The Scholar

Lost Seoul? Assessing Pyongyang's Other Deterrent

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For decades the North Korean military has fallen ever further behind its South Korean and US rivals. Unable to compete symmetrically on the battlefield, Pyongyang has enhanced its military's ability to coerce the South. In addition to its nuclear program, North Korea has enhanced its long-range artillery, which can rain down shells on Seoul. But does North Korea's artillery actually pose an existential threat to the South Korean capital? This article assesses the consequences of an artillery exchange on the Korean Peninsula. With the use of a new model that explores a range of scenarios, we find that North Korea's artillery is far weaker than its public perception. South Korea's military modernization, as well as its extensive civil defense preparations, have greatly reduced the threat of North Korean artillery. A war would be costly for both sides, but the losses in Seoul would be one to two orders of magnitude lower than common estimates. The good news is that if North Korean leaders understand their military frailty, they will be less likely to provoke a conflict. The growing danger, however, is that the weakening position of the North Korean military not only reduces crisis stability (especially the temptation for South Korea to strike first), but it also enhances the risks of nuclear escalation should conventional war erupt.

War has loomed over Northeast Asia since the Korean War ended in 1953. The ceasefire that halted the fighting left the Peninsula divided, and it saddled South Korea (also known as the Republic of Korea, or ROK) and its US ally with a difficult military problem. North Korea's large army remained poised just beyond the demilitarized zone (DMZ), a mere 30 kilometers from the northern edge of Seoul. The challenge for South Korea and the United States was stark: to build such robust defenses that they could halt a major invasion almost immediately—before North Korean forces could advance to the South Korean capital. But as the decades passed, the danger ebbed. The economies of South and North Korea diverged sharply, and the military balance shifted to favor the South. By the 1990s, many analysts concluded that the North Korean military, despite its large size, would be outmatched in a conflict.[1] And in the three decades that have passed since then, the military situation has grown more dire for the North. South Korea now fields a technologically advanced, twenty-first-century military. The North Korean army, on the other hand, is scraping to get by, with rudimentary training, poor health, and outdated equipment.[2]

1 Stuart Masaki, "The Korean Question: Assessing the Military Balance," *Security Studies* 4, no. 2 (Winter 1994/1995): 365–425; Nick Beldecos and Eric Heginbotham, "The Conventional Military Balance in Korea," Breakthroughs 4, no. 1 (1995): 1–9; Michael O'Hanlon, "Stopping a North Korean Invasion: Why Defending South Korea Is Easier than the Pentagon Thinks," *International Security* 22, no. 4 (Spring 1998): 135–70; J. J. Suh, "Blitzkrieg or Sitzkrieg? Assessing a Second Korean War," *Pacifica Review: Peace, Security & Global Change* 11, no. 2 (1999): 151–76; David C. Kang, "International Relations Theory and the Second Korean War," *International Studies Quarterly* 47, no. 3 (September 2003): 301–24.

2 On the state of North Korea's Korean People's Army (KPA), see James Hackett and Mark Fitzpatrick, eds., *The Conventional Military Balance on the Korean Peninsula* (IISS, 2018), 11–31; Kim Min-Seok, "The State of the North Korean Military," in Chung Min Lee and Kathryn Botto, eds., *Korea Net Assessment: Politicized Security and Unchanging Strategic Realities* (Carnegie Endowment for International Peace, 2020), 19–30; Ryo Hinata-Yamaguchi, *Defense Planning and Readiness of North Korea: Armed to Rule* (Routledge, 2021). On malnutrition and poor health in the KPA, see Elizabeth Shim, "Malnutrition in North Korea Military Forcing Parents to Supply Food," *UPI*, July 17, 2017, https://www.upi.com/Top_News/World-News/2017/07/17/Report-Malnutrition-in-North-Korea-military-forcing-parents-to-supply-food/2941500311067; Sofia Lotto Persio, "North Korea Has 1.2 Million Troops but Cannot Feed Them," *Newsweek*, August 24, 2017, https://www.newsweek.com/north-korea-cant-feed-all-its-12-million-soldiers-654732; Gabriela Bernal, "The Worsening Plight of North Korean Soldiers," *The Diplomat*, September 9, 2021, https://thediplomat.com/2021/09/the-worsening-plight-of-north-korean-soldiers/. On the state of the KPA, see Kim Min-Seok, "The State of the North Korean Military," Carnegie Endowment for International Peace, March 18, 2020, https://carnegieendowment.org/research/2020/03/korea-net-assessment-2020-politicized-security-and-unchanging-strategic-realities?lang=en.

The Democratic People's Republic of Korea (DPRK), however, has adapted. Rather than try to build forces to match South Korea on the battlefield, the North enhanced its capabilities to simply hurt the South—and hence advanced its ability to coerce its wealthy rival. In addition to acquiring nuclear weapons, North Korea expanded its long-range artillery which, deployed near the DMZ, can rain shells down on Seoul. The revamped North Korean threat, with its coercive artillery attacks backed by nuclear weapons, gives Pyongyang a tool for deterring, compelling, and terrorizing its neighbor—or so it seems. Has North Korea found a way to compensate for its inferior conventional military power? Or is North Korea's artillery—like the North Korean military more broadly—largely a paper tiger?

Many observers believe that the North Korean artillery threat to Seoul is fearsome.[3] In the popular media, headlines such as "200,000 Dead Without Using Nukes" and "250,000 Casualties in Just One Hour" are common, as are references to the North's ability to "flatten Seoul in the first half-hour of any confrontation."[4] Other reporting cites the North's ability to rain "up to 300,000 rounds on the South in the first hour" of a conflict.[5] Experienced analysts and government officials have echoed these concerns. For instance, Joseph Cirincione points to estimates that "hundreds of thousands of South Koreans would die in the first few hours of combat—from artillery, from rockets, [and] from short range missiles."[6] Researchers at the Congressional Research Service cite estimates that the North could inflict as many as 300,000 deaths in the first few days of fighting, using artillery alone.[7] The US Department of Defense has warned that an artillery barrage from North Korea could inflict 250,000 casualties in Seoul.[8] Specifically citing the artillery threat, retired US Marine Corps General and former Secretary of Defense James Mattis referred to a potential conflict on the Korean Peninsula as "probably the worst kind of fighting in most people's lifetimes."[9] And Steve Bannon, US President Donald Trump's chief strategist during the 2017 North Korea nuclear crisis, said in an interview from August of that year: "Until somebody solves the part of the equation that shows me that 10 million people in Seoul don't die in the first 30 minutes from conventional weapons . . . there's no military solution here, they got us."[10] Unfortunately, very few open-source, transparent analyses of an artillery campaign on the Korean Peninsula have been conducted to allow analysts to evaluate those estimates, and those that exist are dated and hence do not capture the impact of recent changes in the military balance.[11]

Below, we model a hypothetical North Korean artillery barrage on civilian targets in Seoul.[12] We consider three scenarios: *surprise* is a peacetime North Korean artillery attack; *crisis* is an attack that begins when both sides' forces are already on alert; and *preemption* is a crisis that triggers a conventional US-ROK Combined Forces Command (CFC) air strike on North Korean artillery—followed by the shelling of Seoul by residual North Korean forces. We model each of these scenarios twice. First, we use "nominal" values for the key variables, based on the questionable assumption that North Korean forces exhibit normal levels of skill and morale during

3 It is important to note, however, that not all analysts see the North Korean artillery threat in such dire terms. For example, see Prakash Menon and P. R. Shankar, "North Korea Can't Destroy Seoul with Artillery," *The National Interest*, January 5, 2018, https://nationalinterest.org/feature/north-korea-cant-destroy-seoul-artillery-23964; 김민석, "아이언돔 없는데 北이 장사정포 쏘면…현재 대책은 '안방 피난'," 중앙일보, May 19, 2021, https://www.joongang.co.kr/article/24061944.

4 David Axe, "250,000 Dead Without Using Nukes: Why Regular North Korean Artillery Is No Joke," *The National Interest*, March 24, 2020, https://nationalinterest.org/blog/buzz/250000-dead-without-using-nukes-why-regular-north-korean-artillery-no-joke-136812; Michael Peck, "North Korea's Artillery Could Inflict 200,000 Casualties in Just One Hour," *Forbes*, August 11, 2020, https://www.forbes.com/sites/michaelpeck/2020/08/11/north-koreas-artillery-could-inflict-200000-casualties-in-just-one-hour/?sh=4eed19546711; Tony Karon, "North Korea Planning a Nuke Test?" *Time*, April 24, 2003, https://web.archive.org/web/20220810201401/http://content.time.com/time/world/article/0,8599,446776,00.html.

5 Motoko Rich, "In North Korea, 'Surgical Strike' Could Spin into 'Worst Kind of Fighting,'" *The New York Times*, July 5, 2017, https://www.nytimes.com/2017/07/05/world/asia/north-korea-south-us-nuclear-war.html.

6 Joseph Cirincione, quoted in Zachary Cohen, "The Last Resort: How a US Strike on North Korea Could Play Out," *CNN*, August 11, 2017, https://www.cnn.com/2017/08/11/politics/us-north-korea-strike-first/index.html.

7 Kathleen J. McInnis et al., "The North Korean Nuclear Challenge: Military Options and Issues for Congress," *CRS Report for Congress* R44994, November 6, 2017, 18–19.

8 Jim Garamone, "North Korean 'Bolt from the Blue' Attack Remains a Concern," *American Forces Information Service,* October 26, 2006 (available behind paywall at https://www.proquest.com/).

9 James Mattis, quoted in "Defense Secretary James Mattis on 'Face the Nation,'" *CBS News*, May 28, 2017, https://www.cbsnews.com/news/transcript-defense-secretary-james-mattis-on-face-the-nation-may-28-2017/.

10 Robert Kuttner, "Steve Bannon, Unrepentant," *The American Prospect*, August 16, 2017, https://prospect.org/power/steve-bannon-unrepentant/.

11 The best open-source, fully transparent analysis of an artillery exchange in Korea was published in 2012, before the recent modernization of ROK and US counterbattery capabilities: Roger Cavazos, "Mind the Gap Between Rhetoric and Reality," *NAPSNet Special Reports*, June 26, 2012, https://nautilus.org/napsnet/napsnet-special-reports/mind-the-gap-between-rhetoric-and-reality/. Several recent analyses were published by the RAND Corporation, but they rely on data and models that are not publicly available. For one example, see D. Sean Barnett et al., *North Korean Conventional Artillery: A Means to Retaliate, Coerce, Deter, or Terrorize Populations* (RAND Corporation, 2020).

12 On campaign analysis, see Rachel Tecott and Andrew Halterman, "The Case for Campaign Analysis: A Method of Studying Military Operations," *International Security* 45, no. 4 (Spring 2021): 44–83.

the battle, and that their equipment functions well. Then we rerun the model using what we consider to be "realistic" assumptions—designed to reflect the decline in North Korea's military capabilities that has occurred over the past thirty years: obsolete equipment, unreliable munitions, poor maintenance, scant exercises, and substandard health conditions in even frontline North Korean units. Finally, we conduct extensive sensitivity analysis—including a Monte Carlo simulation—to identify the range of potential outcomes, given the wide range of plausible values for the key variables in the model.[13]

The chasm between CFC and North Korean capabilities means that if war erupts, leaders in Pyongyang may rapidly face pressure to employ nuclear weapons.

We find that North Korea's conventional artillery poses a much smaller threat to Seoul than most analysts claim. In what we deem to be the most plausible scenario—a North Korean attack during a major crisis—civilian fatalities in Seoul are estimated at approximately 2,600. Even in the worst-case situation for South Korea—a surprise attack by a surprisingly skilled and motivated North Korean force—the North would inflict only about 4,600 fatalities in Seoul before its long-range artillery was likely destroyed. If South Korea and the United States made the fateful decision to strike first in a crisis, we estimate civilian fatalities in Seoul would be far lower: between 700 and 1,100. Extensive sensitivity analysis and Monte Carlo simulations demonstrate that these estimates are robust across plausible variable values.

