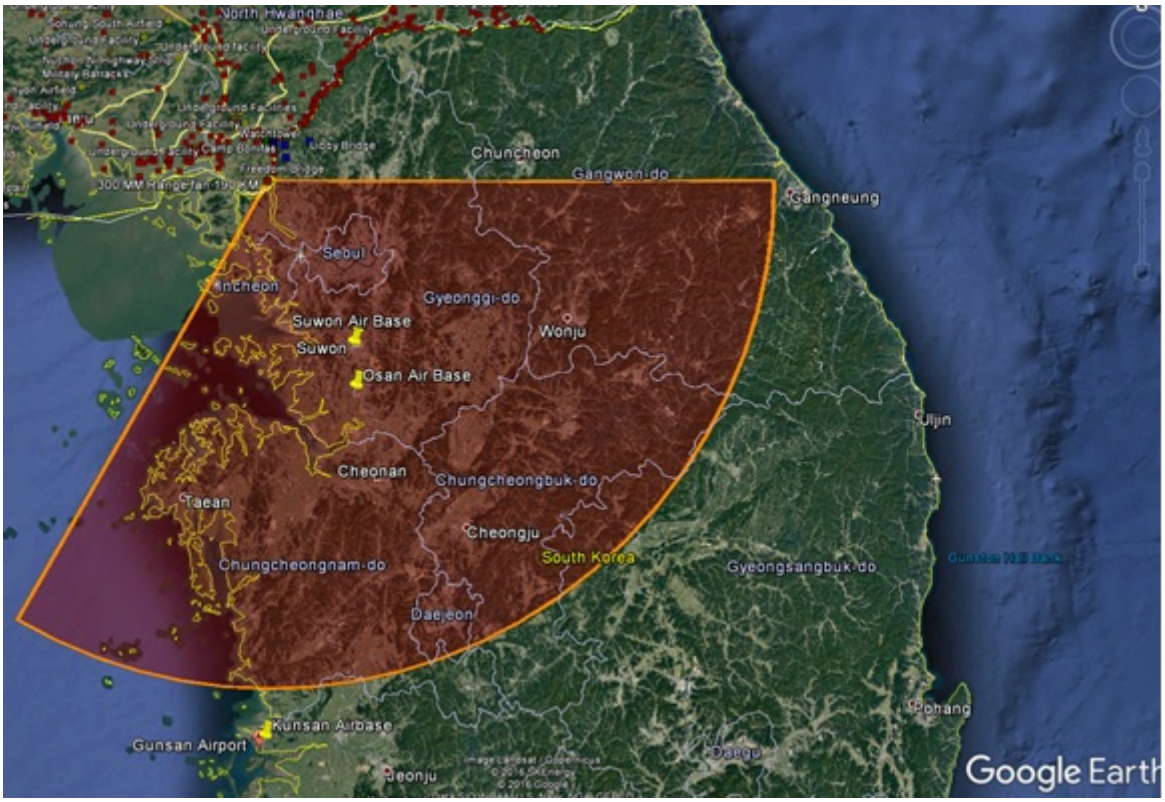
ASSESSING THE DPRK'S KN-09 300 MM MULTIPLE ROCKET LAUNCHER SYSTEM: DECISIVE OR INCREMENTAL?



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PETER D. ZIMMERMAN

JUNE 10, 2018

I. INTRODUCTION

In this essay, the author argues that although the KN09 MRLS “brings many more ROK and United States targets, including all of the Seoul metropolitan area, within range of artillery bombardment from the North,” its specific capabilities and relatively small numbers lead to “the conclusion that the KN-09 is an incremental improvement to existing North Korean capabilities, but does not change either the strategic or tactical situation.”

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Note: this report was updated at 1342 Pacific Standard Time (see endnote 31).

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The views expressed in this report do not necessarily reflect the official policy or position of the Nautilus Institute. Readers should note that Nautilus seeks a diversity of views and opinions on significant topics in order to identify common ground.

Banner image: Forward-deployed KN-09 Range over ROK by Roger Cavazos using GoogleEarth

II. NAPSNET SPECIAL REPORT BY PETER D. ZIMMERMAN

ASSESSING THE DPRK’S KN-09 300 MM MULTIPLE ROCKET LAUNCHER SYSTEM: DECISIVE OR INCREMENTAL?

JUNE 10, 2018

SUMMARY

The KN-09 is a new guided artillery rocket entering service with the North Korean armed forces. Because of its 30 cm diameter, 190 kg payload and 190 km range some have suggested that it is a truly significant addition to the North Korean threat. To be sure, it brings many more ROK and United States targets, including all of the Seoul metropolitan area, within range of artillery bombardment from the North. If its satellite navigation guidance functions, functions (and is not neutralized by the defense), it can attack aircraft parked on the ground, radars, command sites, POL, and specific high value civilian targets of either military or iconic significance.

Nonetheless, the KN-09 is not a game changer. Its precision guidance can be readily neutralized by ROK and US forces, negating the precision attack capability. Even if the conflict begins from a

standing start with no warning whatever, it is unlikely that the SATNAV guidance will be effective after the first KN-09 salvo.

It is deployed in far too small numbers (between 10 and 100 launchers, each mounting eight rockets) to be useful in any area bombardment strategy. And production of tens of thousands of the missiles would surely stress the DPRK procurement and manufacturing capabilities.

It is possible that the North Koreans might believe that certain employment scenarios might be strategic; that is, they might believe that selective use of the KN-09 might function to split the ROK from the United States. However, it is extremely unlikely that such a strategy would work; the alliance would hold.

Careful analysis leads to the conclusion that the KN-09 is an incremental improvement to existing North Korean capabilities, but does not change either the strategic or tactical situation.

1. INTRODUCTION

Seoul, the capital city of South Korea, lies only a few kilometers from the Demilitarized Zone (DMZ), the truce line agreed upon at the end of the Korean War. While the DMZ is lacking in heavy arms, the areas north of the trace are not. Indeed, the DMZ is the most heavily fortified international border on Earth. The Democratic People's Republic of Korea (DPRK) has emplaced thousands of artillery tubes and multiple tube rocket launchers along the border, and not infrequently threatens to "turn Seoul into a Sea of Fire." A 2012 Nautilus Institute report by Roger Cavazos, "Mind the gap between rhetoric and reality," cast great doubt on the DPRK's ability to destroy Seoul with the weapons available at that time.[1]

In the intervening five years, however, North Korea has added to its arsenal of both conventional and special weapons. Should the North choose to launch a nuclear weapon, even one with a yield in the range of the Little Boy and Fat Man used on Hiroshima and Nagasaki in 1945[2], there is no question that a sea of fire over a large part of the city would be the likely result. On 3 September 2017 the DPRK conducted what appears to be its first successful detonation of a thermonuclear device.[3]

The most significant addition to the conventional stockpile may be the reported 30 centimeter diameter artillery rocket often called the KN-09. This report focuses on the utility of the additional firepower delivered by that system and should be seen as a supplement to the Cavazos paper previously cited.

The KN-09 is not well described in the open literature. Indeed, hard facts about the rocket are hard to come by and seemingly authentic sources can differ significantly. Accordingly, this report is based upon a "semi-consistent model" of the KN-09 gleaned from multiple sources.

The Wikipedia article "KN-09 (MRL)" provides a plausible introduction, suggesting that the KN-09 derives from the former-Soviet BM-30 *Smerch* or the Chinese WS-1B. Of the two, the WS-1B with a 180 km range would appear to be closer to the mark than the *Smerch.* The few authentic photographs available on the Internet indicate that the Chinese SY-300 rocket is even closer to the descriptions of the KN-09 than the other possible ancestors. A photograph of the SY-300 rocket can be found on the Defense Update website buried in a long report on "Air Show China, Photo Report"[4]. The SY-300 is described as a precision strike rocket system; canard guidance vanes can be seen near the nose of the rocket, and the missile is stated to have GPS/INS guidance. The launcher vehicle shown differs from that of the KN-09 in that it has six individual launch tubes instead of the eight used by the Koreans.



