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China's BeiDou: New Dimensions of Great Power Competition

Sarah Sewall
Tyler Vandenberg
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HARVARD Kennedy School
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for Science and International Affairs

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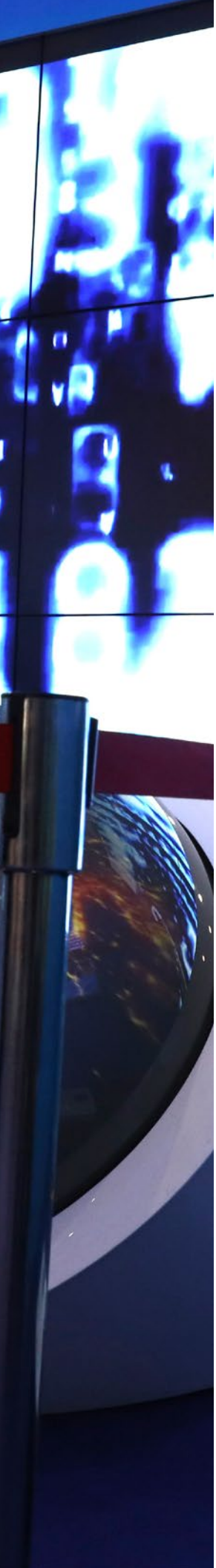
A child watches a video depicting the flow of digital information during the National Science and Technology Week exhibition held at the Military Museum in Beijing on Friday, May 24, 2019. (AP Photos/Ng Han Guan)



Executive Summary

BeiDou[1] is China's Global Navigation Satellite System (GNSS), which reached full global coverage for the first time in 2020. Like the pioneering U.S. Global Positioning System (GPS), BeiDou provides Positioning, Navigation, and Timing (PNT) data worldwide. BeiDou illustrates Beijing's strategic deployment of dual-use technology to enhance China's geopolitical power—a dynamic that increasingly shapes U.S.-China competition below the threshold of war.

Although Beijing developed BeiDou primarily for military purposes, the Chinese Communist Party (CCP) takes a broader view of GNSS capabilities and is encouraging foreign nations to rely on BeiDou for civilian uses. In several regions of the world, BeiDou and its supporting ground infrastructure provide the most accessible and accurate PNT data of any operating GNSS constellation. BeiDou thereby provides a foundation for Chinese infrastructure exports via the Belt and Road Initiative (BRI) and related Digital Silk Road (DSR) as well as consumer offerings. The integration of BeiDou's PNT data with ground station enhancements, 5G telecommunications, and critical infrastructure enhances China's soft power through political and economic relationships and the sale of Chinese technology. Beijing's export of this technology ecosystem may also pose specific security risks via technical manipulation or surveillance—including through BeiDou's noteworthy two-way messaging capability.

The United States and its international partners should evaluate more closely the effects of global reliance upon BeiDou and associated infrastructure and products. Such reliance may increase states' vulnerability to the Chinese government in ways that negatively affect U.S. interests and those of its democratic allies. Policymakers should consider how best to address and promote alternatives to Beijing's strategic use of GNSS commercial technology.

1 BeiDou is also referred to as the "BeiDou Navigation Satellite System," abbreviated to "BDS" by the Chinese government. BeiDou Navigation Satellite System, "System," 2022. http://en.beidou.gov.cn/SYSTEMS/System/.

I. Introduction

The United States in 1978 pioneered the deployment of what would become the first GNSS to provide PNT data worldwide. The United States' GPS was created for national security purposes, and it helped transform U.S. military capabilities to conduct precision warfare. The U.S. decision to make GPS data freely available to the public in turn spurred commercial innovation and economic growth.[2]

GPS has been called the "silent utility." It is easy to take for granted because it is both invisible and everywhere. PNT data allow text messages, phone calls, bank transactions, and photographs to be precisely timestamped and embedded with location data. Modern infrastructure, from transportation to financial services, relies on GPS. The growth of new industries such as self-driving cars and precision agriculture is driving demand for increasingly accurate and resilient PNT.

Since achieving global coverage in 1993 with 24 satellites, GPS has enjoyed a privileged role as the world's GNSS of choice.[3] Although the Soviet Union offered a second alternative, GLONASS, most users worldwide preferred the quality, availability, and reliability of GPS data. Providing a global "silent utility" helped maintain U.S. political, military, and economic relationships and influence. Yet while GPS is accessible everywhere in the world, not all regions have sufficient space- and ground-based infrastructure to calculate the type of precise positioning to which Western users are accustomed and upon which the next generation of PNT-enabled devices rely.[4]

The global GNSS landscape is changing. Europe's Galileo and China's BeiDou constellations have become the third and fourth GNSS, respectively, to offer free

2 From the 1980s until 2000, the U.S. government offered limited use of GPS signals to commercial actors. In 1983, the United States granted commercial airlines access to the GPS Standard Positioning Service. GPS signals were also offered publicly, though subject to "Selective Availability" which prevented nonmilitary users from receiving location data accurate enough for military purposes. In May 2000, the United States discontinued the use of Selective Availability to make GPS more responsive to commercial use. Mark Sullivan, "A Brief History of GPS," PCWorld, August 9, 2012, https://www.pcworld.com/article/461346/a-brief-history-of-gps.html; National Institute of Standards and Technology, "Economic Benefits of the Global Positioning System," June 2019, 2-1, https://www.nist.gov/system/files/documents/2020/02/06/gps_finalreport618.pdf.

3 The U.S. Space Force normally operates 31 GPS satellites, although only 24 GPS satellites are required to maintain global coverage. The additional seven satellites may increase GPS performance but are not considered part of the core constellation. Galileo and GLONASS each have 24+ satellites in orbit. GPS.gov, "Space Segment," June 28, 2022, https://www.gps.gov/systems/gps/space/; GPS.gov, "Other GNSS," October 19, 2021, https://www.gps.gov/systems/gnss.

4 Fumiko Sasaki, "A Risk-Benefit Analysis of China's Belt and Road Initiative Spatial Information Corridor," Air University, July 2022, 21, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/KP_02_Sasaki_A_Risk_Benefit_Analysis_of_Chinas_Belt_and_Road_Initiative_Spatial_Information_Corridor..pdf.

PNT data worldwide. Other states have deployed localized constellations and many governments are building new space programs.[5] Commercial satellites are proliferating and could create new paradigms and vulnerabilities for transmitting information to and from space. GNSS augmentation projects by national governments continue to increase the accuracy of PNT data. Innovative companies are creating new sources of PNT that could augment existing GNSS or stand alone. All these developments occur amid increasing U.S.-China competition and growing military and commercial interest in space.

The U.S. government considers the future of GNSS predominantly through a national defense lens: supporting – and preventing disruption of – military operations and national critical infrastructure. Department of Defense (DOD) plans for GPS modernization are not focused on advancing U.S. economic or diplomatic interests, nor does the U.S. government comprehensively assess the broader implications of other GNSS. Our interviews suggest that few U.S. policymakers are seeking to understand how the changing GNSS landscape, particularly the Chinese government's activities, might affect non-military dimensions of great power competition.