To be clear, the number of fatalities we are describing is horrific. Furthermore, the model only counts the dead—not the injured, the property damage, nor the global economic reverberations.[14] Nevertheless, the outcomes are one to two orders of magnitude smaller than the grim projections often circulated. Furthermore, this revised estimate—and the analysis that underpins it—makes five key contributions to debates over the balance of power and the costs of military conflict in Korea. First, our model is transparent and based on open-source data, which allows scrutiny and replication, in contrast to many previous studies. Second, our model incorporates two elements of an artillery war that are critical but understudied: the game-changing capabilities of modern counterbattery weapons, and the ability of Seoul residents to find shelter. Third, our analysis explores six distinct scenarios to explore how the war might start, and how effectively North Korea's forces might fight. Fourth, we test the robustness of our findings through extensive sensitivity analysis and simulation. And fifth, our results are sharply at odds with the existing consensus among media, policy, and scholarly communities, for reasons we explain further below.[15]

Our results have at least three important implications for South Korean and US defense policy. First, our analysis suggests that, thanks to its recent defense investments, the Republic of Korea military now possesses the weapons needed to defend Seoul from an artillery attack. It is critical, therefore, to attend to the details that would determine the actual outcome of an artillery battle: improving the CFC's intelligence, surveillance, and reconnaissance (ISR) capabilities; stockpiling munitions; enhancing rear-area security; and exercising the frontline forces whose performance—in difficult conditions—would determine how quickly North Korean artillery can be destroyed. Honing CFC counterbattery capabilities would not merely protect Seoul in time of war; it would hopefully deter conflict in the first place.

The second implication is more worrisome: The chasm between CFC and North Korean capabilities means that if war erupts, leaders in Pyongyang may rapidly face pressure to employ nuclear weapons. If a CFC counterbattery operation were to be as effective as our model projects, it might send frontline soldiers fleeing, risking the collapse of the North Korean army. In those circumstances, leaders in Pyongyang would face serious pressure to use nuclear threats to force

13 We would like to add a brief word here on the scope of our analysis. First, we focus on the effects of conventional high-explosive weapons, not chemical munitions, which if used would significantly increase the fatalities. Our analysis, therefore, sheds light on the incentives for North Korea to use chemical weapons in any major coercive operation against Seoul. Second, we model an attack on Seoul itself, not on the smaller cities and towns along the border. And third, for the purpose of generating a worst-case analysis, we assume that North Korea seeks to generate as many civilian fatalities as possible, and therefore aims the bulk of its long-range artillery at civilians rather than CFC military forces.

14 On modern wounded-to-killed ratios, see Tanisha M. Fazal, "Dead Wrong? Battle Deaths, Military Medicine, and Exaggerated Reports of War's Demise," *International Security* 39, no. 1 (Summer 2014): 95–125.

15 As we discuss below, our estimates are considerably lower than previous analyses for three primary reasons. First, our analysis is based on historical evidence from past cases of shelling and bombing in cities, which reveals that civilian losses tend to be far lower (per shell or per bomb) than is often assumed. Second, our study, unlike many previous studies, explicitly models the effects of modern US and ROK counter-artillery capabilities, which would rapidly suppress North Korean artillery. Finally, we consider South Korea's civil defense preparations, which are left out of most other studies.

a rapid halt to hostilities.[16] This possibility seems all the more concerning given the North's 2022 update to its nuclear doctrine, in which it explicitly adopted a first-use nuclear policy.[17] CFC planners, therefore, need to balance important military objectives (for example, destroying North Korean artillery) with crucial strategic goals (for example, avoiding wartime nuclear escalation).

Finally, our findings suggest that if there is a significant military crisis on the Peninsula, leaders in Seoul and Washington may face powerful incentives to strike first. The gap between the projected fatalities in a preemptive scenario (about 700) and those if North Korea struck first (about 2,600) may seem small to analysts conditioned to expect 100,000 fatalities in a North Korean artillery attack. But saving around two thousand lives, preventing thousands more wounded, and avoiding massive property and infrastructure damage in the country's capital are not trivial concerns. By highlighting this danger, we hope to encourage leaders in Pyongyang, Seoul, and Washington to avoid the sort of crisis that has plagued the Peninsula many times since the Korean War, but which—because of these escalation risks—is more dangerous today.

The remainder of this article has five sections. First, we describe the shifting balance of power on the Korean Peninsula and review existing analyses of the North Korean artillery threat. The second section describes the artillery forces deployed on the Peninsula and how they may be operated during a war. The third section describes our model, which tracks the consequences of North Korean strikes on Seoul, the effectiveness of CFC counterbattery operations, and the speed at which the civilian population in Seoul might find shelter. The fourth section presents our results, and the last section discusses the implications of our findings.

The Balance of Power on the Korean Peninsula

Over the decades, scholars and policy analysts have assessed the military balance on the Peninsula—often by evaluating the ability of North Korea to invade the South. By the mid-1990s, these analyses began to conclude that North Korea's forces—as numerous as they were—could not overcome their better-equipped South Korean neighbors.[18] In 1995, a study by Nick Beldecos and Eric Heginbotham found that "South Korean and US defenses [were] capable of thwarting an all-out offensive by the North."[19] A few years later, in 1998, Michael O'Hanlon agreed, concluding that "joint US-ROK forces are, with very high confidence, capable of stopping a DPRK attack cold."[20] An analysis by Jae-Jung Suh went even further, finding that "the ROK by itself is capable of stopping a North Korean invasion without losing much ground."[21] David Kang summarized these findings in 2003, arguing that to "view the North as superior in military terms is mistaken. . . . South Korea could defeat the North by itself."[22]

In the two decades since those studies, economic stagnation in the North has widened the gap between Pyongyang and Seoul even further.[23] Pyongyang's Korean People's Army (KPA) boasts 1.28 million active-duty personnel, yet it relies on obsolete military technology.[24] It is desperately short of basic maintenance items and fuel, hindering its ability to conduct exercises.[25] Even frontline units—those whom one would expect to receive the best supplies—are reportedly malnourished and beset by parasites and illness.[26] Meanwhile, the South Korean military has steadily modernized. Despite reducing the size of its forces, South Korea has invested heavily in new technology—including modern tanks, artillery, and uninhabited aerial vehicles

16 Keir A. Lieber and Daryl G. Press, "The Return of Nuclear Escalation: How America's Adversaries Have Hijacked Its Old Deterrence Strategy," *Foreign Affairs* 102, no. 6, (November/December 2023): 45–55; Keir A. Lieber and Daryl G. Press, "The Next Korean War," *Foreign Affairs*, April 1, 2013, https://www.foreignaffairs.com/articles/north-korea/2013-04-01/next-korean-war.

17 Kelsey Davenport, "North Korea Passes Nuclear Law," *Arms Control Today,* October 2022, https://www.armscontrol.org/act/2022-10/news/north-korea-passes-nuclear-law; Ellen Kim, "North Korea States It Will Never Give Up Nuclear Weapons," *CSIS: Critical Questions*, September 9, 2022, https://www.csis.org/analysis/north-korea-states-it-will-never-give-nuclear-weapons.

18 Masaki, "The Korean Question."

19 Beldecos and Heginbotham, "The Conventional Military Balance in Korea," 6.

20 O'Hanlon, "Stopping a North Korean Invasion," 139.

21 Suh, "Blitzkrieg or Sitzkrieg?" 153.

22 Kang, "International Relations Theory and the Second Korean War," 307.

23 For contemporary assessments of the North Korean military, see Hackett and Fitzpatrick, *The Conventional Military Balance on the Korean Peninsula*, 11–31; Kim, "The State of the North Korean Military," 19–30.

24 Kim, "The State of the North Korean Military," 19–21.

25 Hackett and Fitzpatrick, *The Conventional Military Balance on the Korean Peninsula*, 15; Hinata-Yamaguchi, *Defense Planning and Readiness of North Korea*, 159–160, 164–165.

26 Shim, "Malnutrition in North Korea Military Forcing Parents to Supply Food"; Persio, "North Korea Has 1.2 Million Troops but Cannot Feed Them"; Bernal, "The Worsening Plight of North Korean Soldiers."

(UAVs)—to extend its military advantages.[27] Unable to compete directly, North Korea has invested its limited resources in asymmetric capabilities such as nuclear weapons, chemical and biological weapons, cyber capabilities, and medium- and long-range artillery.

North Korea's nuclear and missile capabilities receive the bulk of the media, scholarly, and policy attention. The artillery threat, by contrast, has remained relatively understudied, and the analyses that exist tend to describe the terrible consequences that could arise from a war, without analyzing how likely those outcomes are.[28] A number of rigorous studies, however, have been conducted over the years.[29] One early examination of the problem, by Bruce Bennett of the RAND Corporation, finds that circa 1995 the KPA may have been capable of firing as many as 200,000 long-range rounds into South Korea on the first day of a conflict—and that even a short 3-to-5-minute artillery barrage into the Seoul metro area could cause as many as 7,500 civilian casualties—with the total fatalities rising much higher if North Korea continued the attack.[30] An analysis from 2012 by Roger Cavazos finds that a North Korean artillery attack on Seoul could produce around 30,000 fatalities.[31] And a recent study by researchers at RAND finds that an hour-long artillery barrage on Seoul would produce between 87,600 and 130,000 casualties, of which between 6,620 and 10,680 would be fatalities—with many more fatalities to come if the artillery bombardment continued.[32]

Each of these studies substantially adds to our understanding of this important question, but there are at least four reasons why additional analysis is needed. First, the recent RAND studies explain in general terms how their analysis is conducted, but the authors do not share complete models and data. The requirement to protect classified information is understandable, but without such transparency, other analysts cannot replicate their findings, nor adjust the inputs as facts change on the Peninsula. Second, previous models treat superficially two core aspects of an artillery attack on Seoul: the effectiveness of CFC counterbattery fire, and the ability of Seoul residents to find shelter.[33] The full incorporation of those two dynamics into the analysis—as we do with our model—has a major effect on the results. Third, existing studies conduct limited sensitivity analysis—varying the values of at most one or two variables. Given the large number of factors that could affect outcomes in a chaotic war, and the inherent uncertainty of combat, robust sensitivity analysis is required. Finally, the artillery balance is changing rapidly. The South Korean military continues to modernize; the KPA decays. The conventional view, even among military experts, has not kept up with changes in the military balance in Korea.

Artillery Forces Near the DMZ

Since the end of the Korean War, the Peninsula has been divided by a de facto border called the Military Demarcation Line (MDL). The MDL generally follows the 38-degree north latitude, but it dips slightly south of the "38th parallel" in the west and protrudes north of it in the east. On either side of the MDL is a 2-kilometer buffer known as the Demilitarized Zone (DMZ), which stretches across the Peninsula. Although the DMZ is largely free of military forces, the land just outside its boundaries is among the most heavily militarized locations in the world—filled with ground forces, mines, barriers, and fortified fighting positions.

From a military standpoint, the most significant feature of the Korean Peninsula is the proximity of the MDL to South Korea's capital. The northern neighborhoods of Seoul are only 30 kilometers from North

27 Ian Bowers and Henrik Stålhane Hiim, "Conventional Counterforce Dilemmas: South Korea's Deterrence Strategy and Stability on the Korean Peninsula," *International Security* 45, no. 3 (Winter 2020/21): 7–39.

28 "How North Korea Would Retaliate," *Stratfor*, May 2016, https://worldview.stratfor.com/article/how-north-korea-would-retaliate; Kyle Mizokami, "Could North Korea Annihilate Seoul with Its Artillery?" *RealClear Defense*, April 26, 2017, https://www.realcleardefense.com/articles/2017/04/26/could_north_korea_annihilate_seoul_with_its_artillery_111248.html; Franz-Stefan Gady, "What Would the Second Korean War Look Like?" *The Diplomat*, April 19, 2017, https://thediplomat.com/2017/04/what-would-the-second-korean-war-look-like/.

29 Michael O'Hanlon presents the basics of how to conduct such analyses: O'Hanlon, *Defense 101: Understanding the Military of Today and Tomorrow* (Cornell University Press, 2021), 123.

30 Bruce W. Bennett, "The Prospects for Conventional Conflict on the Korean Peninsula," *Korean Journal of Defense Analysis* 7, no. 1 (1995): 107, 119, 121. Note that Bennett estimates "losses" in South Korea, which he defines as "a combination of fatalities and incapacitating casualties" (119, note d). His results, therefore, are not directly comparable to our own.

31 Cavazos, "Mind the Gap Between Rhetoric and Reality," table 1.

32 Barnett et al., *North Korean Conventional Artillery*, 17. See also Michael J. Mazarr et al., *The Korean Peninsula: Three Dangerous Scenarios* (RAND Corporation, 2018), 8–14; Gian Gentile et al., *Four Problems on the Korean Peninsula: North Korea's Expanding Nuclear Capabilities Drive a Complex Set of Problems* (RAND Corporation, 2019), 6–10.