Figure 1: KN-09 at launch[5]

Accordingly, I will make the following assumptions about the "KN-09" for the purposes of this report:

1. Range: 190 km[6]
2. Warhead weight: 150-190 kg of which 75 kg is high explosive (TNT) and the rest consists of fragmentation material and fuzing. Alternative warheads could include CBW and small mines; in general we have assumed unitary warheads or fragmentation warheads.
3. Lethal area: 1800 m^2,[7]
4. Rocket weight: 800 kg
5. Launch system: truck mounted; 8 rockets in two four-rocket pods
6. Salvo duration: 50-60 sec.[8]
7. Salvo rate: 8 rockets in 45 minutes
8. Reload time: 45 – 60 minutes[9], [10]
9. CEP: 30-45 m[11] (if satellite navigation systems have not been jammed or turned off)
10. Number of available launcher vehicles: 10-100
11. Fuzing likely for detonation at a specified altitude, although both impact and delayed fuzing are possible. It is hard to see how a standard proximity fuze can work against an urban target where building heights vary and include modern high rise structures.[12]

Scenarios and Employment Doctrine

Any estimate of casualties depends sensitively on the scenario and the employment doctrine selected by the Korean People's Army (KPA). It also depends upon the ability of the KPA to launch rockets over a sustained period, which in turn depends upon the number of rockets forward deployed and the total inventory of rockets. We will make plausible assumptions about these numbers, but it should be understood that they are our best estimates, not something gleaned from authoritative sources.

Accordingly, we state our assumptions explicitly:

1. The conflict does not begin as a bolt from the blue. Tensions have been escalating, and US-ROK forces are on generated alert. Some fighter and ground support aircraft are on airborne alert,

armed, and the pilots briefed as to their first targets. Other aircraft are on quick reaction strip alert; reserve forces are in hardened shelters.

2. Ground forces have been mobilized, leaves cancelled, live ammunition issued, and at least some armored forces loaded on transporters or already forward deployed.
3. At least one US aircraft carrier battle group is deployed off the Korean Peninsula. The US has begun alerting and arming strike aircraft, activated BMD units, and is assembling ground task forces.
4. We believe that the major contribution of the KN-09 to the KPA's combat capability is the ability to strike comparatively small-area targets with precision, not the ability to barrage soft (and mostly civilian) area targets farther from the DMZ than its existing artillery and multiple rocket launchers can reach. Thus, we anticipate that at least the first volleys from the KN-09 will be directed at primarily military targets, in rough order of priority, for example,
    1. Fighter and close air support aircraft on the tarmac at airbases, POL, control towers
    2. Command centers, radars, communications nodes, intelligence centers
    3. Massed ground forces in the hope of degrading the allied response
    4. Major electric power distribution substations
    5. Hospitals
    6. Civilian areas south of those which can be reached by previous KPA artillery in order to panic the population and complicate allied logistics by jamming roads. Civilian panic is, of course, likely to begin as soon as it becomes apparent that the ROK armed forces are mobilizing. Highways leading away from metropolitan Seoul are likely to be jammed unless the ROK government can use its policing authority to prevent refugee traffic. At the first shot, much of the civilian population will, in any case, self-evacuate.
    7. It is reasonable to assume that US-ROK forces will be able to jam the GLONASS system within minutes of the opening shots of the conflict and that the precision codes for GPS will have been encrypted so that the system is unavailable to the DPRK. Denial of the SATNAV signals will severely degrade the accuracy of the KN-09 system. Beyond 70km the system may be little better than a barrage rocket.

5.

Civilian casualties will depend sensitively on the time of the attack. If it occurs in the hours before dawn most civilians will be afforded at least partial shelter from fragmentation effects because they will be in their beds, primarily in apartment buildings. At attack at morning or evening rush hour will find civilians in thin-skinned vehicles (automobiles, buses, commuter trains) or in the open. The following section provides three notional attack scenarios based on the targets of the KN-09. These are primarily military; primarily mixed military and civilian; and primarily civilian targets.

Notional Allocations of KN-09 Missiles Depending On the Strike Philosophy

Assuming that North Korea has an initial inventory of 100 KN-09 launcher vehicles, each mounting 8 missiles, the KPA has several choices for the employment of the first salvo of missiles, the only one where robust defense countermeasures are absent: GPS has not yet been jammed, alliance aircraft are not prepared to strike launchers and launch sites, and neither the command and control system for the North nor the missile system has been degraded by counter-battery fire. We suggest three notional employment scenarios for the KN-09 system:

3. The attack is directed primarily at distinctly military targets, ones for which precision guidance of the missiles is required, with only psychologically important civilian targets being attacked.
4. The attack is designed to strike a mix of military and civilian targets, with the emphasis still on distinctly military ones.
5. The first salvo attempts to inflict significant damage on critical military targets to degrade alliance response to the attack while diverting significant numbers of missiles to important civilian targets *beyond the range* of the conventional artillery tubes and rockets emplaced near the DMZ.

Scenario 1: Primarily Military

Target	**KN-09 missiles**	**Targets Destroyed**
US/ROK fighter aircraft	350	175
Airfield POL	150	80
C^2 and military radars	100	50
Camp Humphreys C^2 and Headquarters	150	80+
Iconic, high visibility civilian buildings	50	30

Scenario 2: Mixed Military and Civilian

US/ROK Fighters	300	150
Airfield POL	100	80
Mobility infrastructure: Bridges, highway interchanges, rail/road crossings	200	105
Seoul municipal rail system (subway, etc.), major nodes incl. switch yards, stations, etc.	100	53
Iconic civilian targets; visible structures	100	53

Scenario 3: Primarily Civilian Targeting

US/ROK fighters	200	103
Mobility Targets	100	50
Seoul Railways choke points	50	25
Seoul Railways station entrances	200	125
Iconic civilian targets	100	50
Major residential complexes in southern Seoul	150	100

All three variants include a strong attack against alliance aircraft. Such attacks require precision targeting possible only if SATNAV systems are still operating, a poor assumption for a second strike on the order of 45 minutes after the first. Further, those aircraft represent possibly the greatest threat to the survival of the KN-09 launchers and other KPA assets after the opening of hostilities.

Scenario 2 emphasizes attacks on alliance aircraft and the infrastructure needed to bring additional troops forward towards the DMZ. The attacks on iconic targets are intended more to produce psychological effects than physical ones. Nevertheless, we suggest that the KPA may opt to direct

some missiles in its first strike to purely civilian targets that are out of range of the well known artillery and rocket forces near the DMZ. Scenario 3, which the author considers less likely to be chosen than the other two, attempts to paralyze Seoul and demoralize its inhabitants by targeting the municipal rail network famous and visible civilian targets such as tall towers, parliament, the financial district and monuments. Finally, it assumes that residential complexes south of Seoul will also be hit as a demonstration that the KPA can strike more deeply into the country, using conventional weapons, than it could before.

2. MILITARY USES OF THE KN-09

The KN-09 is a relatively slow-fire weapon. If it is able to launch one salvo of eight rockets in 45 minutes, the rate of fire is 11 rounds per hour, per launcher. Thus the North Koreans can only count on getting off one or two salvos per launcher before attack suppression efforts are in full effect. As a result, we anticipate that the rockets will be used initially to suppress ROK-US defensive systems.

Very likely the first barrage will be directed at bases with fighter aircraft. ROK/USAF aircraft may be the most effective artillery suppression available to the ROK/US Alliance, and it will be important to the North to eliminate as many aircraft and their supporting infrastructure and personnel as possible in the first few moments of the war.

One reviewer and some serving U.S. officers have suggested that the North Koreans might use the KN-09 to attack the Patriot PAC-2 ballistic missile defense and antiaircraft missile sites. This is plausible. However attacking a PAC-2 battery requires high accuracy because the various vehicles are not terribly thin-skinned and good intelligence with a short cycle time if the region is on war alert. The missile batteries are apt to relocate to unknown positions.

In addition, PAC-2 proved only marginally, but still usefully, effective in the Gulf War against SCUD missiles[13]. The THAAD battery stationed in the ROK is out of range of the KN-09.

It has also been suggested by reviewers and others that the KN-09 might be used strategically to attack the new U.S. headquarters south of Seoul. An attack solely focused on U.S. facilities might be intended to split the U.S./ROK alliance by convincing the ROK to stay out of a conflict between the United States and the DPRK if only U.S. targets were struck, and ROK military and civilian targets protected. It is difficult to estimate the number of casualties might be inflicted in such a bombardment.

Alternatively, attacks aimed solely against ROK facilities, particularly those near to U.S. targets, might be used to convince the United States to stay out of a conflict between the DPRK and South Korea. Both of these hypothetical scenarios are superficially plausible. Whether the DPRK's calculations would hold after the shooting starts is a good question. To be successful, North Korea would have to conduct an aggressive news, information, and diplomatic initiative in the hours before launching an attack and after the rockets landed.