Beijing, on the other hand, recognizes that BeiDou's commercial applications can enhance the CCP's political, economic, and security goals. As part of a multi-dimensional, long-term strategy, Beijing uses BeiDou and associated infrastructure to promote diplomatic and economic ties, facilitate the sale of Chinese products, and potentially access user information and disrupt PNT data.

The BeiDou constellation has grown rapidly from 2000 to 2020, and is now the world's largest GNSS with 45 operational satellites.[6] As a result, BeiDou satellites are today more easily observed and provide more signals in most global capitals.[7] Beijing is supporting BeiDou overseas with additional ground infrastructure that monitors the system and improves data accuracy.[8] BeiDou also has advanced

5 Additional states have deployed smaller regional constellations, including Japan's Quasi-Zenith Satellite System (QZSS) and India's Regional Navigation Satellite System (IRNSS). European Union Agency for the Space Programme, "GNSS User Technology Report," 2020, 11, https://www.euspa.europa.eu/sites/default/files/uploads/technology_report_2020.pdf.

6 Changfeng Yang, "Directions 2022: BDS Enters New Era of Global Services," GPS World, January 14, 2022. https://www.gpsworld.com/directions-2022-bds-enters-new-era-of-global-services/.

7 Kazuhiro Kida et al., "China's Version of GPS Now Has More Satellites than US Original," Nikkei Asia, August 19, 2019, https://asia.nikkei.com/Business/China-tech/China-s-version-of-GPS-now-has-more-satellites-than-US-original.

8 State Council Information Office of the People's Republic of China, "'2021 China's Aerospace' White Paper (Full Text)" (《2021中国的航天》白皮⊠(全文)) January 28, 2022, Translation, http://www.gov.cn/zhengce/2022-01/28/content_5670920.htm.

signal features that GPS does not have—including two way-messaging—which could create commercial advantages as well as pose security risks.[9] As this dual-use technology improves and becomes intertwined with China's infrastructure exports and consumer products, BeiDou's global use will likely grow.

This paper explores BeiDou's role in great power competition short of war. Section II explains how a GNSS works, focusing on GPS, and discusses its benefits and vulnerabilities. Section III reviews BeiDou's origin and comparative features for civilian use. Section IV explores how the Chinese government is using BeiDou to advance its geopolitical aims abroad. Section V offers a conclusion and recommendations for U.S. policymakers.

9 BeiDou is distinct from other GNSS in featuring a two-way communication system, discussed further in section IV.

II. GNSS/GPS Overview

GNSS are constellations of Earth-orbiting satellites that provide PNT data to users on and above the Earth's surface. GNSS constitute an invisible critical infrastructure that is ubiquitous in everyday life, underpinning an array of commercial and national security services. Although governments provide PNT data without charge, most receivers that read transmitted GNSS signals are commercially manufactured. Over time, GNSS PNT data have come to be seen not just as vital military capabilities, but also as global public goods.

GNSS use a complex process of communicating calculations of timing and positioning. Simultaneous signals from three or more satellites allow a receiver to triangulate its exact position on the earth. The greater the number of observable GNSS satellites, the greater the accuracy of data. For this reason, the United States historically has encouraged international standards to make GNSS-enabled devices compatible and interoperable with multiple constellations. Multi-use receivers that gather data from multiple GNSS can also search for alternatives in the event of service disruption.

Nations manage their GNSS through a dedicated ground control system with supporting components deployed across the globe. A ground control system includes ground monitoring stations that track satellites, monitor their transmissions, correct their PNT data, and send commands to the constellation. Using atomic clocks, the ground monitoring stations enable correction of atmospherically distorted satellite data. In 2008, the United States expanded the GPS ground monitoring network from six to 16 stations, which helped improve GPS accuracy by 10-15 percent.[10] These ground monitoring stations are unevenly dispersed, however, and they are especially rare in the developing world.[11]

Governments seek to enhance PNT data accuracy because even marginal improvements can have significant implications for military, commercial, and "safety of life" purposes. The United States, the European Union, and China each operate three satellites in geostationary orbit to increase PNT accuracy and

10 GPS.gov, "Legacy Accuracy Improvement Initiative," September 11, 2020, https://www.gps.gov/systems/gps/control/L-AII/.

11 Nine of 16 GPS ground monitoring stations are located in advanced economies, with five in the United States alone. Two ground monitoring stations are in the African continent, two in South America, and none in Southeast Asia. GPS.gov, "GPS Control Segment," May 2017, https://www.gps.gov/multimedia/images/GPS-control-segment-map.pdf.

reliability in their home regions.[12] Governments and commercial firms can further improve PNT data accuracy in localized geographies through ground-based Continuously Operating Reference Stations (CORS). These systems typically observe all GNSS signals, estimate errors based on their known location, and provide this additional "error correction" to consumer receivers. The consumer receivers combine the additional information with their received GNSS signal to improve positioning accuracy.[13] The National Oceanic and Atmospheric Administration manages a network of 1,776 CORS in the United States.[14]

Modern GNSS are dual-use technologies. GPS offers a Precise Positioning Service strictly for military use, separate from GPS' Standard Positioning Service for civilian purposes. GLONASS and BeiDou similarly offer both military and civilian GNSS signals, whereas Galileo offers an encrypted signal for EU member state emergency services and police in addition to its civilian signal.[15]

Military and Economic Impact

GNSS-provided PNT data has become integral to modern military operations. The U.S. military in the 1980s was the first to use GNSS for precision targeting, helping enable what some described as a "revolution in military affairs."[16] Accurate real-time tracking and targeting have dramatically increased military lethality and effectiveness. GNSS also support highly integrated command and control. Without access to GNSS, modern militaries would be unable to maintain battlespace awareness, synchronize communications, and enhance precision operations for target location, weapons delivery, and logistical support—a fatal disadvantage against an adversary with access to GNSS.[17]

12 EU Agency for the Space Programme, "What is SBAS?" November 2, 2022, https://www.euspa.europa.eu/european-space/eu-space-programme/what-sbas.

13 Kevin Choi, "Current Status and the Future of CORS Network," National Oceanic and Atmospheric Administration, 2018, 2. https://www.gps.gov/cgsic/meetings/2018/choi.pdf.

14 National Geodetic Survey, "NGS CORS Map," https://geodesy.noaa.gov/cgi-cors/sort_cors2.prl.

15 European Union Agency for the Space Programme, "PRS," June 9, 2021. https://www.euspa.europa.eu/european-space/galileo/services/prs.

16 See, for example, Barry D. Watts, "The Maturing Revolution in Military Affairs," Center for Strategic and Budgetary Assessments, June 2, 2011, 15, https://csbaonline.org/uploads/documents/2011.06.02-Maturing-Revolution-In-Military-Affairs1.pdf.

17 U.S. Department of Defense, Strategy for the Department of Defense Positioning, Navigation, and Timing (PNT) Enterprise, November 2018, 12, https://rntfnd.org/wp-content/uploads/DoD-PNT-Strategy.pdf.

