# An Assessment of Uncertainty due to Adversary Mobility

By

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# Abstract

Uncertainty related to an adversary's tactics, techniques, and procedures is often difficult to characterize, particularly during the period immediately before a conflict, when planning for a face-to-face confrontation with a combatant. Adversarial freedom of maneuver and the fixed nature of asset defense leaves limited room for error or half-assessments, yet past analysis of regional defendability presumes a static, symmetric adversary, rather than a nimble, cunning one.

This thesis examines historical events to identify the source of uncertainty with respect to defensive operations, and proposes that an alternative measure of performance be evaluated to fully characterize the effectiveness and limitations of defensive elements in the face of a determined peer.

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## Disclaimer

The views and opinions expressed in this academic thesis represent only those of the author. All systems represented are notional unless otherwise stated. All historical information originated from open, acknowledged sources.

## Notice

An unpublished appendix is available upon request. Please contact the author for further information or to review this material.

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# Lists of Acronyms and Abbreviations

| | |
|---|---|
| ABM | Anti-Ballistic Missile |
| COCOM | Combatant Command |
| DoD | Department of Defense |
| MOE | Measure of Effectiveness |
| MOP | Measure of Performance |
| ICBM | Intercontinental Ballistic Missile |
| TBM | Tactical or Theatre Ballistic Missile |
| CEP | Circular Engagement Probable (Probability) |
| WMD | Weapon of Mass Destruction |
| TEL | Transporter Erector Launcher |
| TTTP | Technology, Tactics, Techniques, Procedures |
| PBS | Public Broadcasting System |
| CIA | Central Intelligence Agency |
| DAL | Defended Asset List |
| IED | Improvised Explosive Devices |

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# Introduction

> *"...employing new technologies in old ways of fighting are helpful, but seldom decisive. Rather, existing technologies employed in new disruptive ways of fighting are, by comparison, generally more effective."*
>
> *– Dr. Terry Pierce*

Despite incredible technological advances, unfettered investment in border reinforcement prior to, and during the Second World War, and perceived defensive parity between the two nations, France was steamrolled by the Germans in about as much time as it takes to create a perfect croissant. Less than one month after the Nazi's began their attack, the Republic collapsed, and the new technology that was created to defend against Hitler was now being used against the Allies. The French did not fully understand the effects of uncertainty posed by the mobility of Hitler's army, and they paid a steep price.

The French did not fail to defend themselves due to a lack of will or conviction, nor did they lose because of technological inferiority. They planned and prepared for a direct, symmetrical assault from an equally equipped adversary. An adversary who, incidentally, had no intention of initiating a direct, symmetrical attack, having learned stinging lessons from prior conflicts. What drove Hitler to victory was quite literally his ability to drive around France's deterrent, a predictable, though asymmetric tactic.

History is replete with examples where opponents do not adequately and completely characterize system performance in the face of adversarial uncertainty and are left with an unenviable disadvantage, one in which they were likely ignorant. In truth, when technology, such as ballistic missiles, are paired with a necessity such as regime survivability or resource needs, the emergence of a disruptive asymmetry will undoubtedly result, mandating an end-to-end uncertainty management strategy.

Be they governed by brutal dictators or a people with honorable intentions, countries waging war win when their opponent is caught in a situation for which they did not adequately prepare; conflicts are often lopsided when nation-to-nation parity is perceived, though not reality. For nations with defensive priorities, this can be avoided by acknowledging the innately uncertain nature of an adversary while also appreciating the capabilities and limitations of defenses in the face of this uncertainty. Doing so requires an end-to-end assessment of defense system performance. It mandates that defense planners know not just the area in which they can defend, but what they can defend against.

From distant lessons of Germany and France, to more recent examples in Iraq, Iran, and beyond, opponents have predictably generated uncertainty through the utilization of asymmetric technology, tactics, techniques, and procedures, such as the deployment of mobile missile systems. The goal has been the same through history: to force a change in the calculus of those defending against these threats. However, with knowledge of how these systems are deployed and recognition of how they have been employed in the past, defense planners may now systematically characterize the uncertainty related to this asymmetry in order to rebalance the equation.

# Part 1: Asymmetry as a Strategy

At the close of the "War to End All Wars," André Maginot[1], recognizing the weakness of the Treaty of Versailles, devised a plan to secure the Franco-German border against the inevitable reconstitution of the German military (Wilde, 2001), thereby mitigating the threat that Hitler could impose on France's sovereignty. Maginot's plan would reduce the risk associated with the vast German border, eliminating the uncertainty of attack from the east – what may be referred to today as *area denial.*

Maginot's plan was simple: build a fixed, heavily-fortified, technologically infused buffer zone along the eastern edge of France, up to the Ardennes forest[2], to defend against direct artillery attacks and advancing troop lines. Referred to as the Maginot Line, the only way the Germans could circumvent this incredibly well fortified boundary would be to go through it, or so the French believed. Yet this belief was vested in an assessment of uncertainty due to only one risk, namely that of Blitzkrieg *troop* warfare. An assessment of other areas around France was seemingly not a priority (History.com, 2009), nor was an assessment of a different flavor of Blitzkrieg, namely *mechanized mobile* warfare.

