortcomings help slow production and weaken military sustainment, resulting in early obsolescence of weapons and equipment.

In looking at the role of foreign technology transfer in China’s RDA process, Tai Ming Cheung analyzes the Chinese technological development strategy of “introduce, digest,

absorb, and re-innovate” (IDAR), which refers to the steps required to turn foreign technology into a remade domestic variant. Cheung concludes that using China’s IDAR model offers a more precise guide in understanding how Chinese entities at the state and corporate level pursue much of their innovation, which consists largely of combining foreign technology with domestic capabilities to produce solutions suitable to Chinese conditions. Cheung also concludes that China is designing and building a significant portion of its national innovation system to support its IDAR strategy. This includes a burgeoning ecosystem of laboratories, information analysis and dissemination institutes, national and corporate engineering centers, and technology transfer centers.

CASE STUDIES

The final section of research briefs covers specific defense RDA programs in detail from each of China’s six defense industries: the J-10 fighter and Pterodactyl unmanned aerial vehicle (aviation), the Beidou navigation satellite system (space), the integrated command platform (information technology), the Type 54 frigate (shipbuilding), the A100 and PHL96 multiple launch rocket systems (ordnance), and China’s first nuclear weapon (nuclear).

For the purposes of the conference, a generalized six-stage RDA process was used to evaluate these weapons programs (see Table 1). Researchers were then asked to use this generalized process as a guide when analyzing their respective weapons programs. In doing so, major milestones and issues or challenges were identified and an assessment made of what factors influenced the program.

CHINESE RDA THEMES

Based on the defense industry case studies presented at the conference, a number of themes were identified. These themes reveal that in most weapons programs China follows a risk mitigation approach to weapons development to include borrowing from foreign sources and measured improvements in technology rather than significant leaps in innovative capabilities. This approach, while beneficial for stable weapons development, would also suggest that China’s ability to develop disruptive technologies is limited.

Similar RDA Processes

All of the weapons programs selected for study followed a process similar to the generalized process outlined in Table 1. However, based on the three different descriptions of the RDA process in their sources, Puska et al.

Table 1. Generalized RDA process

Pre-Program Activities	Requirement/ Needs	Research and Design	Development and Demonstration	Production/ Manufacturing	Operations and Maintenance
Basic and applied research	The identification of equipment needs based on capability gaps and strategic priorities. Concepts are developed and submitted for consideration.	The government accepts a design concept. A feasibility study is conducted. Plans are made to develop or acquire technology and insert into the program. Final specifications are accepted by the government.	A program manager sets a development, industrial production schedule with milestones. Designs are finalized, demonstrated, and approved for production. Contracts are selected and a systems integration plan is set in place.	A manufacturing plan is executed. All production-related activities are defined and monitored. Equipment is tested for final production and acceptance.	System is presented for acceptance. Failures to meet performance requirements may result in rejection and modification. Systems are delivered for operational use. Equipment is maintained and eventually disposed of according to the life cycle plan.

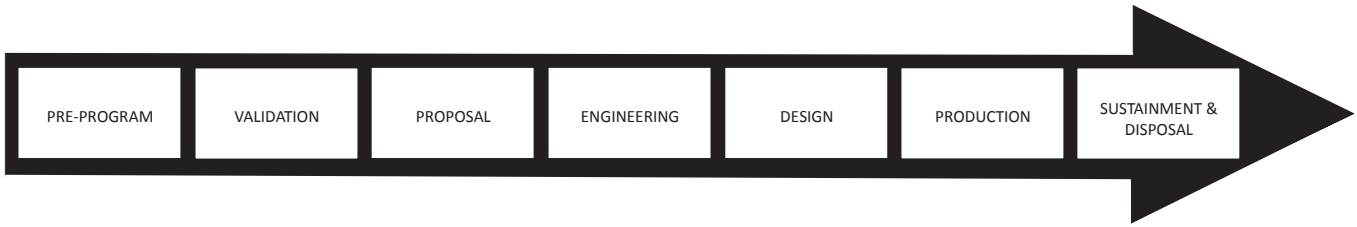


Figure 1. Amalgamated Chinese RDA process based on Chinese sources

have formulated a seven-stage RDA process that separates the project design/proposal stage of the generalized process above into a feasibility stage and a planning stage (Figure 1).