A great deal could go wrong. Two centuries ago Clausewitz pointed out that the best of war plans is unlikely to survive first contact with the enemy.

A brief survey of Google Earth satellite images of ROK and USAF air bases in South Korea shows that almost all major airbases use revetments for storage of fighters and other aircraft. Very few park unprotected aircraft on the tarmac. Most revetments are either concrete semi-cylinders over the aircraft or open cells with high blast proof walls. Frequently these stands also use girders over the aircraft, presumably for the purpose of detonating approaching missiles before they reach the ground.

Photos of revetments indicate that they are slightly longer than the fuselage plus tail structure of the protected aircraft if it extends behind the fuselage and that they are approximately twice the width of the wingspan. The F/A-18 C is a typically sized modern fighter; its length is 17.1 meter, wing span 12.3 m, and wing area 38 square meter.[14] Another modern aircraft, the F-15 Strike Eagle has a length of 19.44 meters, a wingspan of 13 meters and a wing area of 56.5 square meters.[15][16]



Figure 2: Cargo aircraft in open revetment.

Source: Google Earth; post-processing by Peter D. Zimmerman.



Figure 3: A-10 “Warthog” fighters exiting hardened shelter area.

Source: Google Earth. Post-processing by Peter D. Zimmerman.



Figure 4: Open revetment storage at runway.

Source: Google Earth. Post-processing: Peter D. Zimmerman

Fighter aircraft vulnerability was estimated by Robert E. Novak, Jr. in his Master's Thesis "Case Study of an Aircraft's Single Hit Vulnerability" prepared at the Naval Postgraduate School, Monterey California in September 1986.[17] Novak used computer simulations of fragments penetrating the target aircraft, a hypothetical "A-20" attack plane, in flight. He found that four random hits were generally able to guarantee the complete loss of control of the aircraft, its destruction by fire, or its explosion.

Novak's thesis sought to ascertain the vulnerability of an aircraft in flight to a single hit; our task is different; we must make a plausible estimate of the number of hits on a stationary aircraft to prevent it from being able to take off safely and perform properly in combat or to be readily repaired. While in flight an aircraft experiences enormous stresses ranging from g-forces when turning to the dynamic pressure the air exerts on the airframe. In both cases a weakened aircraft is more likely to fail immediately than is a stationary one to be unable to fly at all. Further, the fuel in an airborne plane can catch fire, while a dry plane on the ground will not.

Building upon Novak's calculation and the diagrams in his thesis, we assume that four penetrating fragments per projected square meter are sufficient to kill or force major repairs of a modern aircraft, even if it is on the ground, lacks fuel, is unmanned, and contains no ammunition, all of which are taken into account in the thesis.[18] While an estimate of 75 kg of high explosive in a warhead of 150 kg total mass seems reasonable, we do not have available the North Korean concept of operations for the missile. The warhead could be designed to contain large amounts of prepared fragments, or merely to use the fragmentation of the warhead case produced in the explosion. We examine some possibly limiting cases:

- The design resembles that of the submunition warhead of the United States M-270 MLRS rocket which contains 182,000 fragments large enough to penetrate an aircraft within a 90 kg warhead.[19]
- The warhead fragments from its explosives, but like the BM-30 *SMERCH* Russian system contains

only about the number of fragments of a similarly sized submunition cargo round (approx 4,000 fragments for the heavy fragment version and 26,000 for an antipersonnel munition using .75 gm fragments),[20]

or

- It contains a large number of fragments, 40,000-100,000, but still less than the M270 rocket. A unitary warhead may produce no more than 20,000 fragments.

If we require 4 fragments per square meter, the lethal radius for the M270 type warhead is *63 meters*, quite similar to the radius at which the warhead produces a 5 psi blast overpressure[21]. One of the reviewers pointed out that for cased charges up to 50% of the explosive energy may be consumed in rupturing the casing. If this is the case, then the radius at which a given overpressure from the reduced energy blast is reached will be reduced by $1/2^{1/3}$, that is by 79%, compared to the bare charge.

The BM-30 heavy fragment warhead would have a lethal radius against an aircraft of about *9 meters* while using the 26,000 fragments from the anti-personnel version produces a *22 meter* radius. The quite reasonable assumption of 100,000 prepared fragments still gives a lethal radius of *44 meters*.

These lethal radii must be properly understood. They are for an explosion in free air, not on ground impact. We do not know the fuzing algorithm for the KN-09; an assumption of detonation on impact is the simplest we can make. In such a case ricocheting fragments can extend the lethal radius.

However, if the aircraft are in covered and hardened shelters, only fragments coming through the open ends are effective; the rest will be harmlessly absorbed. If planes are merely protected by walls between single aircraft cells, the damage radii are likely to be reduced unless KN-09 rockets land on the taxiways leading out of the shelter area. Even then, airplanes in some directions will be completely protected, while those in other directions will be vulnerable.

If the lethal radius of a weapon equals or exceeds the CEP of the system, that capacity still does not guarantee the destruction of the target, even when the weapon is correctly aimed and functions properly. CEP means that half of the weapons strike points *further* away from the aim-point than the probable error circle. We illustrate that with a simple graph:

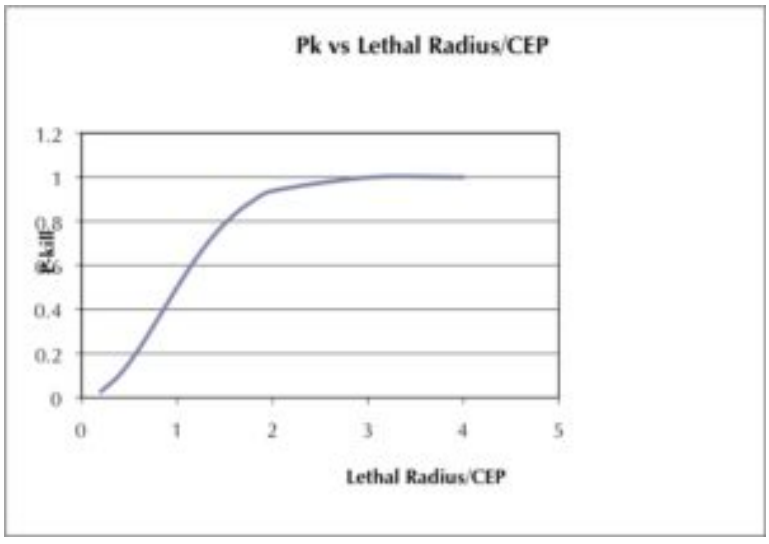


Figure 5: Probability of Kill versus Lethal Radius/Circular Error Probable

The lethal radius must be almost twice the Circular Error Probable (CEP) for the single-shot P_k to exceed 90%, and that is never the case for the KN-09 system against useful targets. Consider the case where R_L is equal to the CEP. The single-shot probability of kill, P_{k1}, is 0.5. If two identical but independent missiles are fired at the target, the kill probability for the two is $P_{k,2} = (1- (P_{k,1})^2) = 0.75$. If three missiles are used, the kill probability increases to $P_{k,3} = 0.875$. The overall kill probability increases but slowly as more missiles are aimed at the target. Because the kill probability does increase so slowly, firing multiple missiles against each target is not a useful allocation of resources unless the number of KN-09 missiles available significantly exceeds the number of targets. Note that this differs greatly from the proper strategy when countering nuclear-armed missile warheads where very many interceptors may be shot at each incoming target.

Since the KN-09 is a real missile, not a mathematical one, its reliability must be less than 1.0. We assume that one round in four launched fails to function properly from launch through explosion. That is, we choose a plausible *dud and failure rate* of **25%**.[22] Consider for a moment the case where four missiles are launched against the same aimpoint. Since each missile is presumed to be independent of all others launched, it's possible for one, none, or even all to fail.[23] This complicates the process of computing kill probabilities, but clearly when duds are factored in the chances of destroying a given target decrease. (Despite the problems in the note below, we assume that failures are uncorrelated.)

This effect of the dud rate may be somewhat compensated for if the defense deploys its targeted assets (aircraft in this case) in such a way that a single incoming KN-09 can damage more than one fighter.

Eight ROK air bases are located within KN-09 range of the DMZ. The KPA may choose to target any, all, or none. The ROK uses several different types of storage for its aircraft, ranging from parking on the tarmac to revetments open to the sky and on two sides, to completely covered shelters open on only one end. Some are apparently camouflaged with only a hidden adit. (An adit is a horizontal passage for the purposes of access or drainage in an underground site.) The adits I have located may, alternatively, be munitions storage. The camouflage cover is easily seen on Google Earth images.

