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The Research, Development, and Acquisition Process for the Beidou Navigation Satellite Programs

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The Beidou navigation satellite system is regarded as a strategic system intended to diminish Chinese reliance on the U.S. Global Positioning System (GPS). Support for Beidou, however, has not always been firm or universal. Early resistance was based on objections over the need to build a system when China was already benefiting from the free service provided by GPS. Financial hurdles also impeded progress on Beidou due to poor economic conditions and resource constraints resulting from priority being given to the human spaceflight program. Improved economic performance and a concomitant increase in funding and the widespread belief among the leadership that China must wean itself from foreign dependence, however, removed these impediments. Today, Beidou is regarded as a strategically important dual-use technology program that is first and foremost intended to enable the Chinese military to conduct modern war but is also recognized as supporting the development of a new commercial industry vital to China's national infrastructure.

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Of China's major defense technology projects, the Beidou satellite navigation programs may have the most far-reaching military, civil, and commercial implications. China's leaders not only recognize the importance of satellite navigation to the needs of a modern military and competitive economy, but also realize that China must develop its own satellite navigation system in order to reduce its dependence on the U.S. GPS system. As a result, Beidou is intended to provide the Chinese military with an independent, Chinese-operated system that enables precision-guided strikes, operations in distant theaters, and the integration of platforms and forces in the conduct of networked information warfare. Beidou will also provide an independent system for use by China's public infrastructure, utilities, and information and communications systems. Finally, Chinese policymakers expect Beidou to nurture domestic receiver and applications industries, offering consumers and industrial users alternatives to GPS-supported products.

THE BEIDOU PROGRAMS

China has two satellite navigation and positioning system programs: Beidou 1 and Beidou 2 (also known as COMPASS). Beidou 1 was made operational in 2003 and uses an active system comprised of two satellites in geostationary orbit, at least one ground station, and customer receiver/transmitters. Beidou 1 achieves accuracies of 20 meters and supports a short message service (SMS) in which users can send messages up to 120 characters long.

Beidou 2 will replace Beidou 1, but unlike Beidou 1, it will use a passive system similar to GPS. By the time it is completed in 2020, Beidou 2 will have 35 satellites, consisting of 25 in medium earth orbit (MEO), 5 in geostationary orbit (GEO), and 5 in inclined geosynchronous orbit (IGSO). The five GEO satellites will provide the same SMS function that Beidou 1 provides and, like other communication satellites, are placed in that orbit to provide the best global coverage. The five IGSO satellites are intended to reduce the "urban canyon" effect, whereby satellite signals are degraded or lost in dense urban areas. Today, Beidou 2 provides free-of-charge location, velocity, and timing services, with positioning accuracies of up to 10 meters.

The rationales and support for the Beidou programs have evolved as China's economic circumstances have changed. In the 1980s and 1990s, elite scientists and military officers joined to advocate building a simple satellite navigation system that could provide a regional service to meet national defense needs. The program was hindered by resource constraints and slowed by leaders who did not see a need to commit resources to build a system that would replace the free GPS service.

By the 2000s, circumstances had changed. Chinese leaders saw the logic of ending China's reliance on GPS and had begun to see the commercial potential of satellite navigation technologies. Importantly, the government now had the means to fund large technology development programs. The rationale for building a more capable, global second-generation system now lay not only in military needs, but also in its potential to drive national innovation by fostering new industries and strengthening national infrastructure. These new motivations are introducing new forms of collaboration based on civil-military integration, feasibility assessments based on commercial opportunities, and funding to foster industrial and technological development.

SPACE INDUSTRY RDA PROCESS

The RDA process used by the China Aerospace and Technology Corporation (CASC) for satellites is set out in official documentation called "Spacecraft Development Phasing and Procedure" (航天产品项目阶段划分和策划). These procedures are based on the procedures of other space R&D organizations, and, in fact, are very close to NASA's R&D process, but have been modified to take into account the characteristics of China's space program.