33 On counterbattery fire, the Cavazos study simply assumes that 1 percent of North Korea's artillery is destroyed for each hour of fighting. The recent RAND studies mention that they incorporated the effects of CFC counterbattery attacks—but how they do so is unspecified, and their results appear to be driven almost entirely by the effectiveness of the North Korean attacks. Similarly, on sheltering Cavazos assumes that half of Seoul's population will be sheltered in three hours without an underlying analysis. The most recent RAND study notes that it accounts in some manner for the South Korean population "taking cover and reducing their vulnerability," but it provides no detail beyond that statement. See Cavazos, "Mind the Gap Between Rhetoric and Reality"; Barnett et al., *North Korean Conventional Artillery*, 4.

Korean territory. As a result, the KPA's long-range artillery, positioned just north of the DMZ, can reach the political, economic, and cultural heart of South Korea.

North Korean Forces and Operations

The KPA is believed to have over 21,000 artillery pieces in its arsenal, but most of them lack the range to reach Seoul from North Korean territory.[34] Two principal artillery systems, however, do have sufficient range to reach the South Korean capital. The first is a large self-propelled gun called the Koksan.[35] With its large bore and long barrel, a Koksan can fire a standard shell up to 40 kilometers—which means there are a few firing positions just north of the DMZ from which Koksans can reach the northern neighborhoods of Seoul.[36] Koksans, however, can also fire rocket-assisted shells, which extend their range to 60 kilometers—albeit with reduced accuracy, less explosiveness per shell, and increased barrel wear.[37] North Korea's Koksans are typically deployed in batteries of five to six guns and they move and fire slowly: about 2 rounds every 5 minutes.[38] The other North Korean artillery systems that can reach Seoul are 240-millimeter multiple rocket launchers (MRLs)—clusters of rockets mounted on a truck chassis. These systems also operate in batteries of five to six launchers and can strike targets up to 40 to 60 kilometers away. MRLs fire salvos of 12 or 22 rockets in 1–2 minutes, and can pack up, move, and establish a new firing position quickly.[39]

Two recent RAND analyses credit the KPA with 432 Koksans and an equal number of 240-millimeter MRLs.[40] But, as the RAND studies suggest, only a fraction of those weapons would be available for an attack on Seoul. Some of North Korea's heavy artillery is deployed far from the DMZ (for example, near the border with China), some is near the DMZ but is too far west or east to strike Seoul, and some (as in every military) is out of service for maintenance. Approximately 70 percent of North Korea's major weapons are deployed in the DMZ region,[41] and we assume that about two-thirds of those along the DMZ are in the west, roughly north of Seoul. If we (generously) assume that 80 percent of North Korea's weapons are mechanically ready, then approximately 162 Koksans and 162 240-millimeter MRLs would be available for an attack on the capital.[42]

North Korea has built a network of what are known as Hardened Artillery Sites (HARTS) near the DMZ, approximately 170 to 200 of which are within 60 kilometers of Seoul.[43] The HARTS vary in terms of their sophistication and the protection they offer. Approximately two-thirds of the HARTS near Seoul are simple structures consisting of a barracks, aboveground sheds for the artillery, and a set of firing positions nearby. These HARTS offer some concealment, but little protection. The other one-third of HARTS are typically comprised of a barracks and a cluster of five to six *buried* shelters for the artillery. Those shelters are typically cut into a hillside and reportedly protected by dirt overhang, a concrete roof, and a metal door. It is unlikely that North Korea's long-range artillery can fire from within their protective structures. The deafening sound and concussive effects of firing large-caliber guns in a confined space, and the backblast generated by long range rockets, would make underground

34 *The Military Balance 2024* (Routledge, 2024), 282–83.

35 For a close look at the Koksan, see Joseph S. Bermudez, "The M-1978 and M-1989 170mm Self-Propelled Guns, Part I," *KPA Journal* 2, no. 6 (June 2011): 1–7; Joseph S. Bermudez, "The M-1978 and M-1989 170mm Self-Propelled Guns, Part II," *KPA Journal* 2, no. 7 (July 2011): 1–8.

36 The northern parts of Seoul are approximately 30 kilometers from the MDL, but when one adds the width of the DMZ, along with the need for North Korea's guns to stand back from the border as well as the dispersion of firing positions across the front, North Korean artillery would need a range greater than 40 kilometers to conduct realistic operations against the center of Seoul.

37 Bermudez, "The M-1978 and M-1989 170mm Self-Propelled Guns, Part I," 2; "M-1978 Koksan North Korean 170mm Self-Propelled Gun (SPG)," OE Data Integration Network (hereafter ODIN), Worldwide Equipment Guide (hereafter WEG), Department of the Army, 2021, https://odin.tradoc.army.mil/WEG. On the rocket-assisted shells, see Mike Fredenburg, "The 170 mm Koksan, North Korea's Not-So-Frightening Tool of Terror," *The National Review*, April 5, 2018), https://www.nationalreview.com/2018/04/north-korean-artillery-koksan-gun-could-be-inaccurate-unreliable/.

38 Bermudez, "The M-1978 and M-1989 170mm Self-Propelled Guns, Part I," 2; "M-1978 Koksan North Korean 170mm Self-Propelled Gun (SPG)," ODIN, WEG. On the typical battery size, see *Opposing Force Training Module: North Korean Military Forces*, FM 34-71 (Department of the Army, February 1982), 6-1.

39 For all of these specifications, see "M-1985 North Korean 240mm Multiple Rocket Launcher" and "M-1991 North Korean 240mm MRLS," ODIN, WEG, https://odin.tradoc.army.mil/WEG.

40 Gentile et al., *Four Problems on the Korean Peninsula*, 7; Barnett et al., *North Korean Conventional Artillery*, 14.

41 *Military and Security Developments Involving the Democratic People's Republic of Korea: Report to Congress* (Office of the Secretary of Defense, 2018), 9; 2022 *Defense White Paper* (Ministry of National Defense, The Republic of Korea, 2023), 26.

42 These totals—162 each for the Koksans and 240-millimeter MRLs—are the same figures that the recent RAND studies use, which suggests that their analysts made similar assumptions about the deployment locations and availability of North Korean artillery. See Gentile et al., *Four Problems on the Korean Peninsula*, 7; Barnett et al., *North Korean Conventional Artillery*, 16–17.

43 See appendix D, which is available online, for details and satellite images: https://doi.org/10.7910/DVN/86HBGS. We conducted an extensive inventory of 171 HARTS locations within 60 kilometers of Seoul using Google Earth Pro. HARTS locations based on "AccessDPRK 2021 Map," AccessDPRK, February 1, 2021, http://mynorthkorea.blogspot.com/2021/01/accessdprk-2021-map-free-version.html. These data are available in the article's supplementary materials. For a discussion of HARTS, see James Dennis, "DPRK Briefing Book: HARTS in North Korea," *The Nautilus Institute*, 1986, https://nautilus.org/publications/books/dprkbb/military/dprk-briefing-book-harts-in-north-korea/; *North Korean Tactics*, ATP 7-100.2 (Department of the Army, July 2020), 4-37 to 4-41, 7-23 to 7-24.

operations dangerous and possibly incapacitating for North Korean forces.[44] Nevertheless, because North Korea's artillery operating from HARTS can fire and then quickly roll back into their shelter, we assume that CFC counterbattery strikes must be aimed at the shelters—a difficult target.

From North Korea's perspective, the major advantage of dispersed, mobile artillery operations is the possibility of hiding them around the countryside.

North Korea has three main options for operating their artillery: They can operate from HARTS, disperse their forces throughout the area near the DMZ, or do a combination of both.[45] Several reasons explain why North Korea might prefer to operate from their HARTS: (1) the weapons would be concealed and (somewhat) protected while they were inside; (2) the weapons would be deployed with their supplies; (3) they would require less fuel; (4) command and control would be simpler; and (5) static operations from HARTS would not require as much initiative from low-ranking soldiers. The major disadvantage of operating from HARTS is that these facilities have been scrutinized by US and ROK reconnaissance for decades, and most have likely been slated for attack.

From North Korea's perspective, the major advantage of dispersed, mobile artillery operations is the possibility of hiding them around the countryside. With luck, many of their guns and rocket launchers would evade detection until they fired, and then could try to scoot away before counterbattery fire arrived at their position. The downsides of mobile operations are equally clear—they sacrifice the safety of hardened bunkers, and they accept the difficulties associated with operating a force on the move: keeping them armed, fueled, and maintained. Furthermore, shoot-and-scoot tactics place a premium on a rapid pace of operations—to relocate quickly before counterbattery fire arrives. The age and poor maintenance of North Korea's artillery make high-tempo operations difficult. To make matters worse, shoot-and-scoot tactics, like most mobile operations, put a premium on decentralized decision-making by junior officers within the dispersed units—a style of command that is anathema to North Korean training and military culture.[46] Faced with these alternatives, we assume that half of North Korea's MRLs operate from HARTS and half conduct mobile operations.[47] The Koksan guns, too slow for shoot-and-scoot operations, all operate from HARTS.[48]

Combined Forces Command Counterbattery Forces and Operations

South Korean and US artillery would play a central role in a CFC counterbattery operation.[49] The most lethal counterbattery weapons on the Korean Peninsula are the multiple launch rocket system (MLRS) launchers operated by ROK and US forces.[50] These launchers are superficially similar to North Korea's MRLs (described above)—that is, they are both vehicles armed with pods of rockets—but the resemblance ends there. Whereas North Korea's launchers fire unguided rockets, more than 80 percent of the CFC's MLRS can fire GPS-guided munitions.[51] And

44 Additionally, the large size of the Koksan guns (15 meters in length), and the need to elevate their 10-meter-long barrels to 45 degrees to achieve maximum range, means that only a very large shelter could accommodate the gun while firing. The existence of firing positions around most HARTS (see appendix D, https://doi.org/10.7910/DVN/86HBGS) supports our interpretation that the guns must be driven out of their shelters to fire. We thank Joseph Bermudez for a helpful conversation on this issue.

45 On North Korean artillery operations, see *North Korean Military Forces*, FM 34-71, 6-1 to 6-9; *North Korea Country Handbook* (Marine Corps Intelligence Activity, May 1997): 77–81, 98–99; *North Korean Tactics,* ATP 7-100.2, A-1 to A-4.

46 *North Korean Tactics*, ATP 7-100.2, A-3.

47 We vary the percentage of North Korean MRLs that operate from HARTS (versus conducting mobile operations) in our sensitivity analysis.

48 The Koksans fire slowly (two rounds in 5 minutes), pack up slowly after firing (up to 10 minutes), and move slowly (an offroad speed of 10 km/h). See "M-1978 Koksan North Korean 170mm Self-Propelled Gun (SPG)," ODIN, WEG. North Korea's rocket launchers, by comparison, can fire a volley of one to two dozen rockets in 45–90 seconds, and can be packed up quickly (in about 2 minutes), which can allow the chance to scoot them to safety before they are destroyed. See "M-1985 North Korean 240mm Multiple Rocket Launcher," ODIN, WEG; "M-1991 North Korean 240mm MRLS," ODIN, WEG.

49 Attacking North Korea's long-range guns and rockets would entail strikes on at least three hundred to four hundred aimpoints. Artillery, which can generate a large volume of fire, is ideally suited for such a mission. Furthermore, many of the counterbattery targets would be time-sensitive; on-call artillery would be the fastest option for striking them quickly.

50 Although the acronym MLRS (which stands for multiple launch rocket system) is formally used to describe the US-made M270/A1, for simplicity (and because of the weapons' similarity) we use the term to describe both those US-made weapons and the ROK-produced K239 Cheonmu system. We exclude South Korea's K136 launchers because their smaller munitions may not be effective against North Korea's HARTS. The counterbattery mission calls for weapons with precisely the characteristics of MLRS systems: long range (to reach KPA artillery positions all along the front), high accuracy (to destroy hardened sites), and the ability to generate a large volume of fire (to execute strikes against hundreds of distinct targets in a short time period).