The FlightGlobal website (https://www.flightglobal.com, accessed 28 November 2017) inventories the ROK air force and estimates that it operates 399 combat aircraft, in large measure fighters and attack aircraft. Using estimates above for the lethal radius and CEP of the KN-09 system, it appears plausible that the missiles would be effective against those aircraft on the tarmac and in open revetments. Depending on the size of the DPRK inventory of KN-09 missiles we find the following in Table 1:

Number of Launchers	Missiles used	Aircraft destroyed
10	80	<40
100	400	100-200
	800	150-300

Table 1: Estimate of aircraft destroyed by KN-09 missile attack assuming that the SATNAV system used in the missile is functioning.

One of the critical assumptions built into the table is that they will be vulnerable only to the first salvo of a KN-09 attack. Given the estimated reload time for the system, it is not plausible that aircraft will remain on the ground in their normal parking places (particularly if open) after the first

KN-09 lands.[24]

If the DPRK has ~100 KN-09 launchers, and if the North Korean strategists decide that it is worth using most of a surprise first salvo to attack the ROK air force and USAF air assets in Korea, it is possible, even including failed missiles, that they can disable half or more of the aircraft on the ground.

This attractive option forces the DPRK military to choose how to allocate the remainder of its first KN-09 salvo. Assuming 400 missiles are dedicated to air asset suppression, the remaining 400 might be used to attack allied forces moving to defend the DMZ. However, the North's ability to do this depends upon their ability to collect intelligence on the location and movements of allied forces and on the North's intelligence cycle time. It also depends on whether the KPA is able to fit their missiles with appropriate warheads. [The website armyrecognition.com states that the KN-09 resembles the Chinese SY-300 which can be fitted with a full range of warhead types. Possibly this applies to the KN-09 as well.[25]]

It seems improbable that the North Korean forces possess sufficient reconnaissance assets to enable them to perform battle damage assessments after the first KN-09 salvo so as to know which targets have survived. Further, alliance forces will surely not remain immobile after the first salvo, and are unlikely to remain at the sites the North Koreans will have targeted. For this reason even if SATNAV systems have not been jammed or turned off after the first salvo, the second round of KN-09 launches cannot be used as effectively as the first to attack point targets such as aircraft and ground forces on the move.

Consider the effectiveness of the KN-09 against troop movements. The lethal area of the missile is estimated to be 1800 m^2. The maximum 800 missiles in a single salvo from 100 launchers has a total lethal area against unprotected soldiers of 800*1800 m^2 or 1,440,000 m^2. This assumes that the lethal areas do not overlap, which in practice is a poor assumption but provides a maximum value. Putting that in a different unit, the area that can be attacked, no matter how distributed and provided the same location is not attacked more than once, sums to about 1.5 square kilometers. That area can be allocated in many ways. If the missiles are used simply for area bombardment, they are neither efficient nor terribly effective given the long time between salvos. To be most effective, and to use take advantage of its guidance system's capabilities, the KN-09 must be aimed at specific targets rather than used to barrage a large area.

Convoys are one possible target. According to an estimate by Michael O'Hanlon of the Brookings Institution, a division on the march consists of roughly 1500 vehicles spaced 100 meters apart, thus taking up 150 kilometers of road moving single file.[26] [27] At a pace of 50 kilometers an hour (only sustainable if tracked vehicles are on transporters), the convoy would take three hours to pass a single point; at a more reasonable average speed of 30 km/h, the time to pass a point rises to five hours.

The assumed lethal radius (anti-personnel) against fragments from the KN-09 warhead is approximately 60 meters, and the covered area is 120 meters in diameter. This is nicely comparable to the inter-vehicular spacing of the convoy so that one missile might damage up to two thin skinned vehicles and the troops carried within. The blast effect of the warhead might easily overturn trucks and vehicles similar to the now-obsolete Humvee (HMMWV) and potential replacement vehicles. It is not clear how vulnerable an MRAP (Mine Resistant Ambush Protected) vehicle would be to KN-09 warheads at impact distances greater than approximately 20 meters (5 psi overpressure). The MRAP's high center of gravity made it susceptible to many rollover accidents on bad roads.[28] The Joint Light Tactical Vehicle has been designated as the successor to the Humvee.[29] Its armor should protect crew and passengers from light fragments.

The typical U.S. lane with is 12 feet or 3.7 meters (standard lanes for Interstate Highways), with two lane roads being, therefore, 7.75 meters wide plus shoulder width of 2-3 meters. The Asian standard lane width is 3.3 meters.[30] An approximate width for Korean roads might be 14 meters, of which half can be used to move a division. The necessary right-of-way results in a channel through all but the most complex countryside of about 30 meters.

If the KN-09 is used to attack a division on the highway, one could expect that roughly one third of the missiles that are not duds should strike within that channel. Unless the KN-09 has a target-identification optical, IR or radar guidance system, it is not possible to target specific vehicles, but a barrage of 8-10 missiles targeted on the center of the highway and spaced out approximately 100 meters apart should have the effect of disrupting the divisional movement with high probability by damaging or destroying vehicles over a one kilometer long kill zone. The effort to bring in recovery vehicles, ambulances, and other necessary equipment should halt the column for at least an hour as roughly ten damaged vehicles and many wounded personnel would need to be evacuated.

This is an efficient and economical use of KN-09 missiles and launchers to disrupt the US or ROK response to an attack from the north. It is likely to be a high priority use for much of the KN-09 rockets in the KPA's arsenal, but not immediately as it will take hours and days for such US-ROK staging to mass and then start to move northwards. At the outset, many of the KN-09 might be used against the area targets presented by the staging areas where units arrive to prepare to move north.

3. ATTACKING CIVILIAN TARGETS

In his 2012 analysis of casualties in the Seoul area from North Korean artillery and artillery rocket fire, Roger Cavazos suggested that we "mind the gap;" arising from the significant difference between predictions that Seoul would vanish in a lake of fire with 'millions,' or at least a million, dead, and the reality. Cavazos pointed out that although the North Koreans did have large numbers of guns and rockets along the DMZ, many of these systems lacked the range to reach Seoul, and that not even all of those that could bombard the city were likely to be used in that role; the North Korean People's Liberation Army (KPA) would have other pressing military tasks in the event of war.

The advent of the KN-09 appeared to change the calculus significantly because its warhead was bigger than those of older weapons, and its range of 190 km put most of the ROK in its reach, and in particular, would enable the KPA to attack civilians in all of Metropolitan Seoul, not just the northern exurbs of Seoul within range of the older hardened artillery units and rockets forward deployed by the KPA. In addition, the long range of the missile opens up many previously unreachable target sets to KPA attack. We have so far demonstrated that the KN-09 has significant military utility to the KPA used as an anti-personnel and offense suppression weapon, that it allows the DPRK forces to target the ROK and US air forces in the first moments of the war when many aircraft will still be on the ground. This is a genuine alteration in the way a second Korean War might be initiated.

Do the new rockets make a significant difference to the fate of Seoul itself? The answer is scenario dependent and assumption dependent. Lacking detailed intelligence, we are forced to make assumptions about North Korean strategy and tactics as well as the amount of resources they have been able to devote to fielding the KN-09 system.

1. We do not know what type(s) of warhead have been fitted to the KN-09 missile. We assume a 150-190 kg warhead, of which 50% is high explosive, roughly equivalent in power to TNT.
2. We do not know how accurate the guidance system is. We assume it employs SATNAV, but likely

not the American GPS system. We also assume that it includes a parallel inertial guidance system in case all SATNAV systems are jammed. A reasonable estimate of CEP is 35-50 meters if the SATNAV is working and 250 meters if it is not.

3. We do not know how many launchers the DPRK has completed and fielded. The ROK Defense Ministry assessed in late 2016 hat there were 10 launchers. If only because round numbers are convenient, we bound the number currently deployed (as of the end of 2017) between 10 and 100.[31]

4. In North Korean terms the KN-09 missile is expensive. It is not clear what their priorities are and how many they can afford to build given that priority. We do not know how many rockets have been built and are available for wartime use. The KN-09 is a less complex system than the Nazi V-2; the Germans were able to turn out approximately 5,000 V-2 rockets per year. We will credit North Korea with the ability to build twice that many KN-09 missiles since the DPRK is not at war and not undergoing bombardment. That would imply that by early 2018 a *maximum* of 20,000 missiles were available for use, assuming that the North Koreans built at their *maximum* Questions of component supply and budget constraints could reduce the production rate. We note that the missiles use GPS, and that GPS systems that can function at high altitudes are embargoed and not available generally. Thus, the DPRK will likely have to make some components indigenously. Similarly, logistical support and storage for rear, resupply, and forward deployment of this stockpile may also severely constrain the numbers that might be employed for the various priority uses in the first hours and couple of days of a war. The total KN-09 inventory is less important than the number in the first salvo and the stocks available for use during the first 24-48 hours of conflict.