CASC divides its satellite RDA process into seven stages (see Figure 1):

1. During the ***mission requirement analysis stage*** (任务需求分析阶段) the client and the contractor analyze mission requirements and proposing initial requirements.
2. During the ***feasibility stage*** (可行性论证阶段) the contractor and the client finalize mission requirements, perform a preliminary analysis of the technological parameters, propose feasibility plans, and complete a feasibility report.
3. During the ***planning and design stage*** (方案设计阶段) the contractor selects a feasibility plan, tests the plan, and completes a preliminary design review (PDR).[1]
4. During the ***prototype research and manufacturing stage*** (初样研制阶段) the contractor obtains data through the design, analysis, and testing of technologies to ensure that the plan meets requirements and to verify that the technologies are feasible. Completion of this stage indicates that a critical design review (CDR) has been completed.[2]

1. A preliminary design (初步设计评审) review is conducted when system requirements have been approved, critical technology requirements have been issued, a plan has been selected, and a research and manufacturing plan has been determined.
2. A critical design review (关键设计评审) is conducted when detailed design activities have been completed, design data documents have already been completed and qualification test plans have already been formulated.

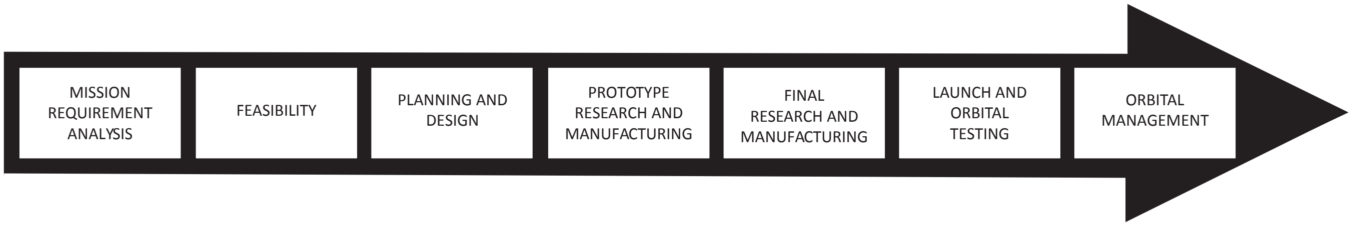

Figure 1. The seven stages of the satellite RDA process

5. During the ***final research and manufacturing stage*** (正样研制阶段) the contractor completes a design based on the preliminary research and manufacturing stage and begins manufacturing the satellite, testing the assembly and electronics, and environmental testing. Completion of this phase indicates that the satellite has gone through final factory and design approval.
6. During the ***launch and orbital testing stage*** (发射和在轨测试阶段) the satellite is transferred to the launch site and the launch team conducts a final inspection of the satellite. The satellite is then launched.
7. During the ***orbital management stage*** (在轨运行管理阶段) the satellite is operated in orbit.

The first two stages, the mission requirement analysis stage and the feasibility stage, make up the "project feasibility stage" (工程论证阶段). The planning and design, preliminary research and manufacturing, and the final research and manufacturing stages make up the "project research and manufacturing stage" (工程研制阶段). The launch and orbital testing and orbital management stages make up the "launch and application stage" (发射和应用阶段).

INNOVATION FACTORS

Several innovation factors shaped the course of the Beidou program. Early on, hard factors imposed the most significant constraints on the program's advancement. The most influential factor was funding. Limited budgets meant that the Beidou program could only obtain formal approval to advance to its prototyping stage only after resources were diverted from other programs. Tight budgets reflected both the nation's economic situation at the time and leaders' prioritization of the human spaceflight program. Limits on funds also impaired efforts to attract capable personnel.

Since then, as China's economy has grown, the resource constraint has softened. Chinese government spending of approximately $US 8 billion to upgrade Beidou to a 35-satellite global system is similar to what other countries are spending on similar systems. If this figure is accurate, it suggests that China's reputed cost advantages in space activities, such as launch vehicle manufacture, do not exist in the area of satellite navigation.

During the early stages of the program, soft factors also mattered at critical junctures. Advocacy and interventions by senior elites and prominent figures proved critical to advancing and continuing the program. One of China's most influential scientists, Qian Xuesen, the prominent scientist and 863 Program founder Chen Fangyun, and PLA officer Bu Qingjun of the Satellite Mapping and Navigation Bureau articulated the need for independent Chinese satellite navigation capabilities to top leaders and formed coalitions to secure approval of the program.

Another hard factor, technology transfer, has also played a role in Beidou's development. The most significant example appears to be the adoption or adaptation of foreign atomic clock technology. Although there is no evidence that Chinese instrument manufacturers have tried to reverse engineer the Swiss technology, such a possibility cannot be ruled out.