French defense planners presumed that Hitler would launch a fast, direct artillery and munitions attack (Wilde, 2001), so they developed the Line to counter this likelihood, designing it as if they were preparing to re-fight World War I, despite advances in adversary tactics, techniques, procedures, and technology such as the Panzer tank. The Maginot Line was a static defensive element countering a nimble, bitter, determined, and *mobile* adversary.

The outcome was profound. The Germans circumvented the Maginot Line by May 15th, 1940, five days after their attack began. France fell one month later. The fortification strategy ultimately failed, not because the fortified line could not repel the German onslaught, but because the German army would simply go around it, employing cheap,

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[1] French War Minister, 1931-1932

[2] The Maginot line was constructed along the entire eastern boarder of France, though areas bordering Belgium and Germany were the most fortified.

fast, radio-connected tanks, instead of using direct artillery and troop attacks (Pierce, 2004). The Luftwaffe simply flew over it. Mobility and attack origination uncertainty were the key discriminators that won France for the Germans.

Disruptive technology, tactics, techniques, and procedures – that which emerges to counter existing defenses, or out of adversarial necessity – must not be evaluated against one set of metrics designed for a static, legacy adversary. Dr. Terry Pierce may have said it best, "...employing new technologies in old ways of fighting are helpful, but seldom decisive."

The myopic focus of the French on defending themselves from a single symmetrical tactic, indeed a single direction of attack, was largely responsible for their subsequent fall. Reality presents us with similar problems today, as unstable states deploy ballistic missiles as a deterrent to external interference. How, then, should defense planners systematically evaluate an adversary that employs asymmetric tactics, techniques, and procedures? Can a systematic approach and alternative measures of performance characterize the uncertainty related to asymmetric, disruptive adversaries?

At the heart of this assessment is one question: Is there a strategy to avoid a Maginot Line approach to the defense of blood and treasure that will help ensure survival against even the most unstable and bloodthirsty adversaries?

Experts in corporate management would argue that a strategy must have the following characteristics in order to be a true strategy, lest it be confused for a slogan or an objective (Rumelt, 2011):

1) A diagnosis that defines the problem
2) Narrowly focused guiding policy that provides a framework for overcoming the problem's obstacles
3) Coherent actions that may be taken to ensure that resource deployments, policies and maneuvers are consistent and coordinated

An opponent developing a strategy using asymmetric tactics would likely describe the problem as one in which the adversary can predict and effectively counter their advances. The focusing guiding policy then leads to anything that may be effectively used to eliminate predictability which results in specific actions that may be taken.

An asymmetric strategy is one in which the adversary disregards "normal" tactics, techniques, and procedures to change the calculus of a situation (Brimley, FitzGerald, & Sayler, 2013). Iraqi insurgents used an asymmetric strategy in an attempt to expel US and coalition forces from Iraq after the second Gulf War. It was their mobility, access to IED technology (albeit crude), and freedom of maneuver that amped up uncertainty and unpredictability in a hostile region.

Historical examples of companies, teams, and people changing the tactics of game play in order to achieve parity, stability, and survivability are not few and far between. To find a contemporary, non-military example of adversarial asymmetry, one need not look further than the original Apple iPod. The iPod delivered no new technology, in fact, it delivered a different packaging of existing, legacy technology. The innovation behind that delivery was asymmetric – it connected an ecosystem of capability that consumers were just beginning to tap into (Utterback, et al., 2006), where all of their music was instantly available. This dramatically differed from other companies who were effectively reinventing the CD player on flash memory. Incidentally, Apple's slogan was "1,000 songs in your pocket," which implied that your iPod was as mobile as you were.

Apple saw the ability to use an ecosystem to increase the parity difference between itself and its competitors, driving up market instability in much the same way that the Germans saw mobility as a way to drive up uncertainty. Each of these combatants had to divorce themselves from the perspective of their adversaries in order to fight on their terms. These entities changed the rules of the game to survive, and ultimately, to win. Microsoft might allege that Apple used unfair tactics[3], an argument that one could imagine the French alleging under their breath as they signed the Second Armistice at Compiègne[4].

## Asymmetry in Deterrence, Parity, Stability, and Uncertainty

The Germans could not succeed via direct assault on the fortified Maginot line – the forward deterrent was just too strong. Yet the Maginot Line was an incomplete deterrent, as it focused on only one component of the problem with Germany. Since a deterrent is only as good as its weakest component, this would prove to be a profound oversight.

France, in fact, was building a wall of isolation and shutting themselves in. By doing so they were driving down their own deterrence and driving up the relative certainty for their neighbor. This shift in certainty (the Germans studied the line to determine where the weaknesses were and understood how the French would defend themselves), would be exactly what was needed to create a low risk tactical approach.

Though plans were in place to deal with the potential of off-axis attacks, the French believed it unlikely that the Germans would traverse the Northern Ardennes Forest (Pierce, 2004), and did not appropriately assess their defenses against a mobile and therefore highly uncertain threat. They believed this Line would help them achieve parity and therefore stability, yet Maginot focused on one measure of performance – the ability to deny troop activity along the border. It was focus on that single measure that allowed the Germans to split the country in two.