While GPS began as a defense investment, the United States gradually expanded civilian access to PNT data, thereby enhancing public safety, scientific exploration, and commercial innovation. In 2000, the U.S. government ended its practice of degrading civilian GPS signal.[18] The increased PNT data accuracy enabled new commercial applications in areas such as fishing, freight management, vehicle navigation, and logistics. Another major wave of innovation occurred after 2010 with the growth of mobile communications and wireless technologies using GNSS. From 1984 to 2017, GPS generated roughly $1.4 trillion in economic benefits for the U.S. economy, with about 90 percent of this figure based on mobile and wireless applications.[19]

GNSS Vulnerabilities

Because of their centrality to military operations, GNSS are expected to be targeted by anti-satellite and electromagnetic pulse weapons during conflict. The United States will aim to protect its GPS satellites and signal while degrading those of an adversary.[20]

The United States has concerns about the potential disruption of GPS signals during peacetime as well.[21] Such disruption could be highly damaging because U.S. critical infrastructure (from electrical grids to transportation networks) relies heavily on GPS. GPS is also vital for the U.S. economy and citizens' daily activities. A loss of GPS service could have a financial impact of up to $1 billion per day domestically, according to the U.S. National Institute of Standards and Technology.[22]

Attacks or disruption below the threshold of war could include jamming, spoofing, and natural interference. Jamming is possible because GNSS signals weaken as

18 The U.S. government's "Selective Availability" policy is explained in footnote 2 on page 2.

19 National Institute of Standards and Technology, "Economic Benefits of the Global Positioning System."

20 U.S. Department of Defense, "DOD Instruction 4650.08 Positioning, Navigation, and Timing and Navigation Warfare," December 2020, 3, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/465008p.pdf?ver=M9B-6zSt5uWSeDoPwocp_RQ%3D%3D; Lt. Col. Scott W. Beidleman, USAF, "GPS versus Galileo: Balancing for Position in Space," Air University, May 2006, 52, https://nsarchive.gwu.edu/sites/default/files/documents/6196458/National-Security-Archive-Lt-Col-Scott-W.pdf

21 U.S. Government Accountability Office, "DOD Is Developing Navigation Systems But Is Not Measuring Overall Progress," August 2022, 12, https://www.gao.gov/assets/gao-22-106010.pdf.

22 National Institute of Standards and Technology, "Economic Benefits of the Global Positioning System."

they reach the Earth's surface.[23] A hacker can blast radio frequencies to "drown out" a ground receiver's ability to find the GNSS signal.[24] North Korea jammed GPS signals in South Korea several times between 2010 and 2016, threatening the safety of civilian aircraft and vessels.[25] In 2018, Norway and Finland claimed that Russia jammed GPS signals during a lengthy NATO military drill.[26]

Parties can also "spoof" GNSS. Each GNSS satellite sends a unique code that identifies it. A hacker can pick up that incoming code and trick the GNSS receiver to accept the hacker as the originating source of the signal. The hacker can then provide inaccurate PNT data that misinforms the GNSS receiver.[27] The Russian military reportedly has spoofed GNSS receivers in eastern Ukraine and Syria.[28]

Finally, natural interferences can impair GNSS service. Naturally occurring solar flares and other disturbances can upset the earth's natural magnetic field and disrupt GNSS operation.[29] One solar flare in September 2017 impaired the transmission of GPS signals for four hours.[30]

The United States is focused on addressing the GPS vulnerabilities of the United States and its allies, predominantly during a conflict scenario. Yet as GNSS systems improve and as modern infrastructure and commercial products increasingly rely on the most accurate PNT, GNSS disruption could acquire broader significance in the gray zone of peacetime geopolitical competition. BeiDou, with its advanced signal features and enhanced accuracy, is increasingly embedded within foreign nations' infrastructure, potentially providing Beijing with new tools to distort, disrupt, or exploit PNT data.

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23 Paul Tullis, "GPS Is Easy to Hack, and the U.S. Has No Backup," Scientific American, December 1, 2019, https://www.scientificamerican.com/article/gps-is-easy-to-hack-and-the-u-s-has-no-backup/.

24 Vivek Mukherji and Aks Chandele, "GNSS Jamming: An Omnipresent Threat," Geospatial World, 2021, https://www.geospatialworld.net/prime/special-features/gnss-jamming-an-omnipresent-threat/.

25 Resilient Navigation and Timing Foundation, "Summary of GPS Jamming by North Korea, 2010 to April 5, 2016," 2020, https://rntfnd.org/wp-content/uploads/North-Korea-Jamming-summary.jpg.

26 Gerard O'Dwyer, "Finland, Norway Press Russia on Suspected GPS Jamming During NATO Drill," DefenseNews, November 16, 2018, https://www.defensenews.com/global/europe/2018/11/16/finland-norway-press-russia-on-suspected-gps-jamming-during-nato-drill/.

27 Paul Tullis, "GPS Is Easy to Hack, and the U.S. Has No Backup."

28 C4ADS, "Above Us Only Stars: Exposing GPS Spoofing in Russia and Syria," 2018, https://static1.squarespace.com/static/566ef8b4d8af107232d5358a/t/5c99488beb39314c45e782da/1553549492554/Above+Us+Only+Stars.pdf.

29 Septentrio, "Solar Wind Blows GNSS Off Course," https://www.septentrio.com/en/learn-more/insights/solar-wind-blows-gnss-course.

30 Ryan Mandelbaum, "Huge Solar Flare Disrupts GPS Satellites," Gizmodo, September 8, 2017, https://www.gizmodo.com.au/2017/09/huge-solar-flare-disrupts-gps-satellites/.

III. BeiDou Emerges

BeiDou is a tangible expression of China's sovereignty and the nation's ascent into the ranks of the world's great powers. CCP General Secretary Xi Jinping has called BeiDou "one of the most important achievements China has made in the 40 years of reform and opening."[31] Beijing regards its GNSS as critical for the nation's defense capabilities, domestic innovation, and economic growth.[32] PNT expert Dana Goward describes BeiDou as China's "declaration of technical independence from the West."[33]

BeiDou's development, economic impact, and global adoption have been impressive. The Chinese government began work toward a GNSS in the 1980s, seeking its own version of this vital defense capability. Chinese strategists' convictions about the military importance of PNT data were reinforced by images of U.S. precision warfare during the 1991 Gulf War.[34] The "unforgettable humiliation" of relying on GPS for military purposes during the 1995–1996 Taiwan Strait Crisis further fueled Chinese efforts to obtain an independent GNSS.[35]

The first BeiDou satellites, initially launched in 2000, served only mainland China. By 2012, the Chinese government had launched its own next-generation PNT satellites serving the broader Asia-Pacific region and began promoting the foreign use of BeiDou.[36] The following year, smartphone manufacturers began incorporating

31 Sina Finance, "Beijing News: More Than Half of the World's Countries Have Begun to Use the BeiDou System" (新京报：全世界一半以上的国家已经开始使用北斗系统), July 31, 2020, Translation, https://finance.sina.com.cn/chanjing/cyxw/2020-07-31/doc-iivhvpwx8359033.shtml.

32 China Satellite Navigation Office, "Development of the BeiDou Navigation Satellite System," 2019, http://www.beidou.gov.cn/xt/gfxz/201912/P020191227430565455478.pdf.

33 Dana Goward, "BeiDou a Threat to the West, but Perhaps Not Individuals," GPS World, August 11, 2020, https://www.gpsworld.com/beidou-a-threat-to-the-west-but-perhaps-not-individuals/.

34 The Paper, "BeiDou System Is a 'Bright Sword' GPS" (北斗系统" 亮剑"GPS), June 24, 2020, Translation, https://www.thepaper.cn/newsDetail_forward_7969801.