51 The CFC's GPS-capable MLRS launchers include the ROK's 218 K239 launchers and 10 M270A1 launchers, and the US Army's 48 M270A1s on the Peninsula. The only CFC MLRS launchers that cannot conduct precision strikes are the 48 ROK M270s. See *The Military Balance* 2024, 51, 286–87.

whereas the North Korean MRLs are based on Cold War–era designs, the South Korean and US MLRS are modern weapon systems with advanced communications, computerized fire control systems, and modern chassis that allow them to maneuver soon after firing. The other critical CFC counterbattery weapons are the ROK's 155-millimeter self-propelled howitzers.[52] They too have computerized fire-control systems and can scoot away quickly after firing—before facing retaliation.[53] In our analysis, we mirror the availability of CFC artillery on the assumptions we used for the North: 80 percent mechanically ready and two-thirds in the vicinity of Seoul (as we will discuss below).

The third pillar of the CFC's counterbattery capabilities is its command-and-control system. South Korea operates dozens of counterbattery radars, which use the trajectory of incoming artillery shells to calculate their launch position.[54] These radars are essential for targeting North Korean artillery conducting mobile operations (that is, away from HARTS), because the mobile forces' location may not be known until they fire.

Just as North Korea would likely allocate some forces to HARTS and others to mobile operations, the CFC must assign some of its counterbattery weapons to destroy the HARTS, while holding others in reserve to strike mobile "targets of opportunity." We assume that the GPS-capable MLRS launchers are assigned to destroy HARTS, that unguided MLRS systems are used to attack North Korea's mobile artillery (by blanketing their launch areas with cluster munitions), and that self-propelled guns are used to deploy artillery-delivered mines around North Korean HARTS.[55]

Finally, if a crisis on the Peninsula convinces ROK and US leaders that war is likely, they may prefer to strike North Korea's artillery forces first. By utilizing US-based bombers and sea-launched cruise missiles (rather than Korea-based forces), the CFC could minimize the risk that preparations for a preemptive strike would be detected by the North. Our model of a preemptive attack scenario envisions a strike against the HARTS closest to Seoul using two squadrons of US bombers plus 120 cruise missiles from ships and submarines at sea.[56] Because a preemptive strike by the CFC would likely only be considered during a crisis, we assume that North Korea's mobile artillery are dispersed. The preemptive strike, therefore, only degrades the long-range artillery operating from HARTS, which leaves the dispersed forces (and those in HARTS that survive the missile strike) to retaliate. The key forces and missions are summarized in tables 1 and 2.

Type	Country	Model	Number	Missions
170mm gun	DPRK	Koksan	162	Strike Seoul from HARTS
240mm MRL		M-1985, M-1991	162	Divided between HARTS and mobile operations

Table 1. North Korea's long-range artillery and missions

52 South Korea owns approximately 2,400 self-propelled howitzers, including 1,300 new, indigenously produced K9 "Thunder." The K9 can fire a wide range of artillery shells—including high-explosives, cluster munitions, and mines—to a maximum range of 50 kilometers. See *The Military Balance* 2024, 286–87; "K9 Thunder Self-Propelled Howitzer," Hanwha Defense, 2019, https://www.hanwha-defense.co.kr/eng/products/firearms-system-k9.do; Oscar Widlund et al., *Jane's Land Warfare Platforms: Artillery & Air Defence, 2018–2019* (HIS Global Limited, 2018), 43–45.

53 "K9 Thunder Self-Propelled Howitzer"; Widlund et al., *Jane's Land Warfare Platforms*, 44–45.

54 See Jeff Jeong, "South Korea Develops Artillery-Locating Radar," *Defense News*, April 24, 2017, https://www.defensenews.com/industry/techwatch/2017/04/24/south-korea-develops-artillery-locating-radar/. South Korea's principal counterbattery radar systems are the AN/TPQ-37, the ARTHUR-K, and the TPQ-74K. See "AN/TPQ-37 American Firefinder Radar" ODIN, WEG; "ARTHUR Norwegian Counter-Battery Radar" ODIN, WEG.

55 We conservatively limit our analysis of CFC counterbattery capabilities to ROK and US artillery forces, given their availability for a relatively rapid response, and due to the large volume of fire they can generate. Other means, such as short-range tactical missiles and aircraft (crewed and uncrewed) could contribute to the counterbattery mission after some delay (more on this below).

56 We allocate 120 naval cruise missiles to the attack, which is twice the number the United States used in the comparatively minor 2017 strike on the Shayrat Airbase in Syria. With two squadrons of bombers (B-1s and B-52s), armed with 20–24 cruise missiles per plane, the strike would entail 650 missiles, enough to hit most shelters at the HARTS with two weapons each. On the strike on the Shayrat airbase, see Emma Graham-Harrison, "A Visual Guide to the US Missile Strikes on a Syrian Airbase," *The Guardian*, April 7, 2017, https://www.theguardian.com/world/2017/apr/07/visual-guide-us-airstrikes-on-syria-donald-trump.

Type	Country	Model	Number	Missions
Multiple launch rocket system (MLRS)	US	M270A1[a] (227mm)	48	Precision strikes versus HARTs
	ROK	K239 "Cheonmu"[a] (239mm)	145[c]	
		M270A1[a] (227mm)	7[c]	
	ROK	M270[b] (227mm)	32[c]	On-call for strikes versus mobile NK artillery
Self-propelled howitzer		K-9 "Thunder" (155mm)	867[c]	Deliver mines versus HARTS
Long-range bombers	US	B-1, B-52	24 bombers; 528 cruise missiles	Preemptive strikes versus HARTS (in preemption scenario only)
Naval land-attack cruise missiles	US	BGM-109 TLAM	120	

Table 2. Key CFC counterbattery forces and missions
[a] Capable of firing GPS-guided rockets.
[b] Older MLRS launchers that cannot fire precision-guided munitions.
[c] We assume that two-thirds of the ROK's total artillery forces are deployed in the vicinity of Seoul.
Source: The Military Balance 2024, 51, 286–87.

Model of an Artillery Campaign

The three main components of the model we created to explore an artillery exchange along the DMZ are depicted in figure 1. The first part, in the middle row, estimates the impact of North Korean artillery strikes on Seoul. The number of available North Korean artillery, multiplied by their rates of fire, multiplied by the lethality of each shot, yields a minute-by-minute estimate of the fatalities in Seoul. The second part of the model, shown in the top row, estimates the effects of CFC counterbattery fire, which reduces the number of available North Korean artillery over time. The third part, on the bottom row, estimates the speed at which civilians in Seoul find shelter, which reduces the population density in targeted areas, thereby decreasing the lethality of North Korean shots. We describe each of the three main components below.

Modeling North Korean Artillery Operations

There are reasons to be skeptical about the performance of North Korean forces.[57] Given their obsolete weaponry, poor maintenance, infrequent training, and poor health, it is unlikely that these forces will operate at the maximum level of efficiency that their weapons allow.[58] To account for this, we run our analysis twice for each scenario. In the "nominal" case, we assume

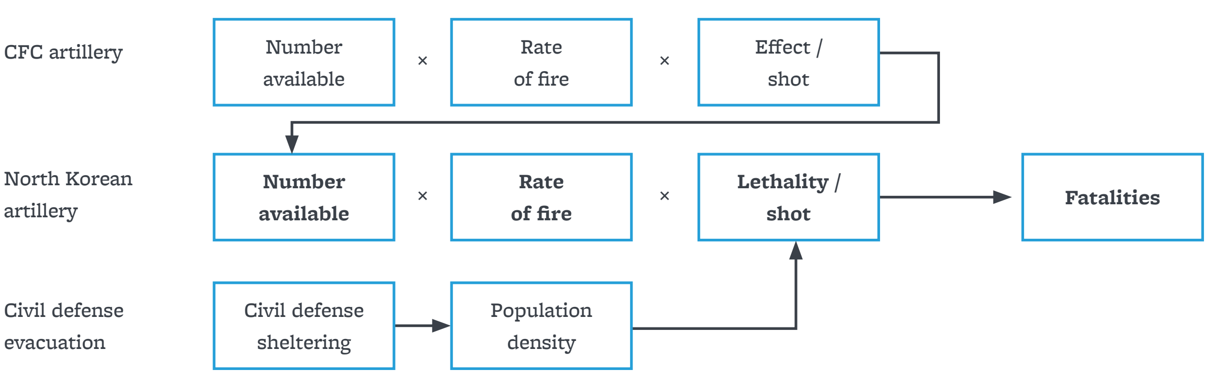


Figure 1. Model: simplified version

57 See appendix E (https://doi.org/10.7910/DVN/86HBGS) for full details on how we model North Korean operations.

58 One might compare the preparedness of North Korean forces to Iraq's frontline infantry in the 1991 Gulf War. Iraq's frontline infantry had the oldest weapons, most deficient training, and worst supply situation in the Iraqi military. Unlike better-equipped and better-trained units, the Iraqi frontline infantry collapsed at first contact with enemy forces. See Daryl G. Press, "The Myth of Airpower in the Persian Gulf War and the Future of Warfare," *International Security* 26, no. 2 (Fall 2001): 14, 16–17, 33–37.

that North Korean weapons work; that their soldiers sustain a normal rate of fire; and that their units fight until they have been destroyed entirely. In what we judge to be the more "realistic" runs, we assume that 25 percent of North Korea's shells and rockets are "duds" (which matches the rate observed during the North Korean shelling of Yeonpyeong Island in 2010)[59]; that key tasks required to fire their artillery take 50 percent longer than they do in the nominal case; and that KPA units collapse after taking 75 percent losses.[60]

Previous studies have made widely varying assumptions about the lethality of artillery in Seoul.

The last crucial element of the North Korean attack component of the model is the lethality of each round detonating in Seoul. This is estimated using formula 1:

$$fatalities = \pi \times (LR_{10})^2 \times (detonations) \times (population\ density) \times \frac{1}{1{,}000{,}000}$$

LR_{10} is the radius in which we expect 10 percent of people to be killed by a detonating round.[61] In open terrain, the lethal radius of a large-caliber shell or rocket is approximately 22 to 24 meters.[62] But in a city as dense as Seoul, the pressure waves from the explosion will be deflected by buildings, and people will be shielded from shrapnel by walls and other objects. Lethal radius will therefore be much smaller in an urban environment—but how much smaller?

Previous studies have made widely varying assumptions about the lethality of artillery in Seoul.[63] A recent RAND analysis presents a lethality-per-shot ratio that implies an LR_{10} of 6.5 to 7.5 meters.[64] On the other hand, a study by Roger Cavazos argues that each shell will kill *all* the people within 12 meters of the detonation—which is equivalent to an LR_{10} of 38 meters.[65] Because of the significant variation between these two estimates, we conducted our own analysis of historical cases in which one party employed artillery or air-delivered bombs against civilians in cities.[66] Our detailed examination of eight cases—six from the German "Blitz" on the United Kingdom (1940–41), plus artillery attacks during the Siege of Sarajevo (1992–94), and the Battle of Shuja'iya between Israeli forces and Hamas (2014)—reveal a scaled LR_{10} of the average bomb, rocket, or artillery shell that varied from 3 to 5.7 meters.[67] Despite these findings, and the data underpinning the RAND study, we took the very conservative step of assuming a LR_{10} of 10 meters, roughly twice as large as our historical analysis.

Finally, formula 1 incorporates the variable *population density*.[68] The average population density in Seoul is 16,136 people/km², but it varies across the city's neighborhoods.[69] North Korea may attempt to focus its fire on the densest parts of the city, but recent operations by KPA artillery suggest that their accuracy is too poor

59 Joseph S. Bermudez, "The Yonp'yong-do Incident, November 23, 2010," *38 North Special Report* 11–1, January 11, 2011, 11.

60 In reality, assuming that North Korean artillery will continue to fight until they take 75 percent losses gives the North Koreans considerable credit. In fact, the Center for Army Analysis Wargaming Analysis Model (C-WAM) rules state that an attacking force will withdraw after taking 50 percent losses and a defending force after taking 70 percent losses. Given their poor training and health, North Korean forces may collapse after suffering much lower levels of attrition. See Dan Mahoney, *The CAA Wargaming Analysis Model (C-WAM),* July 29, 2016, Version 7 (Center for Army Analysis), 59, available at Christopher A. Lawrence, "C-WAM 2," Mystics & Statistics Blog, Dupuy Institute, March 28, 2018, http://www.dupuyinstitute.org/blog/2018/03/28/c-wam-2/. For critiques of the idea of using casualties to predict a "breakpoint" in combat, see Robert McQuie, "Battle Outcomes: Casualty Rates as a Measure of Defeat," *Army 37,* no. 11 (November 1987): 30–35; Christopher A. Lawrence, *War by the Numbers: Understanding Conventional Combat* (Potomac Press, 2018), 288–89.