5. We do not know how many launchers will be used for counterforce strikes and how many for countervalue, to use the language of strategic nuclear arms. The analysis of attacks on airfields demonstrates that it is possible to devote half of the launchers to civilian targets and half to military ones. However, this would likely be considered an inefficient use of a scarce resource which should be employed against the alliance's highest value military targets.

6. We also do not know where those launchers will be deployed at the commencement of hostilities. Surely not all will be close to the DMZ trace; some are likely to be in reserve to counter an ROK-US counterstrike, and for use against ground convoys once they are assembled and head northwards.

Effects of the warhead against civilian targets

Blast overpressure is the principal tool for destroying buildings. If the overpressure is known for a given distance and for a given explosive yield, the radius at which that same overpressure is experienced for other amounts of explosive can be readily computed by noting that the radius of a given pressure scales as the cube root of the amount of explosive. That is:

$$R_Y = R_{y0}[Y/Y_0]^{1/3}.$$

Y is the amount of explosive in question, and Y_0 is the weight of explosive which produces *X* pounds per square inch overpressure at distance R_{y0}.[32]

Table 2 gives the expected radii for given overpressures from 75 kg of TNT. Because the radius at which a given over pressure is reached depends on the *cube root* of the weight of explosive, the 8% difference between the estimates of 75 kg and 95 kg of HE in the KN-09 warhead is negligible in comparison to all the other assumptions in this analysis.

Overpressure (psi)	Range (m)
1	**48**
2	**32**
4	**22**
5	**19**
6	**16.5**
8	**14**
10	**13**

Table 2: Overpressure vs Distance for 75 kg TNT equivalent[33]

The kinds of structural damage experienced at these overpressures have been measured empirically in nuclear explosive tests at the former Nevada Test Site in the USA, and by comparison with the casualties at Hiroshima and Nagasaki as well as with high explosive tests (see Table 3):

Peak Overpressure (psi)	Effects on Structures	Effects on Human Body
1	Window glass shatters	Light injuries from fragments
2	Moderate damage to houses; windows and doors blown out; severe damage to roofs	People injured by flying glass and debris
3	Residential structures collapse	Serious injuries common; fatalities may occur
5	Most buildings collapse	Injuries are universal; widespread fatalities
10	Reinforced concrete buildings are severely damaged or demolished	Most people are killed
20	Heavily built concrete buildings are severely damaged or demolished	Fatalities approach 100%

Table 3: Structural Damage and Effects on Human Body as Function of Overpressure[34]

An overpressure of 5 psi sounds extremely small to cause building collapse; however it is not merely the force exerted on a single square inch but rather the total force exerted on an exterior wall which must be calculated.[35] That is certainly far greater than most structures are designed to resist. As it moves across a building the blast wave first breaks windows, then tends to force floors on the side of the structure facing the explosion upwards. Finally, the blast wave surrounds the structure and begins to exert downward force on the roof and inward pressure elsewhere.

The nuclear case is somewhat *simpler* than that of conventional weapons because the energy is many orders of magnitude greater. As a result, the overpressure does not decay so rapidly with distance from the center of the explosion. In the more complex case of a hundred or so kilograms of high explosive, the overpressure exerted on a building changes rapidly as it spreads from the closest point to the blast out to the sides of the structure. As Cross, *et al.* point out “direct primary air-blast damages tend to be more localized and may be, for example, significantly more severe on the side of a structure facing an explosion than the opposite side (FEMA, 2003)[36] This asymmetry may actually contribute to building collapse.

The streets and roads of modern Seoul cover approximately 22% of the land area, with the modern road/street width roughly 7.2 meters. It was 10.7 m in the areas built before 1990.[37] During commuting hours most workers are likely to be in transit and vulnerable to both the blast and fragmentation effects of the KN-09 (except for the 26.5% using the subway system). Many will be walking between their place of employment and entrances to the subway and to railways. Others will be in buses, taxis, and private cars. However, if the ROK has already declared a state of emergency and begun to mobilize, it is likely that all of the normal commuter patterns will have been disrupted.

During the working day, in contrast, most are likely to be inside modern structures which will provide some shelter from the effects of warheads exploding any place except on their own building or in the streets adjacent. Similarly, at night most Seoulites will be at home in buildings which provide at least some shelter from rockets detonating any place except on their building or within the 4 psi radius (22 meters) at which most residential structures collapse. The area within the 4 psi circle surrounding a KN-09 impact point is:

$$A_c = \pi * 22^2 \text{ m}^2 = \mathbf{1{,}520 \text{ m}^2}$$

Assume that each arriving and exploding KN-09 destroys 1,520 m^2. Assume as well that the DPRK has 10 reloads for each of 100 8-rocket launchers, for a total of 8,000 rounds that could be fired in principle and assuming no interruption by US-ROK attacks in as little time as 7 hours from the first salvo. The destroyed area is 12,200,000 square meters, or roughly 12 square kilometers. However 25% of the missiles are expected to fail resulting in only 9 square kilometers afflicted.

The area of the Special City Seoul is 605 square kilometers. Apparently, if all of the KPA's missiles were fired at Seoul and none at aircraft, command-and-control posts, or staging areas and convoys, the KN-09 fleet can destroy around 1.5% of the Special City on the first day of a war. If Seoul were static and homogeneous, this might be a mere pinprick on top of the bombardments described by Cavazos. But Seoul is neither static nor homogeneous. The KN-09 force need not strike uniformly across the area of the city.

The location of the population changes over the course of a day and week in a predictable manner. The core population more than doubles from before the beginning of working hours until after they end. During that period the population is at elevated density in offices and factories, concentration points. In the evening the population disperses to the residential areas. Seoulites are more spread out, and the population density is lower. The city "breathes."

If the KN-09 were to be used in an anti-city mode, then the North Koreans would likely employ a targeting strategy against the densest concentrations of people in the most vulnerable situations.

The fraction of the Seoul metropolitan area that the KN-09 system can actually destroy is too small to be worth expending the quite expensive and militarily valuable weapons against diffuse or dispersed targets.

If causing civilian deaths is the paramount objective for the system, the firing doctrine should be devised to strike at the beginning or at the end of the working day to attack Seoul when the fewest of its citizens are under cover and when they are the greatest distances from structures which would offer some protection. Gangnam, of all of the districts, has the largest inflow population, over 614,000 people[38]. In addition, it has 123,000 people in the outflow population meaning that at peak transport times 762,000 people could be put at risk. Seocho-gu has an additional 439,000 likely to be on the move at rush hour. The third largest commuting borough is Yeongdeungpo with an additional 402,000. If KN-09 bombardment were restricted to those three boroughs and carried out

during rush hour, the largest number of people could be placed at risk.

A simplified way of estimating casualties is to assume that the population in motion covers roughly 10% of the available street area in each administrative district, but that the North Koreans cannot know very accurately which 10%. Thus, KN-09 rockets must be employed against all of the major streets, above-ground rail stations, surface and elevated train tracks, etc.

Why does not the moving population simply fill the streets? Traffic lights, for example, impose a kind of bunching of pedestrians as well as vehicles. People can cross on green, but gaps between bunches of pedestrians thus exist. Trains fill a very small percentage of the length of track; headway between commuter trains ranges from a couple of minutes (e.g. in the London Underground when operating at peak capacity and efficiency on modern lines such as the Jubilee Line) to 10-12 minutes on the Washington, D.C. Metro at non-rush hour times. A Washington Metro car is 75 feet (22.86 m or approximately 23 m)[39]. Seoul rail cars are similar in size, 19.6 m long, 3.12 m wide and 3.8 m high.[40] An eight car commuter train is thus about 160 meters long.

According to Wikipedia and other sources, the Seoul Metropolitan Subway is the longest urban railway net in the world[41] with 331.5 km of track on the major lines (1-9). Although called a subway in official documents, the network comprises rapid transit, light rail, commuter (heavy) rail, and subway. The Seoul urban railroad network is so extensive, and the fraction of the track occupied at any one instant by passenger-carrying cars is so small, that barraging the entire system is clearly impractical. Various lines operate at speeds from 33 km/h (locals), 47 km/h (express-stopping), to 100 km/h.[42] The above mentioned eight car train would pass a given point in periods ranging from 6 to 17 seconds.