35 According to a retired Chinese general, China's military concluded that an alleged disruption to GPS caused it to lose track of some ballistic missiles it fired into the Taiwan Strait during the 1995–1996 Taiwan Strait Crisis. This was "a great shame for [China's military]... an unforgettable humiliation. That's how we made up our mind to develop our own global [satellite] navigation and positioning system, no matter how huge the cost. BeiDou is a must for us. We learned the hard way." Kevin McCauley, "Putting Precision in Operations: BeiDou Satellite Navigation System," Jamestown Foundation, August 22, 2014, https://jamestown.org/program/putting-precision-in-operations-beidou-satellite-navigation-system/; Minnie Chan, "'Unforgettable Humiliation' Led to Development of GPS Equivalent," South China Morning Post, November 12, 2009, https://www.scmp.com/article/698161/unforgettable-humiliation-led-development-gps-equivalent.

36 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," National Defense University Joint Force Quarterly, April 14, 2022, 26, https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-105/jfq-105_23-31_Millner-Maksim-Huhmann.pdf?ver=URigiNO3M3gxp9rvEge1OA%3d%3d.

BeiDou signal into receivers and global industry began moving toward multi-GNSS chipsets.[37]

The first BeiDou third-generation satellites were launched in 2017 and the complete constellation of 30 BDS-3 satellites providing global coverage was fully deployed in 2020. They are significantly more reliable than previous generation satellites and offer more advanced signal features. In addition, the BeiDou constellation includes 15 second-generation BDS-2 satellites, fully deployed in 2012, that provide coverage in China and the Asia-Pacific region.[38] International standards bodies have approved BeiDou for civil aviation, maritime navigation, search and rescue and other uses, and BeiDou has become an important GNSS in nearly all consumer and higher-performance systems worldwide.[39]

To help BeiDou drive innovation within China, the CCP augmented BeiDou's accuracy at home via CORS and extensive 5G telecommunications networks.[40] This combination provides high-precision PNT data throughout mobile communication networks and was used to enhance the Beijing subway system.[41] The CCP also encourages companies to integrate BeiDou into new product development. For example, in 2020, the Chinese government reportedly urged domestic and foreign auto manufacturers to include BeiDou functionality in vehicles' onboard navigation systems within two years.[42]

CCP investment in BeiDou appears to be bolstering China's commerce, much as the U.S. development of GPS fueled U.S. economic growth. The output value of China's

37 Samsung and Qualcomm were the first to use BeiDou PNT data in their phones, beginning in 2013. GPS World, "Qualcomm Collaborates with Samsung to be First to Employ BeiDou for Location-Based Mobile Data," November 22, 2013, https://www.gpsworld.com/qualcomm-collaborates-with-samsung-to-be-first-to-employ-BeiDou-for-location-based-mobile-data/.

38 State Council of the People's Republic of China, "Factbox: Construction Timeline of BeiDou Navigation System," June 23, 2020. http://english.www.gov.cn/news/topnews/202006/23/content_WS5ef1e57fc6d0a6946639c98c.html.

39 International bodies that have ratified BeiDou include the International Maritime Organization (2014), the International Civil Aviation Organization (2020), the International Cospas-Sarsat Programme (2017), and the International Electrotechnical Commission (2020). Li Zuohu, "BeiDou Navigation Satellite System Construction and Development," UN International Committee on GNSS, October 10, 2022. https://www.unoosa.org/documents/pdf/icg/2022/ICG16/04.pdf.

40 While data on CORS deployed in China is limited, state-affiliated enterprise ComNav Technology in April 2021 reported having built nearly 1,100 of a planned 4,400 CORS stations across China. ComNav Technology, "Establishing a National Wide CORS in China: Challenging but Promising," April 16, 2021. https://www.comnavtech.com/news/251.html.

41 Deng Xiaoci, "China Launches Construction of First BeiDou-Empowering Subway Project in Beijing," Global Times, March 21, 2022, https://www.globaltimes.cn/page/202203/1256424.shtml; European Union Agency for the Space Programme, "GNSS User Technology Report".

42 Foreign auto manufacturers such as Volkswagen and Toyota are including BeiDou functionality in onboard navigation systems for vehicles sold in China. Bruce Einhorn and Dong Lyu, "China Is Building a $9 Billion Rival to the American-run GPS," Hindustan Times, August 20, 2022, https://tech.hindustantimes.com/tech/news/china-is-building-a-9-billion-rival-to-the-american-run-gps-story-jgB39ezqOhMaZJnBjIdyWP.html.

commercial space and navigation services industry has grown from $11.8 billion in 2012 to $68.3 billion in 2021, with speculation that it could reach $156 billion by 2025.[43] The CCP is counting on further advances. The 14th Five-Year Plan issued in April 2021 calls for BeiDou's "deepened promotion and commercial application" in communications, finance, energy, and civil aviation infrastructures.[44]

Beijing appears to have ambitious plans to improve BeiDou and its PNT data. A January 2022 government publication stated that Beijing intends to create a "ubiquitous, integrated and intelligent and comprehensive" national PNT system with "BeiDou at the core" by 2027.[45] An official at China's National Timing Service Center described the Chinese government's intentions to create a more comprehensive PNT architecture that could integrate legacy technology, such as Loran-C,[46] with low-earth orbit (LEO) satellites, new inertial sensors, and potential future technologies like quantum navigation.[47] Enhanced BeiDou capabilities would advance China's military and space policy objectives along with other national goals as discussed below.

Accurately assessing CCP intentions and capabilities regarding BeiDou is inherently challenging. Limited open-source information makes it difficult to evaluate BeiDou's technical capabilities and economic and security implications. For example, we were unable to confirm whether Chinese-manufactured receivers can prioritize BeiDou signals over those of other GNSS. Assessments of BeiDou also require distinguishing between the system's current capabilities and effects and its potential future capabilities and uses. This analysis, particularly concerning specific security threats,

43 This industry includes chipsets for GNSS receivers, navigation software, ground terminal equipment, and other GNSS products and services. Reuters, "China's Beidou navigation system to serve $156 bln home market by 2025," May 26, 2022. https://www.reuters.com/world/china/chinas-beidou-navigation-system-serve-156-bln-home-market-by-2025-2021-05-26; GNSS and LBS Association of China, "Association Releases '2022 White Paper on the Development of China's Satellite Navigation and Location Services Industry'" (中位协发布《2022中 国卫星导航与位置服务产业发展白皮书》), May 18, 2022, Translation, http://www.glac.org.cn/index.php?m=content&c=index&a=show&catid=1&id=8845.

44 Xinhua, "(Two Sessions Authorized Release) The 14th Five-Year Plan for National Economic and Social Development and the Long Range Objectives through 2035" ([两会受权发布] 中华人民共和国国民经济和社会发展第十四个五年 规划和 2035 年远景目标纲 要), March 12, 2021, Translation, http://www.xinhuanet.com/2021-03/13/c_1127205564.htm.

45 State Council Information Office of the People's Republic of China, "'2021 China's Aerospace' White Paper (Full Text)" (《2021中国的航天》白皮书（全文）) January 28, 2022, Translation, http://www.gov.cn/zhengce/2022-01/28/content_5670920.htm.