The terms deterrence, parity, stability, and uncertainty, have added weight when used to articulate nation-to-nation dynamics, specifically with respect to ballistic missile defense.

They are defined as follows:

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[3] With respect to connecting users with iTunes, a system that could automatically link their questionably downloaded music

[4] Though inconsequential to this study, Adolf Hitler forced the French to sign the armistice splitting France at the same location where, in 1918, the Germans surrendered, effectively ending World War I.

### Deterrence

Broadly discussed by Brodie and Schelling, and parameterized by the DoD in their Deterrence Operations manual, "deterrence operations convince adversaries not to take actions that threaten vital interests by means of decisive influence over their decision-making." The manual goes on to highlight the limitations of deterrence, particularly when the adversary views your deterrence as incomplete or non-credible (a la, the Maginot Line).

### Parity

State-to-state parity is achieved when both actors have a credible and balanced deterrent. This could mean that both states are able to strike each other's capitol, both states are able to equally defend against attack, or equally impose economic sanctions, though this list is not exhaustive. At the core, it is deterrence equality. When parity is achieved between two adversaries, they have achieved a steady-state condition. Conversely when parity is broadly different, the relative threat of one nation to another may drive survival instincts.

### Stability

Stability is an overall relative measure of the difference between two state actors. Higher parity differences do not necessarily drive stability decreases, though it has been an early indicator of such differences in the past. The lesser the stability, the higher the likelihood of conflict. States have, in the past, recognized instability in neighboring regions, and have leveraged the opportunity to initiate offensive actions during times of adversarial weakness. Saddam Hussein utilized this tactic after the Iranian Revolution, based on the belief that the new Iranian leadership was weak, and a fear that a similar revolution may occur in his own country if steps were not taken to prevent it (Woods, Murray, & Holaday, 2009).

## Uncertainty

The only metric that drives a wedge between relative stability, deterrence, and parity from a defender's point of view is uncertainty. In other words, uncertainty has a systematic effect. Relative uncertainty stands to dramatically increase as an opponent increases his mobility. As the figure below shows, adversarial uncertainty from the defender's perspective may affect stability and parity independently, though it invariably affects deterrence.

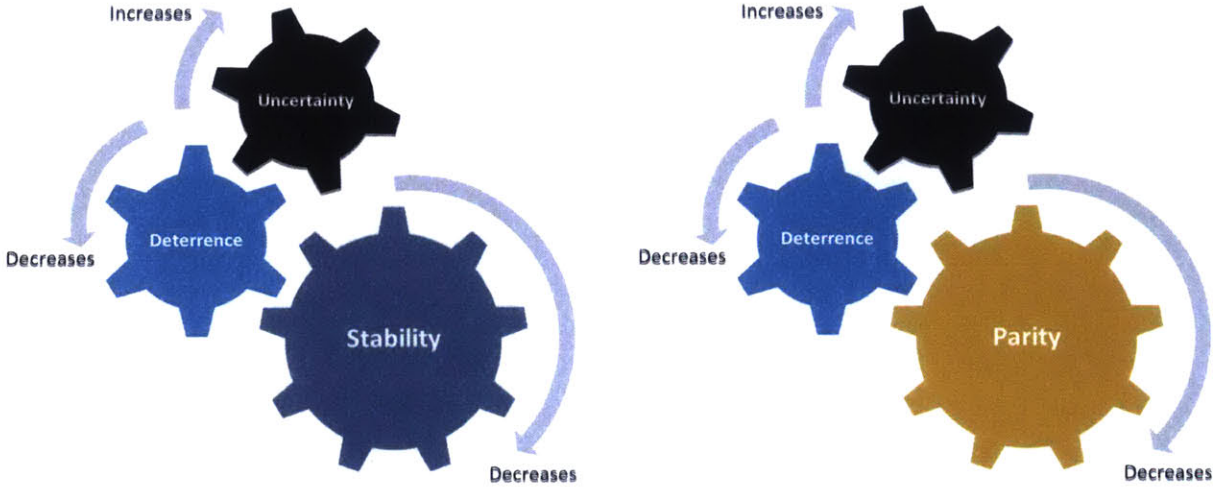

Figure 1 - Systematic Effect of Uncertainty from the Defender's Perspective

This uncertainty could drive up deterrence and drive down parity and stability, potentially resulting in an undesirable position for the defender, as the Iranians found during the Iran-Iraq war. A vast increase in uncertainty may leave a regime desperate, to the point where they capitulate to demands, cease fire, or surrender.

From the adversary's view, the story is similar. If the goal is to heighten the deterrence perceived by those defending against you, the gear or knob that turns with the most profound effect is again uncertainty. Appropriately managing this variable both decreases parity with the opponent, and decreases the state's survival risk.

When these gears no longer freely move, force equality or steady state has been reached.