61 This formula is derived from Cavazos, "Mind the Gap Between Rhetoric and Reality." The first two terms in this formula, , are the area of a circle of radius LR10—meaning the area in which we expect 10 percent fatalities. By multiplying that by the number of detonations and the population density, we get total estimated fatalities.

62 These figures reflect the lethal radius of a 240-millimeter rocket and 155-millimeter high-explosive shell respectively. See Ove Dullum, *The Rocket Artillery Reference Book* (Norwegian Defense Research Establishment, June 2010), 64; and Howard Champion, John B. Holcomb, and Lee Ann Young, "Injuries from Explosions: Physics, Biophysics, Pathology, and Required Research Focus," *The Journal of Trauma* 66, no. 5 (May 2009): 1470. Estimates are similar (24.3 meters) for a 152-millimeter shell. See *Opposing Force Training Module*, 13-12.

63 To compare the estimates employed in previous studies we need a common unit of analysis; we therefore convert their measure of lethal radius to the measure we use (LR10) to facilitate comparison.

64 The details of the model used in the RAND analysis are not publicly available, but its data (number of shells fired, fatalities caused, and the areas targeted) can be employed using formula 1 to solve for LR_{10}. For the RAND study, see Barnett et al., *North Korean Conventional Artillery*, 12–13, 16–17.

65 Cavazos expresses lethal radius in terms of what we call "LR_{100}": the radius of the circle in which 100 percent of the people are killed. Cavazos's LR_{100} of 12 meters is mathematically equivalent to an LR_{10} of 38 meters (this is: 12 × 3.16 = 37.9). See Cavazos, "Mind the Gap Between Rhetoric and Reality."

66 See appendix B (https://doi.org/10.7910/DVN/86HBGS) for full details.

67 By "scaled" we mean scaled from the sizes of the munitions used in those historical cases to the size of the munitions used in a North Korean artillery contingency. Notably, the average high-explosive bomb dropped during the Blitz killed approximately 0.1 people; the average artillery shell used in Sarajevo and Shuja'iya killed approximately 0.06 people.

68 The last term in formula 1 divides by one million, because population density is in square kilometers, whereas lethal area is in square meters. There are one million square meters in a square kilometer.

69 Population density data for Seoul neighborhoods is from 서울시 인구밀도 (동별) 통계, 서울 열린데이터광장, 2022, https://data.seoul.go.kr/dataList/10584/S/2/datasetView.do.

to target particular neighborhoods accurately.[70] We assume, conservatively, that North Korea is accurate enough to focus its attacks on neighborhoods in Seoul that are at the 75th percentile of the city's population density (meaning 31,862/km^2, twice the city's average).

This, then, is the North Korean artillery attack component of the model: available North Korean artillery forces, firing at a given rate, and generating fatalities with each detonating round. For each minute that passes, the model calculates the number of new South Korean civilian fatalities and adds them to the total.

CFC Counterbattery Fire

The second component of the model, shown in the top row of figure 1, focuses on the US-ROK CFC's counterbattery mission.[71] It begins with the number of CFC artillery (see table 2).[72] Then the scenarios—surprise, crisis, and preemption—determine how much of the CFC artillery force is "on alert," and how long they take to respond to a North Korean attack. What these assumptions mean, as table 3 highlights, is that in any of the scenarios, only a small fraction of the CFC artillery force is available for the mission.[73]

MLRS rockets target the HARTS; MLRS launchers with unguided munitions are kept on standby to strike North Korea's dispersed mobile artillery using cluster munitions; and ROK howitzers blanket HARTS with mines.[74] We assume that each GPS-guided rocket can hit and render inoperable a HARTS shelter with 67 percent probability; using two rockets per target thus produces an 89 percent success rate.[75] We assume that mobile North Korean artillery who fire on South Korean positions are located with 50 percent success by CFC fire-finding radar, and that if on-call MLRS are available to respond, the North Korean batteries are destroyed by MLRS-delivered cluster munitions with a 67 percent success rate.[76] Finally, artillery-delivered mines are credited with a moderate effect on North Korean forces at those sites—suppressing operations at 25 percent of the targets that are mined.

Our modeling of a CFC preemptive strike on North Korean forces is comparatively simple. Given that such an operation is assumed to occur during a crisis, we assume that North Korean forces are alert and dispersed, meaning that only HARTS-based forces are subject to attack. We model an attack using two squadrons of US bombers (flown from US territory to avoid detection) firing stealthy air-launched cruise missiles, plus 120 cruise missiles fired by nearby US naval forces; in total

<table>
<tr><th>Scenario</th><th>Mechanical readiness (%)</th><th>Counterfires mission (%)</th><th>On alert (%)</th><th>Time to respond (minutes)</th><th>Cumulative available</th></tr>
<tr><td>1. Surprise</td><td rowspan="3">80</td><td rowspan="3">MLRS: 90
K-9: 67</td><td>25</td><td>15</td><td>MLRS: 42[a]
K-9: 116</td></tr>
<tr><td>2. Crisis</td><td rowspan="2">75</td><td>10</td><td>MLRS: 125[b]
K-9: 347</td></tr>
<tr><td>3. Preemption</td><td>0</td><td>MLRS: 125
K-9: 347</td></tr>
</table>

Table 3. CFC artillery availability across the three scenarios
[a] 36 GPS-guided MLRS (or GMLRS) and 6 MLRS.
[b] 108 GMLRS and 17 MLRS.

The next step in the counterbattery component of the model is the effectiveness of CFC fire. CFC artillery forces have three primary missions: GPS-guided

70 In the 2010 artillery strikes on Yeonpyeong Island, fewer than half (80 out of 170) of North Korea's shells struck the island, which is 7.4 km2, considerably larger than the average neighborhood (*dong*) in Seoul (which average 1.4 km^2). See Bermudez, "The Yonp'yong-do Incident," 3, 10.

71 See appendix F (https://doi.org/10.7910/DVN/86HBGS) for details on how we model CFC operations.

72 As noted above, we mirror the availability of CFC artillery on the assumptions we used for the North: 80 percent of CFC forces are assumed mechanically ready, and two-thirds of the ROK MLRS are near Seoul and can contribute to the counterbattery mission. As table 3 shows, we reduce CFC MLRS availability further, by assuming that despite the importance of this mission, only 90 percent of the available MLRS near Seoul are assigned to the counterbattery operation.

73 Note that in the preemptive scenario, CFC forces are available for counterbattery fire with zero delay. This hypothetical does not suggest that they were warned of the preemptive strike beforehand. Rather, it assumes that (in the preemption scenario) once cruise missiles begin to hit North Korean targets, CFC and North Korean artillery begin to ready themselves to fire. We assume they ready themselves equally quickly, so both forces are ready to fire at roughly the same time, reflecting zero delay for CFC relative to the North.

74 Other analysts have seen likely South Korean counterbattery artillery operations similarly, including 김민석, "아이언돔 없는데 北이 장사정포 쏘면…"; 차두현, "북한의 단거리 미사일/방사포 위협과 대응의 시급성," 아산정책연구원, 이슈브리프, December 10, 2021, https://www.asaninst.org/; 김강녕, "북한의 장사정포의 위협과 한국의 대응," 군사논단, 113권, 2023, 27–29, https://kiss.kstudy.com/Detail/Ar?key=4009778.

75 This is $1 - (1 - 0.67)^2 = 0.89$. Note that although open-source information on the capabilities of the K239 is sparse, modern MLRS such as the US M142 High Mobility Artillery Rocket System (HIMARS) can be programmed to hit multiple targets, and they can adjust their aim in just 16 seconds, which allows multiple aimpoints to be targeted with a single volley. We therefore assume that the K239 has this capability. See "M142 (HIMARS) American Artillery Rocket System," ODIN, WEG.

76 A lot of uncertainty exists around these and other variables, and we therefore examine fire-finding radar effectiveness rates as low as 25 percent and MLRS effectiveness versus mobile targets as low as 50 percent in sensitivity analysis.

this strike uses nearly enough weapons to hit each HARTS shelter twice. We attribute to the US cruise missiles the same effectiveness as we attribute to guided MLRS rockets—67 percent—which reflects their much larger warheads, but potentially lower probability of penetrating North Korean defenses.

This, in sum, is the CFC counterbattery component of the model: available CFC artillery, firing at a given rate, and destroying North Korean artillery with a given probability of success. For each minute of the model, these calculations are conducted and then fed into North Korea's available artillery for the subsequent minute.

Modeling Civil Defense

The third and final component of the model, shown in the bottom row of figure 1, focuses on civil defense evacuation.[77] Once it becomes apparent that Seoul is under attack, many of its residents will seek safety. The good news is that dense cities offer significant protection from high explosives. Buildings, walls, cars, and other structures absorb shrapnel. The stairwells in tall buildings, encased within a shell of reinforced concrete, function as large, vertical bunkers for the people evacuating. Furthermore, South Korea has enhanced the natural protection afforded by a major metropolis by building thousands of bomb shelters across Seoul and other cities, and holding nationwide civil defense drills annually.[78]

We model evacuation by using data on the location of the Seoul population over time (indoors, on the street, and in the subway system),[79] the size of Seoul's buildings,[80] and the density of civil defense shelters throughout the city.[81] The model tracks people's movement through the various steps from initial exposure toward protection using the following assumptions:

> *Seeking shelter: Only 75 percent of Seoul residents seek shelter once attacks begin*[82]
> *Shock: A delay of 2 minutes from initial impacts until civilians begin to move toward shelter*[83]
> *Evacuating floors: Up to 2 minutes for the people on a floor to move into the stairwell*[84]
> *Descending stairs: Up to 2 minutes to descend each flight of stairs*[85]
> *Walking to shelter: Up to 6 minutes to walk to a shelter*[86]
> *Entering the shelter: Up to 5 minutes to queue and enter the shelter*

Using this chain of conservative assumptions, 10 percent of Seoul's population will be protected by minute 5; one-third will be protected by minute 10; two-thirds by minute 20; and a full 75 percent of the population will be protected after 95 minutes. These numbers may sound fast, but partial protection is available for most South Koreans a few feet from their desks (in stairwells and parking structures), and nearly everyone in the city is only a couple hundred meters from a shelter. Seeking shelter during a crisis will undoubtedly involve panic and far-from-perfect execution of civil defense plans, but most who seek shelter will likely be able

77 See appendix C (https://doi.org/10.7910/DVN/86HBGS) for full details.

78 Seoul's residents have become accustomed to crises, so some reportedly take a lackadaisical attitude toward these drills. See Eun-Young Jeong, "South Koreans Know the Drill on Civil Defense—and They Don't Care," *The Wall Street Journal*, August 23, 2017, https://www.wsj.com/articles/south-koreans-know-the-drill-on-civil-defenseand-they-dont-care-1503487926.

79 For example, between 7:00 a.m. and 11:00 p.m., an average of 82 percent of the Seoul public are indoors, 15 percent are on the street, and 3 percent are in the subway. On the location of Seoul residents by hour, see Jinhyeon Park et al., "Spatial and Temporal Exposure Assessment to PM2.5 in a Community Using Sensor-Based Air Monitoring Instruments and Dynamic Population Distributions," *Atmosphere* 11, no. 12 (2020): 5–6. On the fraction of residents on the metro by hour, see 서울교통공사 2019년 일별 역별 시간대별 승하차인원, 2022, http://data.seoul.go.kr/dataList/OA-12921/F/1/datasetView.do.

80 "Buildings by Floor," KOrean Statistical Information Service (KOSIS), Statistics Korea, 2022, https://kosis.kr/eng/index/index.do.

81 On shelters in Seoul, see 민방위대피시설, LocalData, 행정안전부, 대한민국 정부, 2022, https://www.localdata.go.kr/devcenter/dataDown.do?menuNo=20001.

82 The South Korean government instructs the public to evacuate to underground shelters in case of war, but we assume that some people will prioritize finding their family rather than taking shelter. For South Korea's civil defense instructions, see "Emergency Procedures Manual," National Disaster and Safety Portal, Government of the Republic of Korea, 2019, http://eng.safekorea.go.kr/safeguide/selectSafeguidelist.do?searchLrgeclCd=COMM_01_04.