46 China has deployed Loran-C infrastructure chiefly along its eastern seaboard to support coastal and marine navigation and plans to expand its footprint. Wu Haitao et al., "The Loran-C Resource in China and its Potential Applications," Chinese Academy of Sciences, April 2018. https://rntfnd.org/wp-content/uploads/2018/04/China-eLoran.pdf.

47 Dana Goward, "China Leads World with Plan for 'Comprehensive' PNT," GPS World, November 15, 2019, https://www.gpsworld.com/china-leads-world-with-plan-for-comprehensive-pnt/; Mudan Su et al., "BeiDou Augmented Navigation from Low Earth Orbit Satellites," Sensors Journal, January 7, 2019, https://www.mdpi.com/1424-8220/19/1/198/htm.

is therefore inherently speculative. At the same time, any prudent assessment should be informed by contemporary Chinese government policies and actions, including the extensive use of non-military tools such as trade to exert coercive leverage for political gain.[48] Beijing has demonstrated its willingness to transform even nominally benign international dependencies into potent sources of national power.

IV. BeiDou's Role Abroad

Beijing is working to increase BeiDou's global availability and appeal and sell products that can take advantage of its advanced features. BeiDou was a latecomer to a GNSS ecosystem dominated by GPS, which has over 4 billion global users.[49] Although BeiDou became available outside China only a decade ago, it reportedly is used by more than one billion people in over 200 countries today.[50] BeiDou is available in parts of the world that GPS does not serve well and offers greater accuracy via Chinese-supplied ground monitoring stations and CORS. Additionally, through the BRI and DSR,[51] Beijing subsidizes the provision of foreign infrastructure such as railway systems and oil and gas pipelines that use BeiDou PNT data to operate.[52]

As BeiDou's availability expanded beyond China to other parts of Asia, Beijing began linking its PNT technology to infrastructure exports. China's first partnership, with Thailand in 2013, provided more than $300 million in BeiDou-supported disaster relief, power distribution, and transportation projects.[53] China initiated a similar effort with Pakistan the same year.[54]

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48 Over the past decade, for example, Beijing has subjected Australia, Canada, Japan, Norway, the Philippines, and South Korea to national economic boycotts or restricted their access to Chinese markets.

49 Dan Elliott, "Next-Generation of GPS Satellites Are Headed to Space," AP News, December 16, 2018, https://apnews.com/article/north-america-us-air-force-ap-top-news-denver-fl-state-wire-b05b1b6d22ec4058bf7419744205104b.

50 Gu Yekai, "China's BeiDou System Provides Global Users with High-Precision Positioning, Timing Services," People's Daily, April 12, 2022, http://en.people.cn/n3/2022/0412/c90000-10082730.html.

51 In the name of the BRI and DSR, Beijing facilitates the global export of Chinese technology and products. These interrelated initiatives feature large traditional and digital infrastructure projects supported by Chinese government subsidies and loans. For more, see OECD, "China's Belt and Road Initiative in the Global Trade, Investment, and Finance Landscape," 2018. https://www.oecd.org/finance/Chinas-Belt-and-Road-Initiative-in-the-global-trade-investment-and-finance-landscape.pdf and Jonathan Hillman, The Digital Silk Road: China's Quest to Wire the World and Win the Future (New York: Harper Collins, 2021).

52 China has spent some $800 billion in 120 countries on its BRI/DSR. Su-Lin Tan, "G-7's Infrastructure Plan Offers an Alternative to China's Belt and Road Initiative in a 'Deliberate Way,'" CNBC, June 28, 2022. https://www.cnbc.com/2022/06/28/new-g-7-infrastructure-plan-offers-alternative-to-china-belt-road-.html.

53 Ji Jin and Cheng Yingqi, "China to Share Satellite System with Thailand," China Daily, November 1, 2013, https://www.chinadaily.com.cn/china/2013-11/01/content_17072898.htm.

54 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," 26.

As BeiDou coverage expanded beyond Asia, Beijing launched additional scientific and research partnerships with universities and other private organizations, often working through regional forums such as the Arab League and the African Union.[55] The Chinese government encouraged research exchanges, offered technical training, and provided scholarships to study satellite navigation in China.[56]

The CCP now sees BeiDou, alongside Chinese 5G technology, as underpinning infrastructure projects for foreign governments via the BRI and DSR.[57] BeiDou is thus both an enabler of Chinese technology exports and a beneficiary of China's subsidized provision of BeiDou-supported receivers and associated infrastructure.

Cutting-Edge Accuracy

BeiDou's most obvious comparative advantage is a larger constellation that offers greater PNT data availability in many parts of the world. BeiDou satellites are more frequently observed than GPS satellites in 130 of 195 United Nations member countries and in more than 100 of the 137 BRI participating countries.[58] To support this network, China has built 120 worldwide ground monitoring stations abroad, whereas the United States has built just 11 abroad.[59]

55 For example, the PRC China-Arab States BDS/GNSS Center, launched in 2018 in Tunisia, arranges joint research, testing activities, and workshops highlighting BeiDou and Chinese PNT products. The Chinese government also established regional "BDS Cooperation Forums" with the African Union and Central Asian nations. Li Zuohu, "BeiDou Navigation Satellite System Construction and Development," Presentation to the International Committee on GNSS, October 10, 2022, https://www.unoosa.org/documents/pdf/icg/2022/ICG16/04.pdf; Geoff Wade, "BeiDou: China's New Satellite Navigation System," Parliament of Australia, February 26, 2015, https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/FlagPost/2015/February/Beidou_China_new_satellite_navigation_system.

56 Weng Jingnong, "Update of BDS/GNSS International Education and Capacity Building," Presentation to the 15th Meeting of the International Committee on Global Navigation Satellite Systems, September 2021, https://www.unoosa.org/documents/pdf/icg/2021/ICG15/WGC/icg15_wgc_03.pdf.

57 The Chinese government deemed satellite communications and telecommunications technologies "critical" to BRI because they support "key infrastructure" such as railways and ports. China's National Development and Reform Commission, "Guiding Opinions on the National Defense Science, Technology, and Industry Bureau of the NDRC on Accelerating the Construction and Application of the BRI Space Information Corridor" (国防科工局 发展改革委关于加快推进"一带一路"空间信息走廊建设与应用的指导意见), November 23, 2016. Translation. https://www.ndrc.gov.cn/fzggw/jgsj/kfs/sjdt/201611/t20161123_1086163.html?code=&state=123.

58 Kazuhiro Kida et al., "China's Version of GPS Now Has More Satellites than US Original."

59 Zhang Tong, "China's BeiDou Satellite Navigation System Gets a Stronger Foothold in the West," South China Morning Post, November 10, 2022, https://www.scmp.com/news/china/science/article/3199160/chinas-beidou-satellite-navigation-system-gets-stronger-foothold-west; Mark Andres, "Navigating the World," CKGSB Knowledge, March 15, 2021, https://english.ckgsb.edu.cn/knowledges/china-global-navigation-system-beidou/.