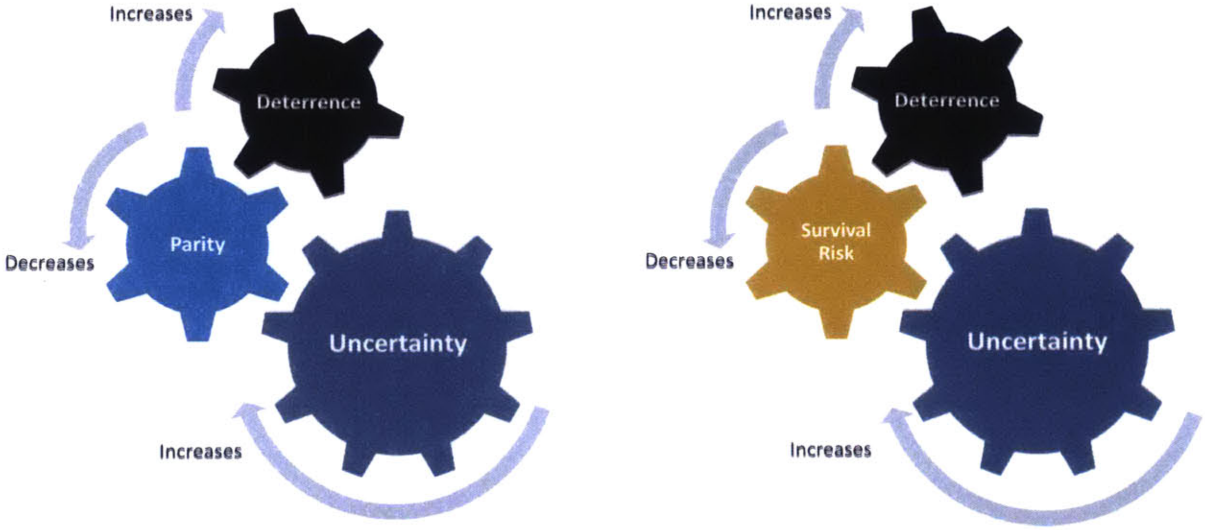

Figure 2 - Systematic Effect of Uncertainty from the Combatant's Perspective

The Germans were able to manipulate their asymmetric deterrence, parity, and stability in 1940 by driving up uncertainty via deployment of the Panzer tank, while at the same time the French drove uncertainty *down* by barricading themselves behind the static Maginot Line.

Germany's uncertainty-generating Panzer and residual bloodlust to conquer Europe, coupled with France's misplaced deterrence effort, allowed Hitler to reach around France's fortified boundary. History naturally repeats itself, and as such, there are more contemporary examples involving the use of ballistic missiles to drive up uncertainty and create a rift between the parity of two border states.

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## Part 2: Legacy Deterrence - Ballistic Missiles

During 20th century wars, ballistic missiles were used to create deterrence, maintain parity, or destabilize a relationship. They served as a strategic force multiplier, and in the case of the United States and Russia, prevented war by assuring mutual destruction in the event of an unprovoked strike. In fact, it could be said that in terms of stability, parity, and deterrence, these two countries achieved steady-state thanks to their force equality.

When conflict arises between two nation states that have parity in such a way, the outcome is less likely to turn kinetic. Smaller nations that do not have a strategic or nuclear deterrent must achieve stability in other ways, yet it invariably involves some aspect of uncertainty. One way in which to do this if defense against an attack is impossible, is to make the retaliation for such an attack so unpalatable that the attacker chooses not to engage, which highlights the concept and value of deterrence (USSTRATCOM, 2006).

If no such parity exists, there is less deterrence, and therefore more opportunity to achieve ones goals by turning to aggressive kinetic means, as Iraq did during the Iran-Iraq war in 1980, and later turn the Persian Gulf War in 1991.

A major driver of deterrence is uncertainty, and a mechanism to efficiently drive uncertainty up is mobility. Ballistic missile launcher mobility drives up deterrence and instability by increasing the parity rift between nation states. In each of the following cases, the tactics, techniques, and procedures of one combatant evolved to increase deterrence or uncertainty, and asymmetrically achieve objectives. By deploying available assets, whether technology, know-how, or both, in new and unexpected ways, these combatants were able to overcome their adversaries. The question becomes, how can defensive systems be effectively evaluated defenses against an uncertain adversary?

## The United States & Russia – Stable & Certain

There is some level of certainty with respect to the "mutually assured destruction" guarantee of strategic Intercontinental Ballistic Missiles (ICBMs). This is to say that assets such as radars have been positioned so that in the event of a first-strike, early warning platforms would likely detect the activity in time to launch a counter strike.

However, it took time to reach this stability. The Cuban missile crisis, de-escalation, and the Anti-Ballistic Missile Treaty eventually imposed an offense-only mindset, which resulted in equal parity, low instability (as indicated below by the relatively low-noise line), and low relative differential over time between the two nations.