83 A two-minute delay from initial detonations before people begin to move toward safety is conservative (that is, it likely overstates the delay); this estimate accounts for panic at the outset of an attack—a phenomenon known as "pre-evacuation" in evacuation research.

84 Given that many stairwells are in the interior of buildings and are encased in concrete, we assume that the stairwells offer 25 percent protection to those that are descending them.

85 Data from sixty-two evacuations of buildings ranging from two to thirty-one floors show that it takes an average of 80 seconds per floor for people to descend by stairs. Two minutes (120 seconds) is the 80th percentile value in these evacuation data. Note that people would move more quickly in actual emergencies, making the two-minute assumption quite conservative. See Guylène Proulx, "Evacuation Time and Movement in Apartment Buildings," *Fire Safety Journal* 24, no. 3 (1995): 237; R. D. Peacock et al., "Overall and Local Movement Speeds During Fire Drill Evacuations in Buildings," *Safety Science* 50, no. 8 (October 2012): 1659; Erica D. Kuligowski et al., "Movement on Stairs During Building Evacuations," *NIST Technical Note*, no. 1839 (2015): 115; Maria Miñambres et al., "Study of Historical Evacuation Drill Data Combining Regression Analysis and Dimensionless Numbers," *PLoS ONE* 15, no. 5 (2020): 7.

86 Seoul has 3,224 civil defense shelters. Given the city's area (606 km^2), that is one shelter per 0.19 km^2. The average distance from any given point to a shelter is, therefore, about 250 meters. At a slow walking speed of 0.82 meters per second, this suggests 5 minutes, 5 seconds of walking time to the nearest shelter, which we round up to 6 minutes to account for any crowding and confusion. Note that in an emergency situation, most people would be traveling faster than a "slow walking speed." On walking speed, see Elaine M. Murtagh et al., "Outdoor Walking Speeds of Apparently Healthy Adults: A Systematic Review and Meta-Analysis," *Sports Medicine* 51, no. 1 (2021): 125.

to find it in less than half an hour.[87] The results of the civil defense model reduce the population density minute-by-minute, which through the calculations in formula 1 affects the number of people killed by each shell that detonates in Seoul.

Most importantly, because the overarching model—which encompasses North Korean attacks, CFC counterbattery fire, and the population of Seoul seeking shelter—involves many estimates and assumptions, we conduct extensive sensitivity analysis, described below, to determine how sensitive results are across the range of plausible values.

Results and Discussion

Figure 2 presents the main results from our model. As it shows, if North Korea strikes first and hits Seoul with all available long-range artillery, the attack would likely kill fewer than 3,000 civilians (assuming "realistic" variable values). This result holds regardless of whether the North Korean attack occurs as a surprise, or in the midst of an ongoing crisis. If, by contrast, we use the less-plausible "nominal" variable values (which, unlike the realistic values, do not penalize North Korea for poor training, maintenance, and morale), South Korean losses rise but still remain below 5,000. And if the CFC struck first during a crisis, losses in Seoul could be reduced to between 700 and 1,100.

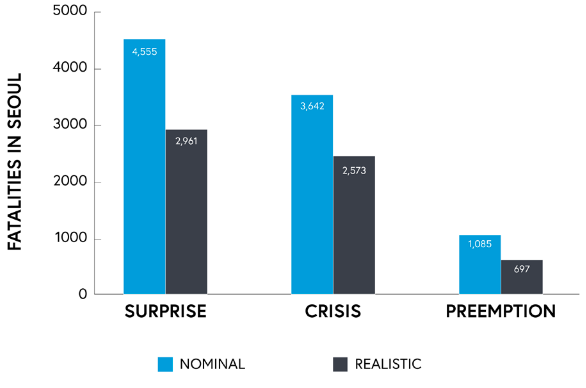


Figure 2. Estimated fatalities in Seoul by scenario. Figure by the authors.

Beyond crude body counts, we draw three main conclusions from our model. First, we discover large discrepancies between the conventional view of likely fatalities and our results. Across all three scenarios, we discover fatality levels that are between 9 and 10 percent of some of the highest-quality professional analyses, and between 2 to 3 percent of some popular assessments.[88] Second, we discover relatively large differences between the nominal and realistic variants of the model. Choosing realistic variable values produces estimates 30 to 35 percent lower than using nominal values. Third, by striking first during a crisis, the CFC might reduce its losses by more than 70 percent—which has important implications for crisis decision-making and crisis stability.[89] We link each of these findings to model output in the paragraphs below.

Figures 3A and 3B reveal the mechanics of the model at work, using the "realistic crisis" scenario as an illustration. Figure 3A shows the pace of North Korean fire and its impact on Seoul. In the first, terrible moments of the attack, North Korean artillery fires hundreds of rounds per minute (the light gray line), killing more than 2,000 civilians almost immediately (the black line). But then the North Korean attacks die down as their guns and MRLs reload and reposition. Their next major volley—35 minutes later—is much smaller and occurs after much of the South Korean population is sheltered, and thus far less vulnerable (as indicated by the sharp decline in fatalities per shot, reflected by the medium gray line).[90]

The reason the second North Korean volley is much smaller than the first is revealed in figure 3B. As the figure shows, North Korea's HART-based artillery (the black line) are rapidly destroyed or suppressed as soon as CFC counterbattery weapons are readied and begin to fire (which occurs at minute 10 in the crisis scenario).[91] North Korea's HART-based artillery are attritted so quickly in the model because their positions are known, they are stationary, and the CFC has enough available launchers to strike each of the hardened shelters *twice* without having to reload—and still have nearly half of the CFC's launchers

87 Note that we examine scenarios involving shares of the population seeking shelter as low as 60 percent in our sensitivity analysis, which would reflect a particularly chaotic and unsuccessful evacuation process.

88 Cavazos estimates approximately 30,000 South Korean civilians killed in an attack like the one we model. Our findings—from 2,600 to 3,000 fatalities—are 9–10 percent of those totals. Popular estimates of the consequences of an artillery barrage on Seoul often predict at least 100,000 fatalities—our estimates are about 2.6–3 percent of those figures. See Cavazos, "Mind the Gap Between Rhetoric and Reality." A recent RAND study estimates that 6,600 civilians would be killed in Seoul in a one-hour North Korean barrage—more than 2.5 times greater than our realistic crisis estimate. Furthermore, the RAND study suggests that North Korean forces could continue the attack beyond one hour, implying that the total ROK fatalities could be many times higher. By contrast we find that the North Korean barrage would be less than half as effective as the RAND study finds and, more importantly, that the North Korean artillery would, at the end of an hour, be largely destroyed. See Barnett et al., *North Korean Conventional Artillery*, 17.

89 Using "realistic" values, striking first during a crisis reduces expected fatalities from 2,573 to 697—a 73 percent decline.

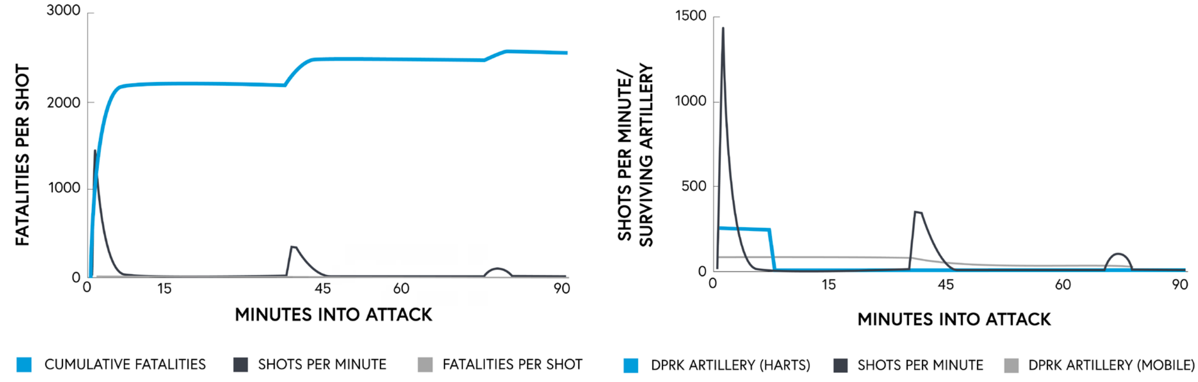
90 Alternatively North Korea could choose to fire a small fraction of its artillery in the first few minutes of war, doling out attacks gradually rather than unleashing a large initial barrage. That strategy, however, would cause fewer fatalities in Seoul, because it would give the population time to reach shelters, and it would allow the CFC to destroy the HART-based forces.

91 Note that DPRK artillery fall to zero at approximately 10 minutes—not necessarily because they are all destroyed, but because they reach the "breakpoint" of 75 percent losses.

available for other missions.[92] North Korea's mobile artillery (depicted by the light gray line) fare only slightly better; they survive to fire a second volley (around minute 37), at which point their numbers begin to fall. They then fire a third, much smaller, volley at around minute 75. Because (as a realistic scenario) it is assumed that North Korea's mobile forces collapse after suffering 75 percent losses, their mobile artillery stops firing after this third volley.

precision air strikes. Rather than using artillery to suppress enemy targets by beating them into submission with inaccurate but overwhelming firepower, the CFC has built the capability to target North Korean HARTS shelter-by-shelter.

To be clear, many CFC counterbattery strikes will fail, and actual operations always deviate from idealized war plans. But the results presented in figure 3A and 3B reflect outcomes that incorporate a large



Figures 3A–B. Results of the "realistic crisis" run of the model. Part A shows DPRK artillery shots and fatalities; part B shows DPRK artillery shots and survival. Figures by the authors.

What figures 3A and 3B reveal is that the difference between our results and those of other recent analyses is much greater than initially appears. For example, the 2020 RAND Corporation study posits 6,500 to 10,000 South Korean fatalities *in the first hour*—and suggests that North Korea could continue its attack on Seoul from there, implying much greater total losses. Our model predicts losses about one-third as high as the RAND study, but more importantly it suggests that after North Korean forces fired once or twice, the battle would essentially stop—Seoul's population would be sheltered, a large fraction of North Korea's long-range artillery would be destroyed, and CFC counterbattery forces would be mopping up the remaining long-range artillery that made the mistake of continuing to strike Seoul.[93]

At a deeper level, what these figures reveal is that the CFC is seeking to transform old-style counterbattery warfare into something that resembles modern number of conservative assumptions about CFC performance, such as fire-finding radars that only locate North Korean mobile artillery 50 percent of the time; GPS-guided MLRS rockets that only hit their targets 67 percent of the time; and MLRS systems that require 35 minutes to maneuver and reload after every launch.

Figures 3A and 3B also reveal one piece of bad news, however: There is not much that can be done by counterbattery fire to further reduce Seoul's vulnerability.[94] In the case of a major artillery strike on Seoul, nearly all the South Korean civilian fatalities would occur in the first few minutes of the attack, before most of Seoul's population can get to a shelter or CFC artillery can start to fire.