If the DPRK has adequate real time intelligence, which it almost certainly will not because it lacks overhead capabilities and adequate C^3, so that it knows where every train is located and heading as well as its speed, the problem changes. In that case, individual trains can be targeted so long as the satellite navigation system relied on by the KN-09 remains operational. Given the reputation that the system apparently has for on-time travel, and if the North Koreans can accurately predict the time on target for each missile, it is likely that a simple time table will allow determining the locations of at least several trains on main lines *when bombardment begins, but not afterwards*. However, within moments of the first salvo landing, the time table will be very little help because the system will likely come to a stop and then slowly recover in part or descend into chaos. In either event, passengers will try to leave stopped trains in order to seek better shelter.

Continuing the bombardment after the first salvo will require real time intelligence such as might be available from drone aircraft surveilling the rail system. Still, *the intelligence cycle time is apt to be too long to permit real-time retargeting of the missiles*. Another important point to consider is that the ROK will have to supply electric power to keep the trains running. This may prove to be extremely difficult, particularly if the KPA is able to strike power nodes and POL.

The conclusion we reach is that attacks on the soft commuter population are best achieved by aiming not at the rail *system* but rather the major stations it serves. Even though the commuting population is spread out in time over both morning and evening rush hours, a substantial part is in or entering the stations continuously over both periods. Looking only at the three major *gu*, about 1.6 million people will enter and leave the stations during each rush hour. If the population is distributed uniformly over those periods, *534,000* people per hour are exposed to KN-09 attack assuming a three hour commuting period.

Many areas of the largest commuter rail stations are below grade and offer significant protection against KN-09 bombardment. Nevertheless, people enter and exit the stations through above-ground

portals. The approximate lethal radius of a KN-09 warhead against unprotected personnel is about 25 m. A pedestrian walking at a reasonable pace of 5 km/h (1.4 m/s) will cross a 50 meter diameter target zone in 36 seconds. Thus a zone 50 meters wide immediately outside all of the portals for the major stations taken together will constantly contain about 5,300 people. Simultaneous KN-09 bombardment of all those portals would, thus, be likely to kill 5,000 immediately and seriously injure perhaps twice that number. Since major stations are co-located with major shopping areas, many more people could well be in the vicinity, and the casualty estimates above should be taken as lower limits. However, the actual number of casualties inflicted by fragmentation warheads used against crowds of people will, in practice, be significantly reduced by the fact that people shield the people behind them.

The number of rockets needed to bombard subway station entrances depends both on the number of entrances and also on the spacing between entrances. Nevertheless, the likely number is not less than one missile per station entrance assuming that the North Korean intent is not to kill as many ROK citizens as possible, but to throw Seoul into chaos.

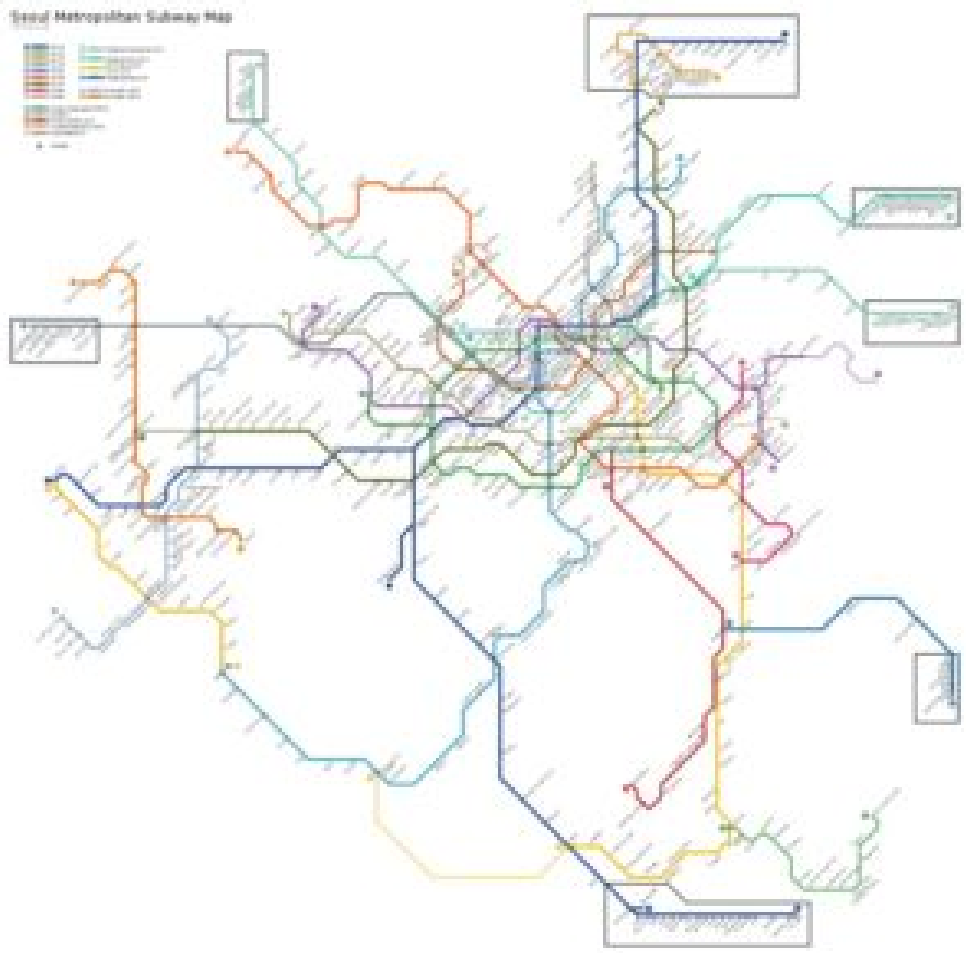


Figure 6: Seoul Subway Map from here.

Shortly after the opening salvo of KN-09 rockets lands, perhaps signaling the beginning of hostilities, most ROK transportation systems will likely be shut down and their customers will seek shelter underground. Attacking people in the transportation sector, as opposed to the infrastructure such as electrical distribution stations, track and signaling, and the above ground components of the stations, front loads the requirements on the KN-09 system, as the only conventional long range North Korean system capable of attacking all of Seoul nearly simultaneously. We do not know the details of North Korean strategic and tactical planning in this regard.

The Seoul subway system has more than 280 stations (see Figure X) most of which have at least 2 and the majority no fewer than 4 entrances, often more. Thus, to hit all the entrances is well beyond the capacity of the KN-09 system, even if all of the launchers were used solely to attack civilians.

Nonetheless, it is reasonable to assume that some portion of the KN-09 missiles would be used for high value government and civilian targets in the first salvos. The precision-guided strikes might include visible landmarks such as TV towers, City Hall, some very tall apartment buildings, the business district, and any point targets of very high value in terms of creating confusion, chaos, and above all, congestion (that would impede military vehicles that might be countering KPA special force attackers in Seoul)—freeway junctions with cross-river bridges, for example.

However, at some point, additional civilian casualties are superfluous to the KPA. Given that its shorter-range artillery and rockets can create carnage involving thousands of civilians in the northern suburbs that will be immediately reported and propagated via social media, additional attacks on civilians in metro-Seoul will have little marginal value at causing panic. One way to estimate this upper limit would be the number of civilian casualties in metro Seoul that would overwhelm first responder transport capacity and emergency room processing capacity. Seoul has about 80 hospitals and about 56.000 acute hospital beds, a large fraction of which will be occupied by patients before an attack begins.

Given that under normal circumstances emergency rooms operate near maximum capacity at nearly all times, swamping the system probably requires only that a few tens of serious casualties reach an ER, particularly if the injuries are of the type of blast, gunshot (shrapnel) wounds, and severe burns requiring rapid, skilled and intensive care. Creating a bottleneck in the approximately eighty emergency rooms could likely be achieved with only hundreds of civilian casualties in central Seoul. Further civilian casualties are probably superfluous both in terms of degrading medical care and terrorizing the surviving population. Early in the war the rockets to cause those casualties would be more effectively directed at military targets.

No more that 50-100 missiles should suffice to overwhelm emergency medical facilities, fewer if directed at crowded subway entrances where people are exposed during rush hours; more if the attack occurs at night when people are indoors and less vulnerable to shrapnel and most blast effects.