Technology transfer may also assist the commercialization of Beidou. In 2013 a leading developer of Beidou receivers, UniStrong, purchased the American high-precision technology business Hemisphere GPS. The transaction included all satellite navigation product lines and associated intellectual property, strengthening UniStrong's marine survey, construction, mapping, and original equipment manufacturing technologies and capacities.

TECHNOLOGICAL ADVANCES

Beidou's progress has benefited from advances in four technology areas critical to satellite navigation: atomic clocks, electromagnetic shielding, satellite antennas, and receivers.

Atomic Clocks

Perhaps the most important technology innovation for the Beidou program was the development of atomic clocks to provide precise positioning, navigation, and timing information. Improvements in these capabilities have improved Beidou 2's accuracy to 10 meters from 20 meters for Beidou 1. The first Beidou 2 M1 satellite reportedly only used Chinese clocks, but this satellite experienced problems with its timing mechanisms. Subsequent satellites use a combination of domestic and Swiss atomic clocks.

The China Aerospace Science and Industry Corporatsion's 203 Research Institute researches and builds the rubidium clocks that serve as the primary timing mechanism for Beidou with backup rubidium clocks supplied by the Swiss company SpectraTime. These clocks do not match the performance of GPS Block IIF clocks (first launched in 2010), but are competitive with older generations of GPS satellite frequency standards.

Electromagnetic Shielding

A possible example of independent technology development lies in electromagnetic shielding. This specialized, highly restricted, and critical component protects sensitive electronics aboard a satellite. In 2007, damaging electromagnetic interference degraded signals and threatened to derail the entire program. According to program officials, a team of defense university-based student engineers tackled and ultimately solved the problem, suggesting an innovative technology breakthrough.

Satellite Antennas

The Beidou program achieved a number of domestic firsts in antenna technology. Beidou 2 satellite antennas receive and transmit the timing signal and SMS data. According to one analysis, Beidou's signal properties have gradually improved and now have exceptional purity, suggesting successive upgrades in the satellites' antennas. Beidou's advances in this area include the first Chinese satellite to use a multibeam antenna, the first to use a domestic automatic level control, and the first to utilize an unfolding antenna.

Ground Receivers

The goal of developing capable, low-cost ground receivers continues to elude China's commercial manufacturers. Chinese-made receivers are costlier and have poorer performance than imports. Commercialization efforts aimed at developing Beidou only handsets and services, however, are at an early stage.

COMPARISON WITH GPS

Despite the technological advances mentioned above, China has realized little or no latecomer advantage in satellite navigation in terms of speed of development or performance. For example, by 2020, the planned start date for global operation, Beidou will have taken 34 years to complete. In comparison, the United States took 37 years to complete GPS, if the start of the Transit satellite navigation system in 1958 is used as a benchmark, or just 22 years if taken from the GPS start date of 1973.

Beidou is also inferior to GPS in terms of performance. Beidou's 10-meter accuracy falls short of the 7.6-meter accuracy provided by GPS Block II satellites first launched in 1989, and far short of the 3-meter accuracy provided by the current GPS IIF satellites. In fact, despite these official figures, most GPS users today actually enjoy accuracies of several centimeters, making the performance gap that much wider.

In addition, GPS satellites have longer service lives than Beidou 2 satellites. Beidou satellites have a service life of eight years. GPS Block I satellites (launched in 1978) had a service life of five years, but the current GPS Block IIF satellites have a service life of 12 years and this will be increased to 15 years with GPS Block III.

BEIDOU ACCEPTANCE

Despite technological progress, efforts to fully integrate Beidou into military, industrial, and commercial operations remain incomplete. Indeed, the system operates at just 15 percent of capacity. Beidou was originally designed to handle 800,000 users, but by 2012 had just 120,000 users and as late as 2010, GPS still had 95 percent of the Chinese navigation satellite receiver market. Moreover, the GPS client base transcends private individuals to include infrastructure vital to China's economy, including power generation, banking, transportation, and Internet systems.

Despite these challenges, the program has made progress in encouraging its adoption by military, government, and civilian users. During border patrols, for example, military units use Beidou for positioning and communication, but still appear to use GPS when needing more precise location data. Civilian government and industry are also reportedly increasingly using Beidou, including those in the financial and electrical power industries and fishing and forestry offices. Some of these users, however, have adopted Beidou because they have less demanding navigation and positioning requirements. Maritime agencies and commercial fisheries have been singled out as ideal customers who do not require the accuracy required by ground or air navigation users. Moreover, Beidou's SMS function appears to be more attractive to some users than its positioning and navigation functions. For instance, during the 2008 Wenchuan Earthquake rescue effort, press reports touted Beidou's SMS function rather than its ability to provide accurate positioning information.