Beijing seeks to augment BeiDou's appeal by building CORS that enable receivers to attain up to centimeter-level accuracy within targeted areas.[60] To date, this has been done by Chinese companies (state-owned or nominally private) as part of a broader BRI agreement. Eleven sub-Saharan nations reportedly have received China's CORS.[61] Indonesia, Myanmar, Pakistan, and Saudi Arabia are said to have authorized China's installation of CORS.[62] While the total number of Chinese-constructed CORS in foreign countries is unclear, their deployment is notable in targeting developing economies in Africa and Southeast Asia. This is distinct from the United States, whose overseas CORS are placed mostly in developed economies.[63]

BeiDou's enhanced PNT accuracy helps China promote the sale of advanced infrastructure abroad. Consider the case of train control systems, which require high PNT accuracy for safety purposes.[64] At home, Chinese firms are building highly sophisticated train control systems, integrated with BeiDou and 5G and augmented by local ground monitoring stations.[65] In countries where China has augmented BeiDou's accuracy, Beijing can sell these more advanced systems in comprehensive packages.[66] These rail lines and train control systems can then be supplied with Chinese-built trains.[67] This illustrates how PNT data accuracy can support China's export of more advanced infrastructure.

Cutting-edge PNT is particularly important for emerging applications such as precision agriculture and autonomous driving. These are likely key areas of future economic growth. One observer described Beijing as marketing a vision of

60 Jana Robinson et al., "China Deploys BeiDou to Project Power and Influence," Prague Security Studies Institute, March 2021, https://www.pssi.cz/download/docs/8505_08-pssi-perspectives-china-deploys-beidou-to-project-power-and-influence-3.pdf.

61 Tracy Cozzens, "COMNAV Helps Bring GNSS Benefits to Africa," GPS World, February 17, 2022. https://www.gpsworld.com/comnav-helps-bring-gnss-benefits-to-africa/.

62 Fumiko Sasaki, "A Risk-Benefit Analysis of China's Belt and Road Initiative Spatial Information Corridor."

63 National Geodetic Survey, "NGS CORS Map," https://geodesy.noaa.gov/cgi-cors/sort_cors2.prl.

64 Yongchao Geng, "Performance Enhancement in BeiDou System – Integrity and Accuracy," Presentation to the International Committee on GNSS, October 20, 2010, https://www.unoosa.org/pdf/icg/2010/ICG5/wgB/02.pdf.

65 Global Times, "China to Build Smart Railway Network by 2035 Using 5G, BeiDou Navigation Satellite System," August 13, 2020, https://www.globaltimes.cn/content/1197628.shtml.

66 Council on Foreign Relations, "China's Approach to Development in Africa: A Case Study of Kenya's Standard Gauge Railway," October 13, 2021, https://www.cfr.org/sites/default/files/pdf/Otele_A%20Case%20Study%20of%20Kenya%E2%80%99s%20Standard%20Gauge%20Railway.pdf.

67 Dylan Gerstel, "It's a (Debt) Trap! Managing China-IMF Cooperation across the Belt and Road," Center for Strategic and International Studies, October 17, 2018, https://www.csis.org/npfp/its-debt-trap-managing-china-imf-cooperation-across-belt-and-road.

"completely self-sufficient technology infrastructure that anticipates life in the 21st century."[68]

Commercial Dependency

BRI technological and economic dependency pathways may become ingrained over time. Industries requiring cutting-edge accuracy may favor BeiDou-linked products and infrastructure and shape the wider consumer market of that country or region. Even if receivers accept signal from every GNSS, local familiarity with BeiDou and Chinese infrastructure could pave the way for adopting other Chinese products.[69] Over time, China's commercial relationships and products may create a feedback loop by which Western companies find it difficult to compete effectively in BRI-participating economies.

The evolution of GNSS standards could reinforce this possibility. The United States previously had pushed to make civilian GNSS open and interoperable, in part to maintain a level playing field for commercial competition. Beijing sees the value of shaping international technology standards to reinforce the "stickiness" of commercial relationships and create economic opportunities for Chinese interests.[70] Policy expert Namrata Goswami argues that BeiDou enables China "to challenge the centrality of the United States to form partnerships and alliances and to control the standards for 5G, information technology, mobile devices, self-driving cars and drones, and the broader Internet of Things (IoT)."[71]

The economic stakes are significant. The next generation of PNT-enabled innovation will support advanced applications with great economic and social impact. Companies that lead in these areas will reap economic benefits, just as U.S. companies enjoyed the benefits of leading in information technology. PNT data accuracy may prove an important factor in enabling national industry to dominate new markets. Commercial dynamics are unpredictable, of course. During the 1980s, the United States feared that Japan would come to dominate the global

68 Namrata Goswami, "The Economic and Military Impact of China's BeiDou Navigation System," Diplomat, July 1, 2020, https://thediplomat.com/2020/07/the-economic-and-military-impact-of-chinas-beidou-navigation-system/.

69 Jonathan Hillman, The Digital Silk Road: China's Quest to Wire the World and Win the Future (New York: Harper Collins, 2021), 180–181.

70 U.S.-China Economic and Security Review Commission, 2020 Annual Report to Congress, Chapter 1, Section 2, "The China Model: Return of the Middle Kingdom," November 2020, https://www.uscc.gov/sites/default/files/2020-12/Chapter_1_Section_2--The_China_Model-Return_of_the_Middle_Kingdom.pdf.

71 Namrata Goswami, "The Economic and Military Impact of China's BeiDou Navigation System."

memory chip industry.[72] Instead, Washington took policy actions to support U.S. industry and ultimately avoided losing a U.S. commercial advantage.

Nonetheless, BeiDou's role supporting China's export of critical infrastructure in foreign countries is an underappreciated dimension of geopolitical competition. One expert speculates: "Insofar as Chinese-constructed pipelines, power grids, and telecommunications networks rely on BeiDou or a successor Chinese system, recipient countries may find it almost impossible to separate themselves from the PRC, no matter what changes in government or relationships may occur."[73] This political dynamic can exist independently of the potential technical vulnerabilities that may accompany BeiDou.

Military Ties

Beijing also uses BeiDou to promote military ties and cooperation. In December 2018, China reportedly gave Pakistan access to BeiDou's military-grade PNT data to provide more precise guidance for missiles, ships, and aircraft.[74] Indian sources claim Pakistan now uses BeiDou exclusively for military and civil use, ending dependence on GPS.[75] In 2019, the Consultative Assembly of Saudi Arabia signed a draft memorandum of understanding with China to cooperate on the military use of BeiDou, although little is known publicly about any implementation of the agreement.[76] Iran and China signed a memorandum of understanding in March 2021 to form a "comprehensive strategic partnership," and Chinese military sources subsequently claimed that Iran had been granted access to BeiDou's military-grade signals.[77]

Beijing and Moscow have collaborated on the mutual development of their respective GNSS, organizing cooperation initiatives aimed at improving

72 Steve Lohr, "Maybe Japan Was Just a Warm-Up," New York Times, January 21, 2011. https://www.nytimes.com/2011/01/23/business/23japan.html

73 Dean Cheng, "Meeting China's Space Challenge," Heritage Foundation, June 14, 2022, https://www.heritage.org/asia/report/meeting-chinas-space-challenge.

74 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," 26.

75 Economic Times, "Pakistan Military to Use Chinese Navigation System BeiDou to Improve Interoperability," August 21, 2020, https://economictimes.indiatimes.com/news/defence/pakistan-military-to-use-chinese-navigation-system-beidou-to-improve-interoperability/articleshow/77675471.cms?from=mdr.