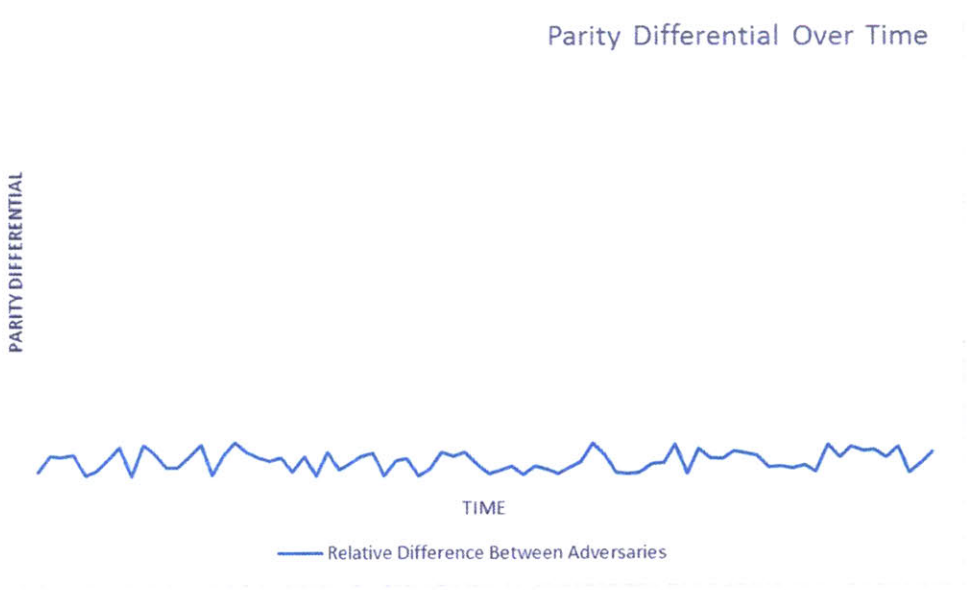

Figure 3 - Parity Difference over Time (US/Russia)

## Iraq & Iran, 1980-1990 – Asymmetric Deterrence

When Saddam Hussein's Iraqi Army invaded Iran in 1980, triggering the protracted, eight-year Iran-Iraq War, he did so not realizing there was a high degree of parity between the two states. Prior to the Iranian Revolution, the deterrence level was relatively equal due to the lack of technology and the relative ineptitude of each military (Woods, Murray, & Holaday, 2009).

Iran possessed no SCUD-B missiles prior to the Iraqi invasion in 1980, yet its air force was backed by the United States (Woods, Murray, & Holaday, 2009), so the parity differences were offset. Once the Shah fell, however, fractures appeared in both the political and military leadership of the Iranian regime, driving down stability with respect to Iraq, lowering parity, and reducing its deterrent. Iraqi leadership perceived Iran to be at its weakest and began an assault.

Saddam believed his asymmetric trump card for quick victory over Iran was his inventory of missile and rocket munitions that could be utilized against border cities of Iran. Iraq had only a few such cities that could be targeted, and was thus dramatically less vulnerable, as the graphic below shows[5].

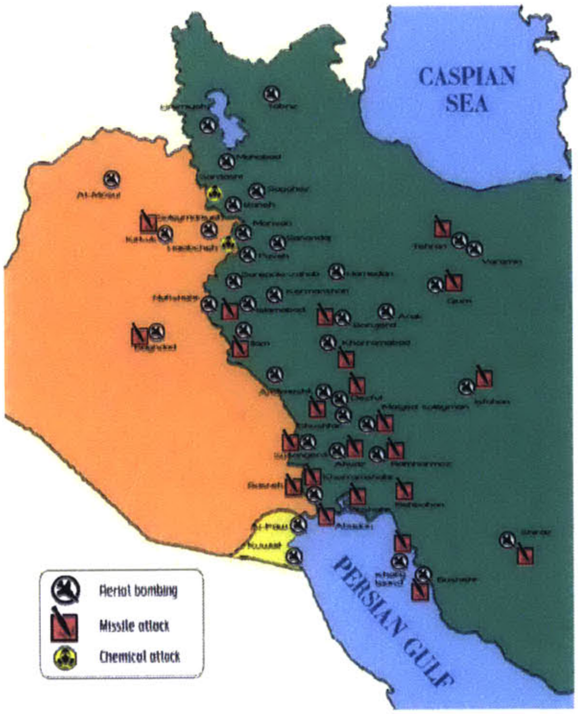

Figure 4 - Iran-Iraq War Missile Attacks (source: gire_3pich2005 [FAL], via Wikimedia Commons)[6]

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[5] Though effective, the Iraqi military would not achieve success until it began to asymmetrically attack Iran with modified SCUD missiles, as well as chemical and biological agents (Woods, Murray, & Holaday, 2009).

[6] The missile attacks highlighted above would wind up causing the deaths about 2,000 Iranians (Takeyh, 2010) ruining citizen morale (McNaugher, 1990).

If deterrence is driven by uncertainty with respect to the location of adversary ballistic missile launchers, then the potential assets that could be targeted should be the assessment metric for the adversary, driving the range required of the ballistic missile system. If this is the case, a defense planner may want to examine all areas that a threat could be launched from, presuming that the adversary will eventually acquire the requisite range capability to strike all assets.