Thus, attributing political and military rationality to the KPA's targeting choices using the KN-09, it is reasonable to bound the fraction of the missiles, assuming it has 100 launchers as the upper end of its capacity, to 6 to 15% percent of the first salvo on D-Day. Once allied defenses are active and SATNAV systems jammed, the KN-09 will no longer be a precision weapon, and will be less useful against many military targets. It is conceivable that relatively dispersed, low-precision targeting of civilians in Seoul might continue, but this use of the weapons would simply "bounce the bodies" and not do much to increase civilian disorder.

Once the DPRK is defeated, it is conceivable that indiscriminate targeting of ROK civilians will be held against the surviving leadership of North Korea. It is also likely that those leaders will have worse problems to contend with.

In short, it is not obvious that using the KN-09 system to inflict large numbers of civilian casualties is more attractive than using the same missiles to attack ROK and USAF aircraft and missiles before they can engage in counter-battery fire, or to degrade the movement of allied troops and equipment to the battle front.

4. CONCLUSIONS

The introduction of the KN-09 missile to the DPRK inventory poses challenges to the Republic of Korea. It places more of the ROK infrastructure, and more importantly, the ROK armed forces at risk in the opening moments of a Second Peninsular War. However, despite posing those tactical and operational challenges to the ROK, the KN-09 does *not* alter the basic strategic calculus of mutual conventional deterrence across the Demilitarized Zone spanning the peninsula.

North Korea has had thousands of artillery tubes and mobile rocket launchers stationed along the DMZ trace in a buildup begun in the late nineteen sixties and continuing until the present. As the city of Seoul expanded northwards, especially from the nineteen eighties onwards, the northern exurbs of Seoul itself have been within range of DPRK conventional artillery and rockets. Although Seoul and its environs cannot actually be turned into a lake of fire by these Cold War systems, even with their modernization in recent years, enough civilians might be killed by these systems at the outset of war—not to mention the casualties that would occur as the war proceeded in days and months following—that the North could be reasonably assured that it could deter any ROK adventurism or American decision to launch a token attack against the North (the so-called bloody nose scenario bruited about in Washington).

In response to the North Korean deployments, the ROK assisted by its allies, essentially built and demonstrated a conventional military force that ensured that the DPRK's leaders and the KPA understood that it could not "win" a new conventional Korean War. The DPRK could not hope to occupy and permanently acquire territory and production capacity in the ROK, especially the Seoul urban-industrial area, because the economic and strategic depth of the allies would permit them to endure long after the North ran out of fuel and ammunition—likely within the first thirty days or less-- even if the KPA were assisted somewhat by China.

Because the KN-09 allows North Korean forces to attack ROK/US forces in garrison and aircraft on some more distant air bases, its introduction can slow down and reduce the impact of the *initial* allied response to a conventional attack, but not the extent of the damage the allies can inflict over the course of time. In that sense the KN-09 does change the game, but not in the way that other writers have claimed, by increasing damage to larger areas of Seoul to the catastrophic level. It may slightly increase the duration of a purely conventional war between the two states, DPRK and ROK.

Even though we lack unclassified intelligence to cast a definitive light on the capabilities and employment doctrine for the KN-09, those conclusions are robust within our assumptions. If the North Koreans seek to change the outcome of a conventional war between the two Koreas, a multiple launch artillery rocket with a 200 kg payload, no matter what its accuracy and range, is not the way to do it.. Absent detailed information about the numbers and deployed locations of the new artillery missile, estimating South Korean and American casualties it can cause is speculation. And absent information about the uses the North Korean military has in mind for the KN-09, it is unclear how we should estimate the number of missiles and launchers in the pipeline.[43]

Two other observations are worth making about the impact of the KN-09 system on the current military situation in the Korean standoff today:

The first is that it may provide Kim Jong Un and the KPA with an intermediate level of conventional attack as an intermediate-level response to, for example, a relatively minor overt or covert skirmish. Such a capability might give the DPRK leadership an alternative to escalation to all-out conventional and/or nuclear war. The implicit question is whether in the North Korean view an intermediate response imposes sufficient costs on the ROK and American political and military leadership to force them to hit the pause button on a major allied attack on North Korea.

Use of a relatively small number of KN-09 precision "signaling" attacks on a small number of high

value civilian targets in Seoul, even while foregoing attacks on the northern suburbs to create overwhelming mass casualties, might allow the North to avoid an all-out war by causing American and South Korean leaders to pause, enabling the DPRK to play for time and space, internally and externally. But the KN-09 is not needed for this role. Existing artillery should suffice. The main role of the KN-09 is to reach more deeply into ROK territory than any of its earlier artillery systems permitted.

Still, this is a very risky business. North Korea's problem making such a Clausewitzian use of the KN-09 is that the signal might be misread as reason to accelerate a counter-attack.[44] A more likely conclusion is that the DPRK might feel impelled crank up the volume of its signal and combine a limited, primarily political, precision KN-09 attack with an extremely limited nuclear strike, perhaps as little as a single demonstration weapon in the very low kiloton yield range, visible throughout Seoul while causing few casualties, in a peculiarly North Korean variant of the American notion of flexible response. This seems improbable because the nuclear signal by itself would probably "drown out" any effect from the accompanying KN-09 bombardment. It is extremely unlikely that the DPRK can fit even a small fission device inside the confines of the KN-09 warhead compartment. However, never say never; the United States has built nuclear weapons for the 155 mm howitzer.[45]

In short, it is the combination of the DPRK's advanced conventional and its nascent nuclear forces that is creating a new form of asymmetric deterrence in the Korean conflict. This ability to threaten the continental United States and its allies with nuclear weapons is a new and dangerous situation with a built-in instability. The DPRK lacks the resilience that might allow it to execute a well-controlled nuclear counter strike following a massive allied conventional strike against the North; this requires it to consider using its nuclear weapons at the outset of a major peninsular war if it is to have the C^3 infrastructure to use them at all.

North Korea must also recognize that a nuclear strike, however small, against a target within the United States or its possessions (*e.g.* Guam) is likely to result in a near-instantaneous and super-proportional retaliatory nuclear strike. However, a precision strike against critical ROK and US targets using the KN-09 to reach previously invulnerable areas of South Korea and previously hard to hit targets, is almost certain not to provoke a United States nuclear intervention. The possibility that North Korea might conduct such conventional strikes, particularly if precise, limited, and minimizing civilian casualties, should act to deter potential ROK adventurousness and to restrain U.S. bluster.

The impact of the KN-09 on mutual deterrence should not be overstated, but it should not be dismissed either. How it interacts with North Korean's emerging nuclear force and its declaratory and operational doctrines for their use remains obscure. It is necessary to examine this issue from all angles, including the integration of conventional and nuclear forces in their forces structure. This paper attempts to bound the problem with some preliminary estimates of its military utility to the KPA, and what it can and cannot do with regard to holding Seoul, the ROK's center of gravity, hostage to conventional and nuclear threat.

III. ENDNOTES

[1] Roger Cavazos, "Mind the gap between rhetoric and reality," *NAPSNet Special R*eport, 2012. https://nautilus.org/napsnet/napsnet-special-reports/mind-the-gap-between-rhetoric-and-reality/#figureone.

[2] Little Boy, the gun-assembled weapon dropped on Hiroshima, had a yield variously estimated at

12-15 kilotons. The implosion-assembled Fat Man used against Nagasaki had a yield of approximately 20 kilotons.

[3] https://www.norsar.no/press/latest-press-release/archive/the-nuclear-explosion-in-north--orea-on-3-september-2017-a-revised-magnitude-assessment-article1548-984.html. NORSAR is the Norwegian National Data Centre for verifying compliance with the Comprehensive Nuclear Test Ban Treaty and operates seismic arrays in Hedmark, Troms, and Finnmark as well as on Spitsbergen and Jan Mayen islands. https://www.norsar.no/about-us/

[4] http://dev.defense-update.com/page/9?attachment_id

[5] See:

http://www.armyrecognition.com/weapons_defence_industry_military_technology_uk/north_korea_has_tested_a_new_local-made_300mm_mlrs_multiple_launch_rocket_system_11003161.html accessed 2 December 2017.