76 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," 26.

77 One Chinese military analyst wrote, "with the blessing of the BeiDou military system, Iran's combat effectiveness...will undoubtedly be greatly enhanced." Zhu Jiangming. "How Much Will China's Opening Up of BeiDou Help Iran's Missile Technology?" (中国开放北斗对伊朗导弹技术有多大帮助？) Southern People's Weekly, May 14, 2021. Translation, https://www.nfpeople.com/article/10661.

interoperability of their two systems.[78] Collaborations have included satellite monitoring and assessment as well as joint design of GNSS chipsets.[79] In 2022, Moscow and Beijing agreed to build ground monitoring stations within one another's borders to enhance functionality of their respective GNSS.[80] Their increased cooperation strengthens an alternative PNT ecosystem independent of the West.

While the point should not be overstated, it is conceivable that nations' political preferences, military ties, and/or economic dependencies eventually could lead to global bifurcation of GNSS ecosystems – with BeiDou and GLONASS representing one technological and ideological camp and GPS and Galileo another.

Two-Way Messaging

BeiDou offers more advanced signal features, including a two-way messaging function that could pose security risks. While other GNSS simply broadcast signals, BeiDou can send and accept messages. This means that BeiDou can identify the location of two-way messaging users. The CCP could use BeiDou to monitor individuals' locations, although the ability to do so at scale is currently constrained. BeiDou's capabilities to track and communicate with its global users will hinge upon the growth of commercial two-way messaging and upon future BeiDou augmentation (via ground monitoring stations and satellites).

BeiDou's two-way messaging feature is limited by several factors. First, it requires a dedicated receiver that is not yet widely available on the commercial market. Additionally, the messaging capacity is only 78 bytes of data per transmission or 1,200 Chinese characters. Furthermore, two-way messaging requires access to ground monitoring stations that enable Radio Determination Satellite Service (RDSS). RDSS uses the round-trip time of signals from a BeiDou satellite to the ground monitoring station to compute a user's position.[81] Receivers with two-way messaging-can then relay this positioning back to the BeiDou satellite.[82]

78 Mark Stokes et al., "China's Space and Counterspace Capabilities and Activities," report prepared by the Project 2049 Institute for the U.S.-China Economic and Security Review Commission, March 30, 2020, 89, https://www.uscc.gov/sites/default/files/2020-05/China_Space_and_Counterspace_Activities.pdf.

79 Ibid

80 John Hardie, "China, Russia Deepen Partnership on Satellite Navigation," Foundation for Defense of Democracy, October 20, 2022, https://www.fdd.org/analysis/2022/10/20/china-russia-satellite-navigation/.

81 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," 26.

82 Ibid.

Even with these limitations, two-way messaging is useful for emergency communications. The Chinese government emphasizes the safety benefits of two-way messaging. More than 50,000 commercial Chinese fishing boats have installed BeiDou-enabled navigation systems with the two-way messaging feature.[83] Via this service, users can send alarms to China's Bureau of Fisheries and associated departments when emergencies arise. This function may not be used exclusively for safety purposes.[84]

Two-way messaging is valuable in emergencies because it enables users to relay their physical location data. This feature also could enable Chinese security services to track a specific individual's whereabouts without their consent. At present, though, BeiDou's inability to manage huge numbers of transmissions simultaneously prevents the use of two-way messaging for surveillance at scale.

BeiDou's two-way messaging function theoretically could enable implantation of malware onto a device.[85] However, experts consider widespread CCP hacking or spying through the system currently infeasible because of the small amount of data permitted per message.[86]

Yet the key factors currently limiting two-way messaging may disappear over time. Two-way communication devices appear poised to enter the mainstream commercial market. Huawei recently released its new Mate 50 cell phone with two-way communications receivers that connect to BeiDou's satellite network.[87] This feature enables communication even outside the range of cellular coverage, at no additional cost to the user (unlike commercial satellite communication services).[88]

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83 Geoff Wade, "BeiDou: China's New Satellite Navigation System," Parliament of Australia.

84 Given disputes over fishing rights in the South China Sea, Chinese fishing vessels could use emergency messaging to summon support from China's maritime militia. Jordan Wilson, "China's Alternative to GPS and Its Implications for the United States," U.S.-China Economic and Security Review Commission, January 5, 2017, 6, https://www.uscc.gov/sites/default/files/Research/Staff%20Report_China%27s%20Alternative%20to%20GPS%20and%20Implications%20for%20the%20United%20States.pdf.

85 Dana Goward, "BeiDou a Threat to the West, but Perhaps Not Individuals."

86 John Xie, "China's Rival to GPS Navigation Carries Big Risks," Voice of America, July 8, 2020, https://www.voanews.com/a/east-asia-pacific_voa-news-china_chinas-rival-gps-navigation-carries-big-risks/6192460.html.

87 Allison Johnson, "The First Phone Maker to Add Satellite Texting to Its Devices Is … Huawei," The Verge, September 6, 2022.

88 Chris Hall, "Satellite to Cellular: Everything You Need to Know about Satellite Communication on Smartphones, Including iPhone 14," Pocket Lint, September 8, 2022, https://www.pocket-lint.com/phones/news/162507-satellite-communication-smartphones-ntn-availability-specs-details.

Today, Huawei's two-way messaging service is available only in China, but the expansion of BeiDou ground monitoring stations abroad could support adoption of two-way messaging devices in other parts of the world.[89] One expert speculated that two-way messaging could become a standard tool for autonomous vehicles, informing an owner about required maintenance or receiving requests for assistance.[90] It appears likely that additional applications for two-way messaging will emerge, incentivizing further investment in BeiDou ground monitoring stations.

A third current limitation on two-way messaging could erode as Beijing implements its plans to modernize BeiDou. Chinese authorities are considering options to augment BeiDou with LEO satellites. LEO bandwidth could allow BeiDou to move more data, both in terms of the absolute number of transmissions and the data size of individual transmissions. This could transform Beijing's ability to track a small number of individual communications into a large-scale surveillance capability. It will be important to assess the evolution of commercial use of two-way messaging and BeiDou's ability to support the expansion of two-way messaging volume.

PNT Vulnerabilities

Separate from two-way messaging, BeiDou-supported technology may create additional security risks. Chinese-manufactured GNSS equipment could include malware or other cybersecurity vulnerabilities. Evidence of "backdoors" has appeared in BRI-related projects. For example, Huawei-installed computer systems at the African Union's headquarters transferred confidential information daily to servers in China between 2012 and 2017.[91]

By virtue of its authoritarian political system and national laws, the Chinese government can exert control over nominally private Chinese technology companies and exports.[92] These dynamics increase the risk that

89 Misha Liu, "Huawei's Latest Satellite Capability Launches China's BeiDou into the Global Smartphone Race," DigiTimes Asia, September 7, 2022, https://www.digitimes.com/news/a20220906VL204/beidou-huawei-mobile-devices-satellite-smartphone.html.

90 Interview with Dean Cheng, October 31, 2022.

91 Finite State, "Finite State Supply Chain Assessment: Huawei Technologies Co., Ltd.," June 2019, 5.

92 China's National intelligence Law requires all Chinese firms "to support, provide assistance, and cooperate in national intelligence work." The National People's Congress of the People's Republic of China, "PRC National Intelligence Law" (中华人民共和国国家情报法), June 12, 2018, Translation. http://www.npc.gov.cn/npc/c30834/201806/483221713dac4f31bda7f9d951108912.shtml.