If Iranian leadership had evaluated the areas in which they could deny launches from, or those areas in which they could defend, they would have likely seen that a capability mismatch existed, and that their perception of projected deterrence was inaccurate. If this analysis had been performed, it is conceivable that both sides would have made different decisions. The two countries seemed to have strengths and weaknesses that offset each other, yet there was one important exception: The Iraqi's had the ability to purchase Soviet ballistic missiles, which they did in 1983, and they had access to East German know-how regarding the deployment and reverse engineering of those missiles (Bradsher, 1991), which they performed and employed by 1985, as noted by the jumps on the chart below.

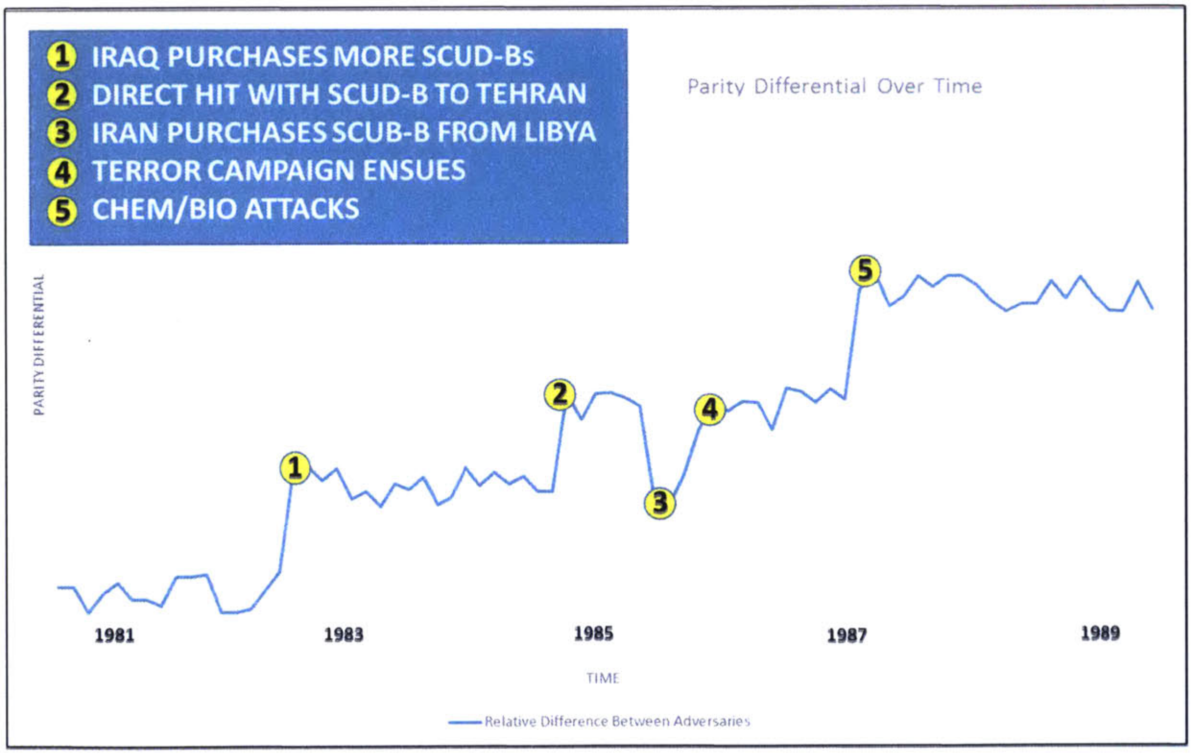

Figure 5 - Parity Differential over Time - Iran-Iraq War

The Iranians had figuratively burned bridges during the revolution prior to the Iraqi invasion, yet they still were able to purchase their first batch of SCUD-B missiles from Libya. When this happened in 1985, parity started to normalize, though this was only temporary as Iran had difficulty targeting Iraq's capital city (GlobalSecurity.org, 2014).

Up to this point, Tehran believed itself to be insulated from attack given its range from the border, and known range limitations of the Soviet SCUD-B. However, Hussein used his technological access to his advantage, directing his strategic missile forces to modify existing SCUD-Bs by reducing warhead weight in order to achieve longer range, thereby resulting in the possibility of direct attack on the city of Tehran, despite knowing that modifying the airframe would result in a high probability in-flight failure (Carus & Bermudez, 1990)[7].

Taking a page from Hitler's V-2 playbook, Hussein used rockets and ballistic missiles as terror weapons instead of strategic assets, a tactic that would result in a very war weary Iranian population (Hobgood, et al., 2009). As shown in Figure 4 - Iran-Iraq War Missile Attacks (source: gire_3pich2005 [FAL], via Wikimedia Commons), Hussein broadly employed his ballistic missiles as city-attack terror weapons (Aboul-Enein, Bertrand, & Corley, 2012) that Iran could not counter, and for which they did not have a satisfactory deterrent.

Hussein's use of chemical and biological weapons during attacks in 1987 and 1988, as indicated by the last peak on the chart above, proved to be the asymmetry he needed to win the war[8]. The Iranians were on the wrong side of a hard lesson – a lesson that drove the Germans' advantage fifty years prior – that mobility exponentially drives up uncertainty.