CIVIL-MILITARY INTEGRATION

Civil-military integration (CMI) harnesses the innovative potential of commercial high-technology firms and the organizational strengths of the defense industry to benefit both. In practice, pursuing CMI consists of adopting measures to link the military, the defense scientific and industrial community, and the government through the transfer of technology and knowledge, the co-location of facilities, and the expansion of policy linkages between these three constituencies.

While Beidou is first and foremost intended to meet military requirements, its proponents are increasingly focused on its commercial potential. Beidou is now viewed as basic technological infrastructure upon which new and strategic emerging industries can develop. China's goal is to foster commercial firms that research, develop, and manufacture across the entire satellite navigation industrial chain—from chip technology through receivers to services for consumers.

Policymakers envision a CMI strategy as a means to shrink the gap between the near-universal utilization of GPS and the reluctant, piecemeal adoption of Beidou. This approach translates into measures aimed at improving innovation and competitiveness in the field of satellite navigation by establishing joint high-technology R&D, production, and applications centers; promoting investment in strategic and emerging industries; and encouraging the assimilation of foreign technology and the development of domestic technology.

China seeks to expand the commercialization of Beidou throughout the entire industrial chain, from chip manufacturing, navigation mapping technology, terminals/receivers, and system integration. Program officials believe the Beidou system and associated domestic companies will eventually develop competitive advantages over foreign companies in China's navigation market. By 2020, Beidou receivers must capture 70 percent of the market to offset the 60 billion yuan that is to be spent on Beidou by that point. The director of China Space Navigation Office asserts that a homegrown Beidou-supported applications industry can capture a 15 to 20 percent market share by 2015 and a 70 to 80 percent market share by 2020.

One of the most significant commercial markets is the upstream segment of chip manufacturing. However, this segment also features the highest barriers to entry due to the sophisticated technology required for manufacturing. Chinese-made Beidou chipsets are significantly more expensive than rival products, and currently more than 95 percent of terminals in China utilize the U.S. GPS system and GPS chipset. Indeed, the current Chinese low-cost leader for Beidou receivers is Beijing UniStrong Science and Technology Co., maker of a bare-bones receiver that costs several times more than a comparable GPS unit. Competition is also increasing, as foreign firms are beginning to add Beidou compatibility to their GPS receivers. Until they achieve significant breakthroughs in these respects, Chinese companies are likely to continue to focus on developing terminals, which typically utilize GPS chipsets.

The greatest source of competitive advantage for Beidou products is likely to be large government subsidies to nascent domestic technology firms. Government support for the commercialization of Beidou targets support at applications development in industrial parks, including financial and tax or fiscal subsidies to attract companies; low-cost state loans to satellite navigation-related industry; relaxed venture capital controls to allow more private investment in firms pursuing applications products; and, state procurement regulations favoring domestic companies holding Chinese technology patents.

CONCLUSIONS

Although information about the Beidou program is scarce, we can tentatively draw two major conclusions about innovation and China's RDA process. First, the program has achieved distinct forms of innovation across different products and technologies. For example, the initial development of atomic clock technology may have relied on duplicative or creative imitation, but may now be characterized by incremental innovation or a very modest improvement over existing technology. Some antenna technology may also be characterized by incremental innovation.

Second, the evolution of satellite navigation systems in China suggests that both hard and soft factors have shaped its course, their respective contributions varying over time. As resources grew more abundant, the general political environment became more supportive of science and technology development and large-scale space activities, a precondition for Beidou activity to advance from initial studies to production and launch. Leaders' commitment to upgrading military systems and shaking a reliance on foreign systems has also ensured their support for Beidou.

In parallel, the redefinition of Beidou as an element of larger economic strategies for developing commercial applications, reforming the defense conglomerates, and implementing civil-military integration has helped channel resources toward building and launching the satellites on a rapid schedule. These factors also make innovations in the areas of ground-receiver technology and applications far more probable than in the past and portend a satellite navigation industry that will be more competitive against its GPS counterparts.

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