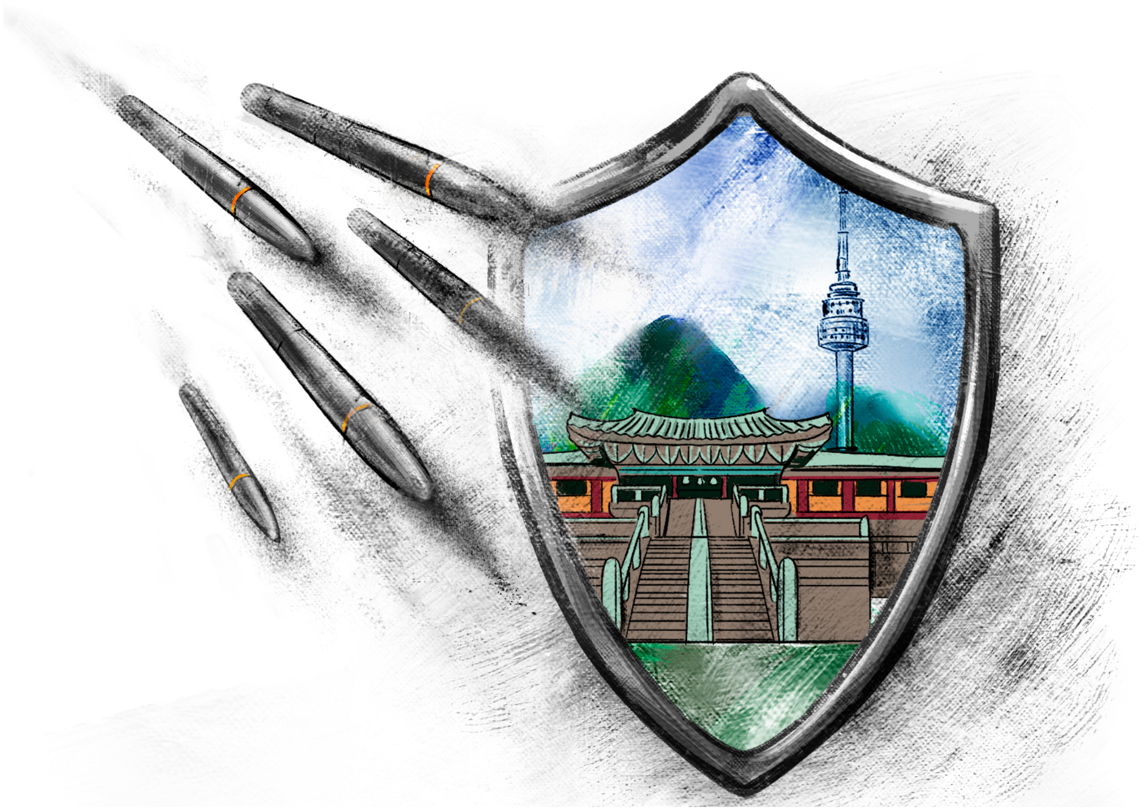
Sensitivity Analyses and Simulation

All the results presented above were derived using point estimates for the key variables in the model.

92 In the realistic crisis scenario, the CFC has 108 GMLRS available (see table 3), each of which carries 12 rockets. There would be approximately 350 HARTS-based targets to strike, because there are up to 200 HARTS in the vicinity of Seoul, and 41 are slated for attack (162 Koksan HARTS + 81 240 mm HARTS = 243 / 6 artillery per HARTS = ~41), and we assume 10 percent overtargeting (200 HARTS – 41 slated for attack = 159 remaining × 10% overtargeting = ~16), and there would be about 6 targets per HARTS targeted (41 + 16 = 57 × 6 = 342). Striking each of these 350 targets twice would therefore require 58–59 of these systems (350 × 2)/12 = 58.3).

93 As mentioned above, North Korea could adopt tactics to slow the pace of the war. For example, it could order its mobile artillery to fire less frequently (and thus remain hidden longer). But such a tactic by the North would mean fewer strikes in the critical first 30 minutes (while Seoul residents were seeking shelter) and allow CFC uninhabited aerial vehicles (UAVs) and aircraft to hunt and destroy more of the dispersed artillery before it fires. The result would be fewer losses in Seoul.

94 Other potential steps to reduce fatalities further are preemptive strikes—which are modeled here, and which come with their own dangers—and active defenses.



But substantial uncertainty remains about many of these parameters. How do the results change over a range of plausible values for key variables? To examine this question, we conducted extensive sensitivity analyses of thirty-four variables in the model—focusing on the realistic crisis scenario.[95] For each variable, we defined a plausible range of values and then set each to the lowest and highest value of their range, one by one, to see how these changes influence the number of estimated fatalities in Seoul. For twenty-seven of the thirty-four variables, moving from the baseline to the lowest or highest plausible values caused very small changes in the model's results (less than 5 percent change in total fatalities). For four other variables, large swings in value produced moderate changes in the model's output (in the 5 to 15 percent range).[96]

The input values of three variables, however, are very influential in terms of the final results, with sensitivity tests (moving from baseline to the lowest or highest plausible) producing changes in estimated fatalities between 20 percent and 84 percent. The first of these variables is the number of North Korean 240-millimeter MRLs available for the scenario. Increasing this value from its baseline of 162 to 202 (a 25 percent increase) leads to a 23 percent jump in estimated fatalities under the realistic crisis scenario (579 additional fatalities). Thus, each additional North Korean MRL is associated with approximately 14 fatalities over the course of the battle. As a result, if our estimates of North Korean MRL deployments are off by 35 to 40 launchers, losses in Seoul could increase or decrease by 500 or more.

The second important variable is population density in the targeted areas of Seoul. Recall that we set this value to 31,862/km^2, representing the 75th percentile population density among all of Seoul's neighborhoods. If North Korea can significantly increase the accuracy of its artillery, the KPA could target the densest neighborhoods in Seoul, whose populations approach 40,000/km^2; this might increase fatalities by as much as 25 percent. The opposite possibility seems more likely, however. Namely, if North Korean artillery is inaccurate—as it was against Yeonpyeong Island in 2010—their shells would fall almost randomly across the city. In that case, the effective population density

95 See appendix A (https://doi.org/10.7910/DVN/86HBGS) for full details and results.

96 The variables that produced moderate changes to the results (5–15 percent of total fatalities) are: share of DPRK 240-millimeter artillery in HARTS, DPRK shell "dud rate," CFC fire-finding radar effectiveness, and the percent of South Koreans seeking shelter. For instance, decreasing the 240-millimeter artillery based in HARTS from 50 percent to 30 percent led to a 6 percent increase in projected fatalities. Similarly, decreasing the DPRK dud rate from 25 percent to 15 percent led to a 13 percent increase in projected fatalities. Reducing CFC radar effectiveness from 50 percent to 25 percent led to a 13 percent increase in projected fatalities. And increasing the percentage of the South Korean public not seeking shelter from 25 percent to 40 percent led to an 8 percent increase in projected fatalities.

would be 16,136/km², reducing fatalities by 50 percent relative to those in figure 2.

The third and most influential variable in the model is the lethal radius of North Korean shells and rockets. As noted above, we operate in the model with a concept of LR_{10}—meaning the radius within which 10 percent of people are killed, a value we set to 10 meters. Increasing this value just two meters (20 percent), increases the estimated fatalities by nearly 45 percent, to 3,704.[97] A 50 percent increase in LR above our expectations would double the expected fatalities in Seoul (to 5,788). Although those results are still far below the conventional view, they paint a significantly grimmer picture for the South Korean capital.

We accounted above for the sensitivity of our results to the size of the lethal radius of North Korean shells by selecting a value that substantially exceeds historical evidence. As noted above, an LR_{10} of 10 meters is nearly *three times* greater than any value observed during the five well-documented historical cases of high-explosive bombing and is about twice the LR_{10} observed from artillery shelling during the Siege of Sarajevo (1992–94) and the Battle of Shuja'iya (2014). Our estimate, therefore, should be regarded as conservative.

lation, values were randomly selected from uniformly distributed ranges for each variable, input into the model, and estimated fatalities were produced and recorded. We ran 10,000 simulations for each of our three scenarios, using both nominal and realistic variable values, totaling 60,000 runs.

Table 4 presents our baseline model results as well as the 5th and 95th percentile values for each scenario. An extreme estimate of fatalities on the low end is between 107 and 869, depending on the scenario. An extreme estimate on the high end is between 1,372 and 7,813 (again, dependent upon the scenario). For the kind of scenario we deem most plausible—the crisis scenario using realistic variable values (in gray)—90 percent of the runs of the model produced results between 470 and 3,887 fatalities. Thus, even with some potentially extreme values for inputs and unexpected combinations, the total number of estimated fatalities remains far below typical estimates.

Our results differ quite substantially from previous analyses, for at least three primary reasons. The first is our findings about the limitations of artillery in built-up urban environments. We assume that, on average, a detonating round in Seoul will be fatal for 10 percent of people within a 10-meter radius. While this figure greatly exceeds the 3 to 6 meters implied by comparable historical cases, it is still significantly smaller than some existing analyses.[99]

Scenario	5th percentile		Baseline		95th percentile
1. Surprise (nominal)	869	←	4,555	→	7,813
1. Surprise (realistic)	551	←	2,961	→	4,728
2. Crisis (nominal)	675	←	3,642	→	5,564
2. Crisis (realistic)	470	←	2,573	→	3,887
3. Preemption (nominal)	171	←	1,085	→	2,127
3. Preemption (realistic)	107	←	697	→	1,372

Table 4. Monte Carlo simulation results by scenario

Our sensitivity analysis suggests that our results are robust across plausible variation in any single variable, but it is possible that allowing many parameters to vary simultaneously could produce greater variance. To explore this possibility, we ran Monte Carlo simulations for each of our scenarios, varying 35 inputs simultaneously.[98] For each run of the simu-

The second is our treatment of CFC counter-artillery operations. Rather than assuming a slow, linear

97 The results are highly sensitive to lethal radius because fatalities are calculated by *lethal area* × *population density*. Lethal area is a function of *lethal radius* squared (πr^2), so small changes in lethal radius have large effects on fatalities.

98 Monte Carlo simulation is a computational method that uses repeated random sampling to help model uncertainty. See appendix A (https://doi.org/10.7910/DVN/86HBGS) for details and results. On the use of simulation in campaign analysis, see Tecott and Halterman, "The Case for Campaign Analysis," 70–73. For a similar approach to a related question, see 하유진, "몬테카를로 시뮬레이션을 통한 장사정포요격체계 효과분석에 관한 연구," 한국국방경영분석학회지, 제 45권2 호, 2019, 45–55, https://morsk.jams.or.kr/co/com/EgovMenu.kci?s_url=/sj/search/sjSereClasList.kci&s_MenuId=MENU-000000000053000&accnId=AC0000000002.

99 Cavazos, for instance, implicitly operates with a LR_{10} of 38 meters. See Cavazos, "Mind the Gap Between Rhetoric and Reality."

attrition of North Korean forces,[100] we carefully model counter-artillery operations and incorporate the latest information on South Korea's sophisticated capabilities. This approach contributes to a more rapid rate of attrition of North Korean forces, and therefore lower fatalities in Seoul.

The number of additional fatalities in this excursion depends on how long it would take the CFC to destroy the surviving bunkers with heavier munitions.

The third important reason our estimates are significantly lower than others is our assumptions about civil defense sheltering. Based on a detailed examination of South Korean civil defense procedures, facilities, and evacuation research, we argue that most Seoul residents who seek shelter will find adequate protection within about 30 minutes. Existing analyses are either unclear on this issue, or assume evacuations will take place much more slowly.[101] However, to generate the kinds of fatalities estimated by existing analyses or popular assessments—on the order of 30,000 or even 100,000 fatalities—the assumptions need to be truly unrealistic.[102]

But What If We're Wrong?

With any complex military model, it is important to ask: How might the model fail? What assumptions do our results depend on, which normal sensitivity analysis might not reveal? Here we consider two.

One important assumption is that CFC artillery—and in particular the rockets fired by MLRS—can destroy North Korea's buried HARTS shelters.[103] There are reasons for this confidence: The CFC's rockets are highly accurate and armed with penetrating warheads (South Korea procured them with this mission in mind).[104] Nevertheless, approximately one-third of HARTS are buried and aligned so that their blast doors face north—shielded from strikes from the south.[105] What if the dirt overhang on many shelters is too thick for MLRS rockets to penetrate?

To explore this possibility, we consider a scenario in which 50 percent of the DPRK's buried HARTS are invulnerable to MLRS strikes.[106] This scenario would start like the others—with CFC counterbattery forces attacking North Korean shelters. But North Korean fire would continue from launch positions near their surviving HARTS. Cued to this problem by fire-finding radar, the CFC could restrike the recalcitrant targets, but if the shelters were truly invulnerable to the MLRS rockets, the artillery deployed at those HARTS would continue to fire until the CFC could employ heavier weapons against the recalcitrant shelters.[107]

100 Cavazos assumes North Korean artillery will be attrited at a rate of 1 percent per hour. See Cavazos, "Mind the Gap Between Rhetoric and Reality." The RAND analysis incorporates counter-artillery strikes, but it is unclear how they do so and to what effect. See Barnett et al., *North Korean Conventional Artillery,* 4.

101 Cavazos assumes 50 percent of South Koreans will be sheltered within three hours. See Cavazos, "Mind the Gap Between Rhetoric and Reality." The RAND analysis incorporates civil defense sheltering, but it is unclear how they do so and to what effect. See Barnett et al., *North Korean Conventional Artillery*, 4.