Variations on these frameworks were also found to exist for industry-specific RDA processes. The aviation industry for example, follows a five-step process; the information technology (IT) industry follows a four-step process, and the space industry follows a seven-step process for satellites (Figure 2). Specific activities undertaken during these stages may also differ according to industry. For example, prototype aircraft may be flown to test airworthiness and the function of systems and subsystems.

Such testing of satellites, however, may be forgone due to the expense and difficulty of launching satellites into orbit. As a result, a functioning prototype may not be fully tested in space before a design is finalized. Information technology, on the other hand, may be widely distributed for operational use with limited testing due to the relative ease in which upgrades can be installed.

One significant difference between the generalized process and industry-specific processes identified in Chinese writings is the inclusion of requirements generation during the pre-program or pre-research stage. This research goes beyond the basic and applied technical research that is

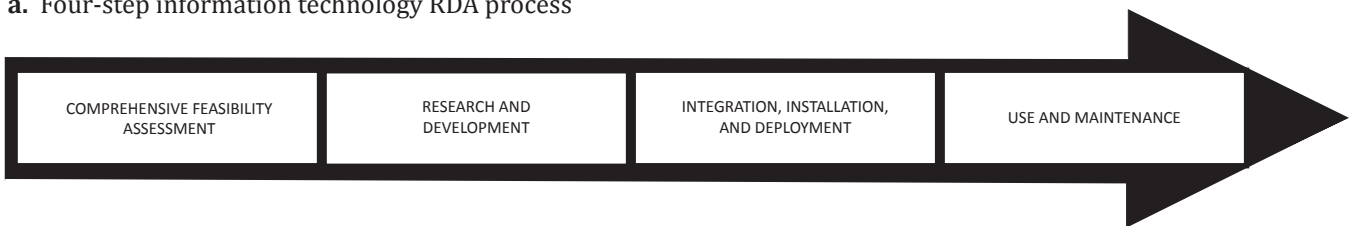
listed in the generalized process and includes an assessment of China's security needs, its military strategy, and generation of operational and technical requirements that can meet these needs while retaining fidelity to the military strategy. Once these requirements and needs are identified, then technical and cost feasibility studies are conducted to see if it is possible to develop the technology that can meet those needs within the identified budget and time frame.

The Role of Foreign Technology

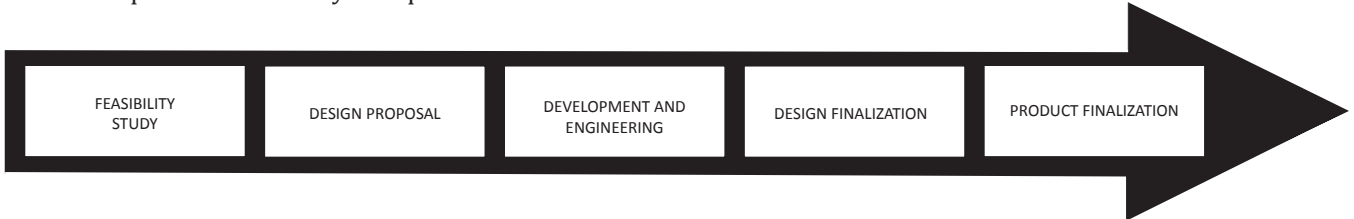
In five of the industry case studies, the acquisition and absorption of foreign technology plays a critical role in the RDA process. This should not

Figure 2. Industry-specific RDA processes

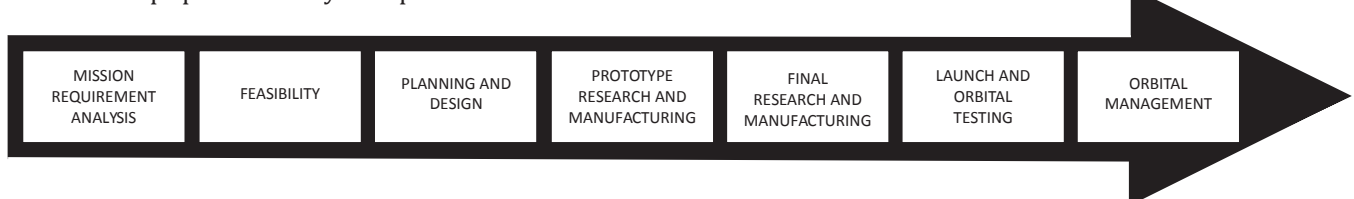
a. Four-step information technology RDA process