Chinese-manufactured GNSS receivers, ground monitoring stations, or other BeiDou-related equipment could be remotely activated to disrupt the processing of PNT data.[93] This could especially affect infrastructure that relies on the most accurate PNT data, such as mass transit systems, electrical grids, and financial transaction systems that require precision timing. Analysts speculate that sourcing information and communications technology products from Chinese firms therefore presents cybersecurity risks.[94]

These vulnerabilities should be assessed in the context of broader Chinese security threats, however. China's military possesses advanced cyber warfare and hacking capabilities independent of its GNSS and associated systems. Additionally, many other aspects of Chinese technology infrastructure, including 5G systems and fiber optic cables, may enable CCP surveillance or geopolitical leverage.[95]

Reliance upon foreign-made technology infrastructure often is a modern reality. It is important that governments understand the potential implications of their technology choices. Few national leaders will be concerned primarily about the geopolitical ramifications of decisions they regard as essential for economic development and modernization. Even the potential impact of infrastructure dependencies on a state's sovereignty and national security may be overlooked as policymakers prioritize cost, financing, and convenience. It behooves democratic powers to ensure that other nations can make informed and meaningful technology choices.

V. Conclusion

BeiDou is a predictable manifestation of China's growing military, economic, and technological power. BeiDou can play a positive role in international affairs as a free global good, because access to multiple GNSS enhances the availability and accuracy of PNT data. BeiDou helps promote economic development within

93 David H. Millner et al., "BeiDou: China's GPS Challenger Takes Its Place on the World Stage," 26.

94 Tara Beeny et al., "Supply Chain Vulnerabilities from China in U.S. Federal Information and Communications Technology," Contracted Report prepared for the U.S.-China Economic and Security Review Commission, April 2018, 15, https://www.uscc.gov/sites/default/files/Research/Interos_Supply%20Chain%20Vulnerabilities%20from%20China%20in%20U.S.%20Federal%20ICT_final.pdf.

95 Sabena Siddiqui, "China's 'Belt and Road' Push Brings Risks, Rewards to Mideast," Al-Monitor, July 6, 2020, https:// www.al-monitor.com/originals/2020/07/china-mideast-gcc-beidou-gps-digital-silk-road-belt-road.html.

China and brings more reliable PNT and related infrastructure to the developing world.

Yet as this paper has argued, BeiDou and its associated ecosystem of CORS and receivers embedded in infrastructure and consumer products over time may undermine the national interests of the United States and partner nations. The United States is focused largely on the hard security implications of China's GNSS. BeiDou strengthens China's defense and space capabilities. It removes a potential source of U.S. leverage over China during conflict.[96] It provides China with greater freedom of military action and may increase incentives for attacks against U.S. and allied GNSS. In the military sphere, DOD monitors Chinese and Russian GNSS and adapts its plans and capabilities accordingly.

BeiDou's non-military implications are less well appreciated by U.S. policymakers. As BeiDou meets global PNT needs and BeiDou-linked infrastructure is sold abroad, Beijing reaps economic advantages and increases foreign political ties and potential leverage over other governments. These trends could intensify as nations become more reliant on automation and PNT data for critical infrastructure and commercial goods. BeiDou and BeiDou-linked technology can reinforce China's efforts to expand its sphere of global influence. In addition, BeiDou's two-way messaging over time could provide the technological means for global tracking of users' location data, and cybersecurity vulnerabilities inherent in Chinese manufactured technologies might enable the CCP to manipulate GNSS equipment (e.g., GNSS receivers, CORS) exported to BRI countries.

It is worth evaluating BeiDou in light of the U.S. experience with Huawei. The U.S. government was late to recognize the security risks posed by the Chinese company's export of 5G infrastructure. The initial American response was largely defensive: protect U.S. citizens and the homeland by banning (and requiring removal of) Chinese 5G equipment. The U.S. government also recognized that U.S. allies' use of Huawei 5G could compromise the integrity of sensitive communications. U.S. officials then sought with mixed success to dissuade other governments from adopting Chinese 5G components. Americans continue to face an uphill battle trying to convince other nations to forgo an affordable and effective next-generation technology.

96 This echoes China's promotion of alternative international payment systems that offer independence from Western-dominated sanctions. See Sarah Sewall and Ming Luo, "The Geopolitics of Digital Currency," Belfer Centre for Science and International Affairs, January 21, 2022, https://www.belfercenter.org/publication/geopolitics-digital-currency.

The analogy is imperfect, but at least two lessons emerge. First, protecting the U.S. homeland from China's dual-use technology is necessary, but insufficient, to secure the full range of U.S. interests related to Chinese technology exports. The U.S. government aims to defend GPS and promote PNT resilience, and Congress has barred China from building BeiDou ground monitoring stations in the United States.[97] Yet these actions will not address broader concerns about Chinese influence and security risks globally. A second lesson lies in the difficulty of dissuading foreign governments from adopting affordable, capable Chinese infrastructure, particularly in the absence of offering viable alternatives.

BeiDou underscores questions facing the United States and its democratic partners in a global competition increasingly defined by dual-use technologies and their role in advancing multiple aspects of national power. How can the West better anticipate when Chinese commercial technologies pose specific or generalized security risks to foreign countries? Might Western companies over time become locked out of economies built upon a Chinese technology foundation? Can the United States help foreign countries exercise meaningful choice regarding modernizing their infrastructure and maintaining political independence?

BeiDou may prove to be a contributing factor in a gradual but potentially seismic shift away from interoperable technologies and products, open trade and commercial competition, and shared platforms to exchange information, currency, and other fundamental components of international relations. It is in the U.S. interest to prevent such a shift, and to ensure that increasingly accurate PNT data remains a reliable and secure public good.

97 National Defense Authorization Act for Fiscal Year 2014 §2279, Pub. L. No. 113-66, 127 Stat. 973 (2013), codified at 10 U.S.C. §2281 (2013), https://www.congress.gov/113/plaws/publ66/PLAW-113publ66.pdf.

Recommendations

1. **Monitor** China's political, economic, and technological efforts to promote reliance on BeiDou, including the role of ground monitoring stations and CORS.
2. **Evaluate** specific security risks associated with BeiDou technology, BeiDou-linked infrastructure, and BeiDou's two-way messaging capabilities.
3. **Assess** the current and future impact of BeiDou and BeiDou-supported infrastructure upon U.S. diplomatic and commercial interests.
4. **Use** simulations to better understand how China's leaders could use BeiDou and related infrastructure as a tool of coercion below the threshold of armed conflict.
5. **Educate** nations on the potential vulnerabilities that could arise from reliance on BeiDou and related Chinese infrastructure and consumer products.
6. **Consider** how the U.S. government, with foreign partners, can expand alternatives for developing nations as they seek to modernize their digital infrastructure.
7. **Consult** with private sector actors about innovation and alternative technologies to meet the developing world's GNSS/PNT needs.
8. **Incorporate** findings from the above recommendations into U.S. plans for GPS modernization and next-generation PNT technologies.

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