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[7] Accuracy and airframe worthiness were significantly compromised during this re-engineering since the guidance system was designed for shorter-range shots (Carus & Bermudez, 1990). This, however, was unimportant to Hussein since he would not be targeting physical structures, instead focusing his attack on the hearts and minds of the Iranian people. What resulted was a systematic uncertainty that drove a parity mismatch between Iran and Iraq.

[8] The conflict would end in 1988 when Iran was decimated, and both sides agreed to a cease fire following the highly publicized and devastating two-year long "War of the

The inability to adequately comprehend asset vulnerability to mobile threats, coupled with no way to equalize parity in the short term, and the lack of a credible deterrent, forced Iran to sign a cease fire in 1988.

### 1990 and Beyond – Mobility Drives Instability

Hussein again disregarded standard military tactics, techniques and procedures, in fact throwing out the manual itself, in order to survive pre- and post-launch military strikes from the United States and others during the first Gulf War (Rosenau, 2002).

Though anti-SCUD sorties[9] were a small percentage of overall air operations, they still accounted for a sizeable 4,750 missions (Kipphut, 2003), with not a single TEL successfully engaged (Rosenau, 2002). 88 missiles were launched by Iraq during the Persian Gulf War, yet sources reported that the Iraqi Army had only 36 missile launchers available to them, which presumes that these launchers were reloaded multiple times (Rosenau, 2002).

The pre- and post-launch inability to pinpoint these TELs is what drives uncertainty, and is further complicated by the survival-related tactics, techniques, and procedures of the system operators. Historical precedent suggested that it would take ninety minutes to become road-mobile after a missile launch (Rosenau, 2002). As such, a fifty-minute targeting cycle would have been satisfactory for engagement of these systems, post-launch. There was, however, a survival based innovation somewhere along the line, likely during the Iran-Iraq war. The Iraqi's reduced this timeline to less than thirty minutes, leaving the launch site long before they could be engaged (Rosenau, 2002).

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Cities," during which Iraq would launch 520 missiles at population centers in Iran, the majority of which targeted Tehran (Cordesman & Wagner, The Lessons of Modern War - Volume II - The Iran-Iraq War, 1990), while Iran launched 177, which were primarily misses (GlobalSecurity.org, 2014)

[9] Sortie are missions flown for a specific purpose

What enabled this innovation was roadway access. As of this year, some countries with road-mobile TELs have approximately 200,000 kilometers of roadway, providing access to 1.5 million square kilometers of landmass (CIA, 2014) in which to mobilize a ballistic missile launcher.

As shown below, roads are a key component of mobile ballistic missile operations, impacting all phases of the pre-launch and post-launch process. The more roadway access an opponent has, the greater their regional threat, and therefore the greater their deterrent.

RANDMR737-1.2

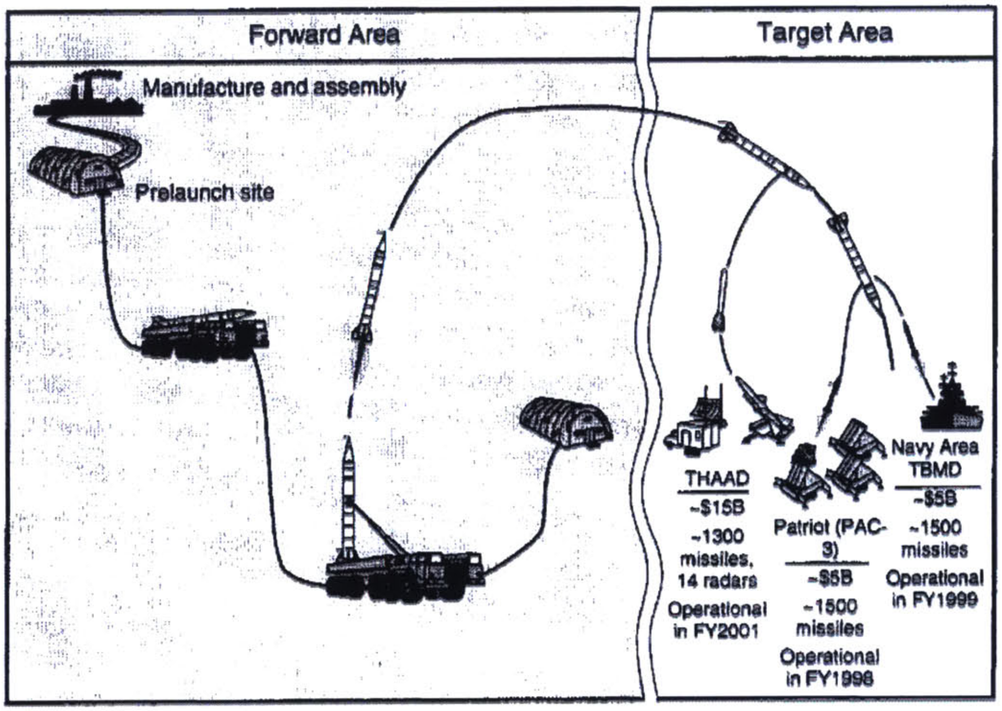

Figure 6 - TEL Mobility (Isaacson & Vaughan, 1996)

Defense planners would benefit if these systems could be eliminated after they launch an attack. However, in reality, urban and rugged rural geography is a challenge to search. Even after a launch occurs, detection, tracking, and engagement have proven to be difficult, as highlighted during the first Gulf War (Rosenau, 2002). It is clear that detection and subsequent engagement of these systems is complicated and rife with uncertainty, so elimination of them as a threat cannot be relied upon. As such, the threat must be dealt with holistically. The mobility of missile launchers creates an inherent problem for defense planners, particularly if the defense planner positions his weapon system after computing the defended area associated with the fixed launch site or region.