[6]In flat earth approximation and in the absence of an atmosphere, the rockets would be fired at a 45 degree angle for maximum range, but then will likely strike the sides of buildings and be comparatively ineffective at inflicting structural damage. This is because Seoul's streets are fairly narrow. In the presence of a real atmosphere a long-range system would have its trajectory optimized to spend more time at high altitudes where the air is thin. The trajectory would be considerably "flatter" than the simple approximation indicates. It is possible that a well designed system could alter its terminal trajectory to enter very steeply. I thank one of the reviewers for pointing this out. Alternatively, the trajectories can be lofted so that more rockets reach ground level; in that case they are more effective against people because of their fragmentation effect, and the air blast is effective against structures. Although lofted trajectories imply shorter ranges so that the launchers must be deployed closer to the DMZ trace, the very long range of the system will still complicate its suppression by ROK/US forces. This should extend the useful life of the KN-09 system against the Korean population and infrastructure.

[7] In this sense the "lethal area" means that area in which an unprotected soldier standing upright would be incapacitated, not necessarily killed.

[8] Ove Dullum, private communication.

[9] Ove Dullum, private communication

[10] One website, militaryfactory.com, states that the eight rockets are packed in two four-round pods which can be reloaded "in short order." The same site gives the maximum on-road travel speed as 60 km/h. See: https://www.militaryfactory.com/armor/detail.asp?armor_id=1065 accessed 11 February 2018. However, for the purposes of this paper we accept Ove Dullum's estimate of 45-60 minutes to reload.

[11] Militarytoday.com estimate for combined inertial and satellite navigation guidance for the similar but larger Chinese A-300 system. Ove Dullum's estimates are in this region.

[12] I thank one of the reviewers for the insight into the operation of a proximity fuze in an urban environment.

[13] The author was deeply involved in the classified analysis of the Patriot's record defending Israel and Saudi Arabia. For that reason additional comment on the effectiveness would not be appropriate in this paper.

[14] See: www.fighter-planes.com/info/f18.htm, accessed 20/11/2017.

[15] See: http://www.af.mil/DesktopModules/ArticleCS/Print.aspx?PortalId=1&ModuleId=854&Article=104499 accessed 20 November 2017

[16] See: http://fighter-planes.com/ accessed 20 November 2017.

[17] See: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA175723 accessed 20 November 2017.

[18] There is a story from World War II, possibly apocryphal, that a senior officer sought to save lives by examining bombers returning from raids over Germany. He identified the areas where the most bullet holes were found and directed ground crews to strengthen those places. In fact, he was observing the strongest parts of the plane which need not be hardened. Bombers hit in the most vulnerable areas never made it home, so an examination of their "wounds" was impossible.

[19] See: https://wikipedia.org/wiki/M270_Multiple_Launch_Rocket_System/ accessed 22 November 2017.

[20] See: https://Wikipedia.org/wiki/BM-30_SMERCH accessed 22 November 2017/

[21] Note that we have no usable information about the velocity of the fragments approaching the end of their trajectories, nor of their densities, so that it is not quantitatively possible to determine whether or not they will penetrate the skin of the aircraft. The loose definition of "lethal area" implies that we should assume these fragments do damage their targets.

[22] This is the same dud rate used by Cavazos. It appears that Cavazos has combined the true dud rate (fuzes which fail to detonate the warhead's explosives) with the failure rate (missiles that fail to launch, fail to fly successfully, or which go significantly off course). Other authors might separate the two factors recognizing that historic dud rates for missiles which reach their target are close to 25% and that still more missiles are lost to failures. For institutional consistency we use 25%.

[23] Missiles are not, in fact, independent. If there is a specific situation in which one round is likely to fail, and the next follows a similar trajectory and is launched and prepared similarly to the first, it is also likely to fail. Or suppose that a fuze is badly designed and fails to detonate the warhead under common circumstances, as was the case in submarine torpedoes fired by the United States Navy early in World War II; very often all rounds will be duds. Failures are frequently not random, but are correlated, even though it is mathematically easier to use uncorrelated failure probabilities.

[24] We do not know the character of the KN-09 warhead. It could be primarily blast or primarily fragmentation. It can be proximity fuzed or impact fuzed or something else including fuzing for side strikes of the descending airframe against vertical structures. It is possible that there are several interchangeable warheads for the missile making quantitative analyses of its effects difficult, since they could include CBW, cargo rounds and scatterable mines. Scatterable mines could be held to be prohibited anti-personnel mines and hence generally prohibited. The DPRK may not, however, care.

[25] See: http://www.armyrecognition.com/weapons_defence_industry_military_technology_uk/north_korea_has_tested_a_new_local-made_300mm_mlrs_multiple_launch_rocket_system_11003161.html accessed 29 November 2017.

[26] Michael O'Hanlon, private email communication, 29 November 2017.

[27] A convoy on a two-lane road must move single file because the second lane must be reserved for command vehicles, accident-clearing vehicles, and emergency vehicles of all kinds.

[28] See https://en.wikipedia.org/wiki/MRAP#Rollovers_and_electric_shock accessed 30 November 2017.

[29] See: https://en.wikipedia.org/wiki/Joint_Light_Tactical_Vehicle accessed 30 November 2017.

[30] See: https://www.researchandexperts.com/report/00RV-CIC180543PP/mltm-shinji-gog-um-road-development-republic-of-korea-project-profile/ accessed 30 November 2017.

[31] ROK Ministry of National Defense, *2016 Defense White Paper*, Publication Registration Number 11-1290000-000446-11. Update, June 11, 2018: We note that on June 10 2018, RAND Corporation published "The Korean Peninsula: Three Dangerous Scenarios" by Michael J. Mazarr, *et al.,* RAND Perspective Report PE-262-A, Santa Monica, at: https://www.rand.org/pubs/perspectives/PE262.html This report (page 8) estimates that the KPA currently possesses 36 KN-09 launchers. This estimate fits well within the bounds of ten to one hundred launchers assumed in the present report. If 36 is the correct number of launchers, the maximal estimates in this report should be scaled back by about a factor of three. In that event, the options for KN-09 use available are significantly reduced, and the missile is even less of a strategic threat than we estimated.

[32] We depart from SI (metric units) for blast overpressures which are normally given in pounds per square inch, a legacy of studies of the effects of nuclear weapons.

[33] Author's calculation based on graphs, tables, and equations in Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, Third Edition. (U.S. Departments of Defense and Energy: Washington DC, 1977), Chapters 3, 4, and 5.

[34] Kenneth Cross, Ove Dullum, N.R. Jenzen-Jones, Marc Garlasco, *Explosive Weapons in Populated Areas: Technical Considerations relevant to their use and effects,* Armament Research Services (Australia: May 2016), p. 14. More detailed results can be obtained from Glasstone and Dolan, *op. cit.*, Chapter 5. However the difficulty of calculating those results is fairly high.

[35] The *force* on a ten foot square section of wall when the *overpressure* is 5 psi is:

F= 5(psi)*(100 sq ft)*(144 sq in/sq ft) =5*100*144=72,000 pounds or 36 tons.

[36] Cross, *et al.,* p. 15. *Primer to Design Safe School Projects in Case of Terrorist Attacks*, Risk Management Series, FEMA 4328. December 2003. Said to be available at http://www.fema.gov/pdf/plan/prevent/rms/428/fema428.pdf, but the link apparently does not exist.

[37] See: http://www.atlasofurbanexpansion.org/cities/view/Seoul accessed 2 December 2017.

[38] 2015 census data

[39] See: https://en.wikipedia.org/wiki/Washington_Metro_rolling_stock. Accessed 13 February 2018.

[40] See: https://en.wikipedia.org/wiki/Seoul_Metropolitan_Subway_rolling_stock. Accessed 13 February 2018.

[41] See: https://en.wikipedia.org/wiki/Seoul_Metropolitan_Subway. Accessed 13 February 2018.

[42] See: https://www.railway-technology.com/projects/seoul-metro/. https://www.railway-technology.com/projects/seoul-metro/. Accessed 21 February 2018.

[43] It may be that foreign sales of the KN-09 turn out to be more important to North Korea than the increment the missile provides to its own combat power. The KN-09 may turn out to be most important to the DPRK as a source of foreign currency rather than as a weapon for its own use.

[44] Such a signal would need to be accompanied by rapid and emphatic diplomatic efforts designed to reassure the ROK and US leadership that the North Koreans had no interest in a wider war and would stand down immediately after one KN-09 salvo. It is not obvious that the allies would respect that effort and would withhold their own retaliation.

[45] But such weapons are exceedingly difficult to design and build. At present they are well beyond DPRK capabilities, and if the North does cease testing, they will never acquire them.

IV. NAUTILUS INVITES YOUR RESPONSE

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