b. Five-step aviation industry RDA process



b. Seven-step space industry RDA process



be surprising. As Cheung points out in his brief on Chinese efforts to acquire foreign technology, this is standard practice for countries seeking a shortcut to technology development. As Cheung also points out, however, China is not content to simply copy foreign systems. Foreign technology is to be assimilated so that even though the platform, system, or technology may have a direct lineage to its foreign counterpart, it has been improved upon and localized to such a degree that it possesses many unique Chinese characteristics.

China's activities in this regard are governed by an official Chinese strategy known as "introduce, digest, absorb, and re-innovate" (引进 Yinjin, 消化 Xiaohua, 吸收 Xishou, 再创新 Zai Chuangxin), or IDAR, that refers to the different steps required to turn foreign technology into a remade domestic variant. Under this strategy, Chinese companies are encouraged to attract foreign technology through importation, partnerships with foreign companies, or R&D centers. This technology is then studied (digested) and ways of developing and manufacturing are then explored (absorption). Finally, the technology is improved upon and localized to meet the needs of the Chinese customer (re-innovation).

The most well-known examples of this include the J-11B, which borrowed heavily from the Russian Su-27, and the CRH380A high-speed train, which borrowed heavily from Japanese models. Examples from the case studies that best exemplify this strategy include China's first nuclear weapon, which was based on Soviet technology, and the J-10 fighter, which is based on Israeli technology. The A100 and PHL96 multiple launch rocket systems (MLRS) may also be a candidate for this approach, although further research is required.

J-10 Fighter Aircraft

The J-10 jet fighter appears to be largely based on the design of the Lavi jet fighter, an Israeli warplane devel-

oped during the early 1980s but cancelled in 1987–88. Israel approached the Chinese aviation industry in regards to a cooperative program, although there is no official acknowledgement by Chinese sources that the Chinese aviation industry accepted this overture. The look of the J-10, with its "tailless delta canard" design, however, strongly suggests that whether or not Israeli plans were provided to China's aviation industry, the Lavi served as a strong influence on its design.

China's aviation industry has also reportedly received Russian assistance on the J-10, including the use of a wind tunnel for aerodynamic testing and the reverse engineering of the Russian Phazotron radar system. In addition, Chinese engineers were reportedly granted access to Pakistani F-16s, which allowed them to study the aircraft's fly-by-wire system. Significantly, due to the aircraft industry's inability to develop capable jet engines, the J-10 uses a Russian AL-31N engine.

Beidou Navigation Satellite System

China's Beidou navigation satellite system has relied on foreign technology for a key component. The Beidou 2 satellite uses Swiss atomic clocks as backups for its timing mechanism. Although no evidence exists that China has reverse engineered these clocks, such a possibility cannot be ruled out. Without the addition of foreign clocks, Beidou may be unable to achieve its designed accuracies. China also reportedly received assistance from European countries in the development of other satellite navigation application technologies during its short-lived cooperation with the European Union on the Galileo satellite navigation system. Per Chinese sources, development of these technologies would not have been possible without such assistance.

Integrated Command Platform

The integrated command platform (ICP) may rely the least on foreign

technology out of the seven technologies examined. For systems architecture and security reasons, much of the software was custom built for the ICP using open source software. There is evidence that the ICP may use Windows 2000/XP for user interface and Oracle 8i database management software, however.

Type 54 Frigate

The Type 54 frigate is said to be influenced by the French La Fayette frigate, although no evidence exists that France or French designs assisted the Chinese. Russia, on the other hand, is rumored to have assisted China, and the Type 54 shares many traits with Russia's Project 11356 frigates. In addition, many of the ship's subsystems are based on or reverse engineered from foreign, mainly Russian, systems. These include the ship's search and fire control radars and sonar.

Multiple Launch Rocket System

Both the A100 and PHL96 are derived from the Russian Smerch long-range MLRS, which was acquired by China in the mid-1990s.