102 For instance, to generate about 37,000 fatalities under our realistic crisis scenario, we'd need to assume an LR_{10} of 38 meters or an "LR_{100}" of 12 meters. While existing analyses have made this kind of assumption, this estimate envisions a scenario in which every detonating artillery round generates 10 or more fatalities in the opening rounds, a figure that is dramatically out of step with the historical record of such attacks. For instance, as shown in appendix B (https://doi.org/10.7910/DVN/86HBGS), in the siege of Sarajevo, each detonating round generated an equivalent of 0.02 fatalities (508 fatalities/52,140 shells fired), and in the battle of Shuja'iya during the 2014 Gaza War, each round generated 0.1 fatalities (55 fatalities/600 shells fired). To generate 100,000 fatalities under our crisis scenario, we'd need to make nominal assumptions (all rounds detonate, no breakpoint for North Korean forces, and North Korean forces operate fully efficiently), assume a LR_{10} of 38 meters, 400 North Korean artillery pieces involved in the attack, North Korea exclusively targeting the very densest neighborhoods in Seoul (40,000 per km^2), and 40 percent of Seoul residents not seeking shelter and leaving themselves entirely vulnerable to attack.

103 As noted above, we assume that each GPS-guided rocket can hit and render inoperable a HARTS shelter with 67 percent probability, so using two rockets per target produces an 89 percent success rate $[1 - (1 - 0.67)]^2$.

104 South Korea's K-239 rocket was procured to give the ROK army "a guided rocket . . . [with] a penetrator warhead to be used as a 'bunker buster' solution against the large number of bunkers along the DMZ." See "K-239 Chunmoo South Korean 130mm/227mm/239mm Multiple Rocket Launcher (MRL)," ODIN, WEG.

105 See appendix D (https://doi.org/10.7910/DVN/86HBGS) and the "HARTS Data" in the supplementary materials.

106 As discussed above, only approximately one-third of the HARTS have buried shelters; the others are "shed-type" structures, which provide concealment but not meaningful protection.

107 South Korea has a number of options for such an attack. In the late 2010s, it purchased 260 KEPD-350 stealthy air-launched cruise missiles (ALCMs), which can be armed with 480-kilogram penetrating warheads. It also plans to indigenously develop an ALCM with similar capabilities by 2028, and has also reportedly deployed a bunker-busting short-range tactical missile, the Korea Tactical Surface-to-Surface Missile (KTSSM). See Fergus Kelly, "South Korea Signs Contract for 90 More Taurus Bunker Buster Cruise Missiles," *The Defense Post*, March 13, 2018, https://www.thedefensepost.com/2018/03/13/south-korea-contract-taurus-bunker-buster-cruise-missiles/; Kang Seung-woo, "Korea to Develop Air-Launched Cruise Missile by 2028," *Korea Times,* December 12, 2022, https://www.koreatimes.co.kr/www/nation/2024/08/113_341560.html; "Military Deploys New Homegrown Bunker Buster Missile amid North Korean Threats," *JoongAng Daily*, February 18, 2025, https://koreajoongangdaily.joins.com/news/2025-02-18/national/defense/Military-deploys-new-homegrown-bunker-buster-missile-amid-North-Korean-threats/2244436.

The number of additional fatalities in this excursion depends on how long it would take the CFC to destroy the surviving bunkers with heavier munitions. Given the high priority of protecting Seoul, air strikes on the surviving shelters might begin a few hours after it became clear that these targets were resistant to MLRS fire. If it required 8 hours to destroy the surviving HARTS, fatalities in Seoul (under the realistic crisis scenario) would increase by about 300—a higher total, but one that is not substantively different than the main results we present.[108] To reduce this danger, CFC planners could preplan air or missile strikes against the most fortified HARTS shelters.

A second question about the model is our focus on North Korea's artillery: What if the KPA also uses short-range ballistic missiles (SRBMs) to strike Seoul? North Korea fields approximately 100 KN-02 "Toksa" missiles.[109] With a range of 120 to 170 kilometers, these missiles could reach targets deep in South Korean territory, or North Korea could use them to attack Seoul from deeper within its own territory.[110] If we assume employment of a proportion of SRBMs similar to the North's long-range artillery, then approximately 38 might be used.[111] If these have a higher LR_{10} and the North fired one missile every minute into Seoul, we would expect about 45 additional fatalities.[112] Thus, the addition of SRBMs wouldn't change our estimates substantially.

It is impossible to predict battlefield outcomes with precision. But the results in figure 2 and the ranges identified in table 4 suggest that a conventional artillery attack on Seoul would—across a wide range of scenarios—produce fatalities one or two orders of magnitude smaller than most public estimates. Furthermore, the CFC has a lot of agency in determining whether an attack could kill a few hundred civilians, a few thousand, or many more. CFC military forces now own the "kit" to rapidly blunt a North Korean attack; to employ these capabilities effectively, they must train and exercise to carry out the difficult counterbattery missions critical to defending Seoul.

Conclusion & Implications

Pyongyang's long-range artillery—like much of the North Korean military—is a shadow of the force it pretends to be. The list of the KPA's weaknesses is long: old equipment, poor maintenance, minimal training, and substandard health among soldiers. But the core problem North Korea faces is more fundamental: The KPA has none of the attributes of a force designed to conduct sustained mobile operations, and twenty-first-century warfare is not kind to forces sitting in pillboxes. North Korea's guns and rockets could cause panic, property damage, and a couple thousand fatalities in Seoul. But doing so would trigger a massive counterbattery strike, which would rapidly neutralize one of North Korea's most feared tools of war.

Our findings have five implications—two reasons for optimism, and three reasons for concern. First, our results cast doubt on the dire predictions that dominate discussions of the artillery balance on the Korean Peninsula. CFC forces *can* protect Seoul from this kind of North Korean attack—if they train, exercise, and prepare. South Korea's recent investments in MLRS units and fire-finding radar enable the CFC to defend the capital, but only if they stockpile the necessary munitions; conduct the maintenance required to keep these complex weapons in the field; protect their communication networks and rear areas from disruption; and, most of all, intensively train to execute the counterbattery mission.

A second optimistic implication concerns conventional deterrence on the Korean Peninsula. North Korea's artillery force is highly vulnerable. If that message is absorbed in Pyongyang, North Korea should be more cautious about using its artillery coercively to initiate military crises along the DMZ or to initiate attacks on the South.

A third, more worrisome, implication has to do with the risk of nuclear escalation on the Korean Peninsula. A North Korean artillery attack—even a small-scale provocation—could trigger an intense counterbattery

108 With all the Koksans and half the long-range MRLs operating from HARTS, North Korea's long-range artillery would, at the outset of the war, be occupying approximately 240 shelters within HARTS complexes. As noted earlier, only one-third of those shelters are buried (the rest are "shed-type"). If half of the buried shelters are invulnerable to MLRS fire, there would be approximately 27 Koksans and 13 MRLs in resilient shelters. Using the realistic assumptions, in one hour each MRL can fire 41 rounds (17 rounds every 25.5 minutes); each Koksan can fire 3 (2 rounds every 40.5 minutes). Using the same modeling assumptions described in this paper, surviving KPA artillery in survivable shelters could fire approximately 475 munitions the first hour, and gradually less each hour as they were destroyed by air strikes over 8 hours. If they ceased firing after taking 75 percent losses, the additional fatalities in Seoul would be 297.

109 See Joseph S. Bermudez Jr., "The KN-02 SRBM," *KPA Journal* 1, no. 2 (February 2010): 7–12; Gentile et al., *Four Problems on the Korean Peninsula*, 7; "KN-02 (Toksa)," Missile Threat: CSIS Missile Defense Project, July 31, 2021, https://missilethreat.csis.org/missile/kn-02/.

110 "KN-02 (Toksa)," CSIS.

111 This is 162/432 (long-range artillery) = 37.5% × 100 SRBMs = ~38 SRBMs.

112 To be conservative, we assume that every North Korean SRBM launched at Seoul functions perfectly, and that they are accurate enough to hit parts of Seoul at the 75th percentile of population density. For these calculations, we scaled up the LR_{10} from the artillery analysis to account for the greater weight of explosive fill in the SRBMs (120 kg versus 45 kg for the rockets, meaning [10 m × (485 kg / 45 kg)$^{1/3}$ = ~14 m]). This SRBM LR_{10} was used to estimate fatalities given the population density at the time of detonation, using formula 1. For the likely explosive fill weight for the KN-02, see "OTR-21 Tochka (SS-21)," Missile Threat: CSIS Missile Defense Project, March 31, 2022, https://missilethreat.csis.org/missile/ss-21/.

response, which in turn could cause the collapse of North Korea's artillery, and perhaps other frontline units, fairly quickly. Facing collapse along the DMZ, the North Korean regime would face life-or-death incentives to escalate in a "gamble for resurrection."[113] This risk appears all the more real given that the 2022 update to North Korea's nuclear doctrine outlines imminent threats to leadership and to the state as two of the key conditions under which the North would resort to nuclear use.[114] More broadly, the weakness of North Korea's long-range artillery—supposedly Pyongyang's most potent conventional asset—suggests that the regime will have to rely more heavily on its nuclear capability than has been commonly appreciated. This increased dependence will translate into a broader range of circumstances in which the North will threaten to use, or actually employ, nuclear or other weapons of mass destruction during crises or conflict on the Peninsula.[115]

A fourth implication of our analysis is the considerable crisis instability that exists on and around the Korean Peninsula. Our findings highlight an important "first mover advantage" for ROK and US forces—striking first at North Korea's artillery during a crisis could substantially reduce South Korean casualties in a coming conflict. On the other hand, striking first forfeits any chance of preventing the war altogether. CFC leaders should think hard in peacetime about which warnings and indicators so clearly predict war that they merit crossing this threshold. Additionally, our analysis demonstrates that a preemptive strike might greatly reduce deaths and damage in Seoul—but launching a preemptive attack on North Korea's artillery, especially if conducted using US-based bombers and hundreds of cruise missiles from US ships and submarines, may look to leaders in Beijing like an incoming strategic attack on China. Warning Chinese leaders about the incoming attack could reduce its effectiveness (if they pass the information to Pyongyang), but keeping Beijing in the dark might also be dangerous.[116]

The fifth and final implication concerns North Korea's nuclear weapons program. The KPA's overarching military weakness—even in artillery, where it is purportedly most threatening—may help explain the extreme sacrifices North Korea has made to acquire nuclear weapons. North Korea's nuclear pursuit is sometimes seen as puzzling, given the economic sanctions and diplomatic isolation that it has triggered. Instead of backing down, however, North Korea has redoubled efforts to enhance its nuclear capabilities, including steps toward intercontinental delivery systems.[117] Its steadfast nuclear pursuit would be more puzzling if North Korea truly had "another deterrent force"—its long-range artillery—to keep enemies at bay. The analysis presented above, however, suggests that North Korea's nuclear arsenal is likely more important than ever in Pyongyang, and that calls to abandon its program will continue to fall on deaf ears.[118] Rather than serving as another deterrent force, North Korea's artillery is better understood as a paper tiger.

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Image: *View of a fire-assault drill at an undisclosed location in North Korea on March 10, 2023. (Korean Central News Agency via REUTERS)*[119]

113 On "gambling for resurrection" (GFR) in war, see George W. Downs and David M. Rocke, "Conflict, Agency, and Gambling for Resurrection: The Principal-Agent Problem Goes to War," *American Journal of Political Science* 38, no. 2 (May 1994): 362–80. For analyses that apply GFR logic to Korea, see Lieber and Press, "The Return of Nuclear Escalation"; Bowers and Hiim, "Conventional Counterforce Dilemmas," 33–36.

114 Kim, "North Korea States It Will Never Give Up Nuclear Weapons."

115 This same logic may also apply to any other North Korean weapons of mass destruction, including chemical and biological weapons.

116 On China and nuclear escalation, see Caitlin Talmadge, "Would China Go Nuclear? Assessing the Risk of Chinese Nuclear Escalation in a Conventional War with the United States," *International Security* 41, no. 4 (2017): 50–92; Fiona Cunningham and M. Taylor Fravel, "Dangerous Confidence? Chinese Views on Nuclear Escalation," *International Security* 44, no. 2 (2019): 61–109.

117 See Ankit Panda, *Kim Jong Un and the Bomb: Survival and Deterrence in North Korea* (Oxford University Press, 2020).

118 For the latest iteration of this policy, see *National Security Strategy* (The White House, October 2022), 38.

119 For the image, see https://www.reuters.com/news/picture/kim-jong-un-oversees-latest-north-korea-idINRTSH2618/