Nuclear Weapons

China's nuclear weapon program received extensive assistance from the Soviet Union during its early stages. In 1955, the Soviet Union provided China with a cyclotron, a nuclear reactor, and fissionable material for research, provided plans and designs, and trained Chinese scientists in nuclear technology. This cooperation ended in 1959 with a breakdown in relations between the two.

Primacy of Demand Pull

In each of the case studies, the impetus for developing the technology arose from demands from the military or high-level leadership in response to perceived security needs. In no case study was there evidence that China's defense industry "pushed" unwanted or unneeded technologies or platforms to the People's Liberation Army (PLA). Even though the needs were generated by the military, it

did not necessarily have oversight or control of the program. The nuclear weapons program was overseen by a 15-member special commission composed of many of China's top leaders and run by the Defense Science and Technology Commission and the National Defense Industry Office, both of which were staffed with military officers but not strictly military organizations. Similarly, the J-10 was run by the Defense Industry Office and the Ministry of Aviation, not the military. According to Andrew Erickson et al.,

This caused many problems, including products failing to meet end-users' needs, and unrealistic technical demands imposed by the designated agency.

It should be noted, however, that both of these programs were conducted before the establishment of the General Armament Department in 1998 and the current situation of military oversight of weapons programs is probably much changed.

J-10 Fighter Aircraft and Pterodactyl UAV

PLA Air Force Commander Zhang Tingfa proposed a next-generation fighter with equivalent capabilities of the U.S. F-16 to Deng Xiaoping in 1981. Deng Xiaoping then issued a command to pursue what would become the J-10 after discussions within the Central Military Commission (CMC). The CMC and the State Council approved the project in 1986.

The Pterodactyl UAV was initiated on the basis of a General Staff Department (GSD) decision around the year 2000 to build unmanned weapons to meet the requirements of fighting and winning a war under informatized conditions. The plethora of other Chinese UAV designs, however, suggests that these platforms are not all being built for the Chinese military. This increased competition could possibly result in improved UAV performance and more options for the PLA, which could help drive

UAV development through technology push factors, particularly in the realm of command and control systems for the aircraft and in sensor technology used to target weapon systems and gather intelligence.

Beidou Navigation Satellite System

The need for a satellite navigation system was first proposed by 863 Program founder Chen Fangyun in 1983, but was also heavily pushed by the GSD's Survey, Mapping, and Navigation Bureau. The bureau also appears to have played a critical role in technology development and continues to play a role in the development and utilization of Beidou as a military platform and civilian utility. In this role, the bureau may have served as the program management organization for Beidou, indicating a strong oversight role for the military.

Integrated Command Platform

The ICP was originated by the director of the GSD 61st Research Institute in response to a lack of information systems that could enable joint operations. The 61st Research Institute then became the lead organization for the development of ICP and supervised the work of commercial entities. This is the only technology program out of the seven case studies in which the military played a direct role in running the program and served effectively as the prime contractor.

Type 54 Frigate

Demand for the Type 54 frigate was based on the PLA Navy's need for a ship with better air defense capabilities and one that was less costly than the previous Type 053H3 frigate.

Multiple Launch Rocket System

It is suspected that the the A100 and PHL96 were developed to fill a PLA need for a fire support system that could provide coverage in the 40–300 kilometer range left unfilled by China's artillery and short range ballistic missiles. This range was needed to seize control of or suppress Taiwan-

held islands in the Taiwan Strait and to support amphibious operations on Taiwan itself.

Nuclear Weapons

The impetus for developing nuclear weapons came directly from Mao Zedong in response to a perception that the United States would use its nuclear arsenal to threaten China. China also did not want to be under the protection of a Soviet nuclear umbrella and chose instead to rely on its own nuclear deterrent.

Risk

Risk is a measure of a project's degree of difficulty and the ability of China's defense industry to take on advanced technology. The degree of risk was found to vary according to the program, with the nuclear weapons program being the most risky of the technologies examined and the ICP the least risky. With the exception of the nuclear weapons program and the J-10 fighter program, which were the most risky of the projects, China's defense industry demonstrated a risk-averse approach to technology development in these case studies. This has potential negative implications for China's ability to generate radical innovations with disruptive effects, which may be more technologically complex and inherently more risky.

J-10 Fighter Aircraft

The J-10, with its tailless delta canard, was an inherently risky design. The PLA Air Force purposefully chose such a design with the intention of having it outperform existing fighter aircraft. The acquisition, however, has exhibited a cautious approach, with limited numbers of aircraft purchased, indicating that the performance of the J-10 may not have met design requirements.

Beidou Navigation Satellite System

China used a risk-averse approach to develop the Beidou satellite navigation system. Beidou 1 was a two-satellite system that used a radio deter-

mination satellite system involving a ground station to provide positioning information. This system provided only regional coverage and was much less accurate and technically advanced than the U.S. global positioning system (GPS), but was within the technical and cost restraints imposed upon the space industry at the time. Not until Beidou 2 is fully operational in 2020 will China have a global navigation satellite system similar to GPS.

Integrated Command Platform

According to the ICP's chief designer, Wang Jianxin, the ICP was not technologically difficult, but it did require a full understanding of the military's requirements in order to be successful. As a result, the ICP is as much a program management success as a technological achievement and is thus a less risky technological proposition.

Type 54 Frigate

The Type 54 frigate, which possesses good, but not exceptional antisubmarine and air defense capabilities, represents a balance between capabilities, cost, speed of availability, and reliability. Consequently, a less risky approach was used with this vessel. As Gabe Collins et al. note:

In broader terms, the design of the Type 054A may be reflect a more general mindset in China's approach toward the design of naval vessels, one favoring "regular and measured strides" as opposed to "small, rapid steps" in terms of developing and deploying weapons and equipment. This is primarily conditioned upon a consideration of cost and the assumption that, in the long run, it is more costly to continually rush the best available equipment into service as it becomes available because it creates greater variation in capabilities between vessels and reduces economies of scale.

Nuclear Weapons

Mao's decision to develop nuclear weapons is the most risky of the

technologies examined. This decision led to a massive mobilization of resources, the creation of many new organizations, and the eventual development of a whole new industry that was overseen by the top leadership. The nuclear weapons program is one of the "two bombs, one satellite" programs and is often referred to as a model for how China's defense industry should organize and conduct large-scale, risky projects.

Foreign Military Sales

As Chinese weapons become more advanced, an indicator of their capability may be their acceptance in the international marketplace. Evidence from the four of the six case studies indicates that China's efforts at foreign military sales is a qualified success. China has sold a version of the J-10 and a modified version of the Type 54 frigate, designated the F-22P, to Pakistan. China has had more success with the less technologically complex MLRS. China has sold variants of the rocket system to Pakistan, Tanzania, Morocco, and Thailand.

Although it is not exporting Beidou satellite navigation and positioning satellites, China is seeking to export Beidou 2 receivers to open up civilian markets for Chinese satellite navigation products. It has signed agreements to set up Beidou ground stations in Brunei, Laos, Pakistan, Sri Lanka, and Thailand to help promote the spread of Beidou products.

DIRECTIONS FOR FUTURE RESEARCH

The framework used for this conference was recognized as a logical methodology for examining the RDA process. The focus of the framework on the RDA process rather than on RDA as a system raised questions among some participants on its broader utility for analyzing technology development beyond understanding the length of time it takes for China to develop weapons systems.

In the coming year, IGCC will conduct additional research on both the RDA process and on improving the framework for understanding technology development programs. In particular, IGCC will explore developing a comprehensive and more academically rigorous methodology for examining defense RDA that can be tested using case study methodology.

To this end, IGCC has commissioned a comprehensive literature review of existing frameworks that will evaluate technology programs at the industrial, firm, and program levels of analyses. Based on the results of this research, IGCC will then assess the comprehensiveness, commonalities, and differences of the various approaches and their suitability for use in analyzing R&D programs and will use these assessments to develop a comprehensive and universal methodology that can be used to analyze technology programs.

IGCC has also commissioned research to assess the evolution of China's RDA process from the founding of the People's Republic of China in 1949 to the present, focusing in particular on the "two bombs, one satellite" period as the archetype of China's technology development programs. It will then look at the RDA process for more minor weapons programs. Finally, it will discuss the reforms of the RDA process that have occurred since the late 1990s as China has reformed its defense innovation system to produce more capable weapons and equipment.

IGCC will also conduct extensive research on the requirements process. All case studies completed for this conference identified the determination of requirements as the most important part of the RDA process. IGCC research will identify the different actors and their roles in the requirements process through additional case studies that range across multiple industries and time periods.