The mobility advantage can be seen as recently as 2001, as the Iranians used Saddam's own techniques against him (Tarzi & Parliament, 2001) in order to avoid detection (Figure 7 - April 18, 2001 Iranian Missile Attack, According to MKO Claims ). Without the ability to know, with certainty, where a missile attack will originate, and burdened by the unlikelihood of launcher suppression by strike forces, it is incumbent on the designer to eliminate, to the greatest extent possible, the defense uncertainty associated with adversary mobility.

Figure 7 - April 18, 2001 Iranian Missile Attack, According to MKO Claims (Tarzi & Parliament, 2001)

If faced with an uncertain, mobile adversary, such as the ones highlighted in previous sections, it is paramount for the planner to incorporate this mobility reality into the assessment of the defense design.

Systematically characterizing and assessing the uncertainty associated with mobile ballistic missile operations is possible. When assessing the ability of a threatened nation to defend itself against an unstable state, one must also systematically utilize available tools in new and novel ways to characterize the uncertainty posed by the adversary.

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## Part 3: Modeling Mobility Uncertainty

In order to characterize the uncertainty associated with mobility of ballistic missile launchers, the entire architecture, complete with threat and counter-threat systems, must be evaluated. This analysis need not include six degree-of-freedom models since as a first-blush assessment, the goal is not to produce a thorough analysis, but instead to identify trends to focus future analysis.

It would be computationally difficult to model the movement of TELs across a network adversary roadways, in fact, it is extremely unlikely that doing so would yield meaningful data. There is nothing stopping a determined missile operator from spontaneously building a new road out of necessity. However, all TELs are bounded by their country's borders[10], and all TELs must stop to launch their missiles, which makes modeling this architecture less of a dynamic, non-linear problem, inching much closer to a discrete solution.

Zarchan outlines a method to discretely model this system in his book *Tactical and Strategic Missile Guidance*[11]. This modeling paradigm has been utilized with varying degrees of fidelity in the past (Corbett, 2013). The two systems that must be modeled (outside of the Earth's physics) are the ballistic missile system-of-systems, and the anti-ballistic missile system designed to counter these threats.

### Ballistic Missile Systems

Ballistic missiles have varying designs and capabilities, but all are launched from the ground, all follow Newtonian Physics during their course of travel, and all eventually impact. This truth provides defensive planners with the ability to characterize threat missile performance and the associated ability of a defensive system to negate it. However, though fixed launch-point to impact-point attacks are likely, they are not novel, in fact, they are highly predictable. Successful adversary techniques are often those that are unpredictable, creating a natural deterrent, and supporting survivability.

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[10] Submarine launched ballistic missiles notwithstanding

[11] All missile parameters are notional

Adversaries may seek to reduce the possible characterization of their systems by eliminating an opponent's ability to predict the launch site[12], which may only be done in two ways:

1. Covertly building the launch site
2. Mobilizing the system that launches the threat

The difficulty with building fixed launch sites is inherent in their very nature. In much the same way that you cannot "un-ring a bell," once the launch site is discovered, its utility is greatly diminished (from the perspective of attack geometry uncertainty). This section discusses the relevant system characteristics related to the latter concern, though both of these tactics achieve the same objective.

### Missiles

Threats are modeled using the minimum amount of energy required to get the missile from its launch point to its intended impact point. Therefore, trajectories launched from regions further away from the launcher are inherently more difficult to intercept than those which are closer due to the increased terminal velocity resulting from the increased launch energy required. Since in this analysis the interceptor is represented by a static volume, increased speed of the inbound ballistic missile directly correlates to reduced time to engage the threat.

There is no CEP associated with these trajectories – they are precisely targeted in order to eliminate noise associated with guidance uncertainty. Additionally, the threat ballistic missile is a unitary complex, meaning it does not separate into smaller components such as a reentry vehicle or tank.

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[12] Though impact point is important, as will be seen later, an adversary would (presumably not on purpose) target an area of little value (i.e., an ocean area 100 km offshore where there is no island mass and no maritime activity).

### *Phases of Flight*

Ballistic missiles have several phases of flight which are either powered – the initial portion of the flight in which the rocket motor is burning, and unpowered – where the missile is truly ballistic, influenced primarily by gravity and atmospheric drag (Isaacson & Vaughan, 1996). Newton's second law of motion provides a high degree of missile path certainty, turning the problem of trajectory interception in a discrete problem (in the absence of countermeasures, decoys, etc.). This makes the concept of "hitting a bullet with a bullet" a solvable, albeit complex challenge that some call a "wicked-hard problem" (Smithson, 2012).

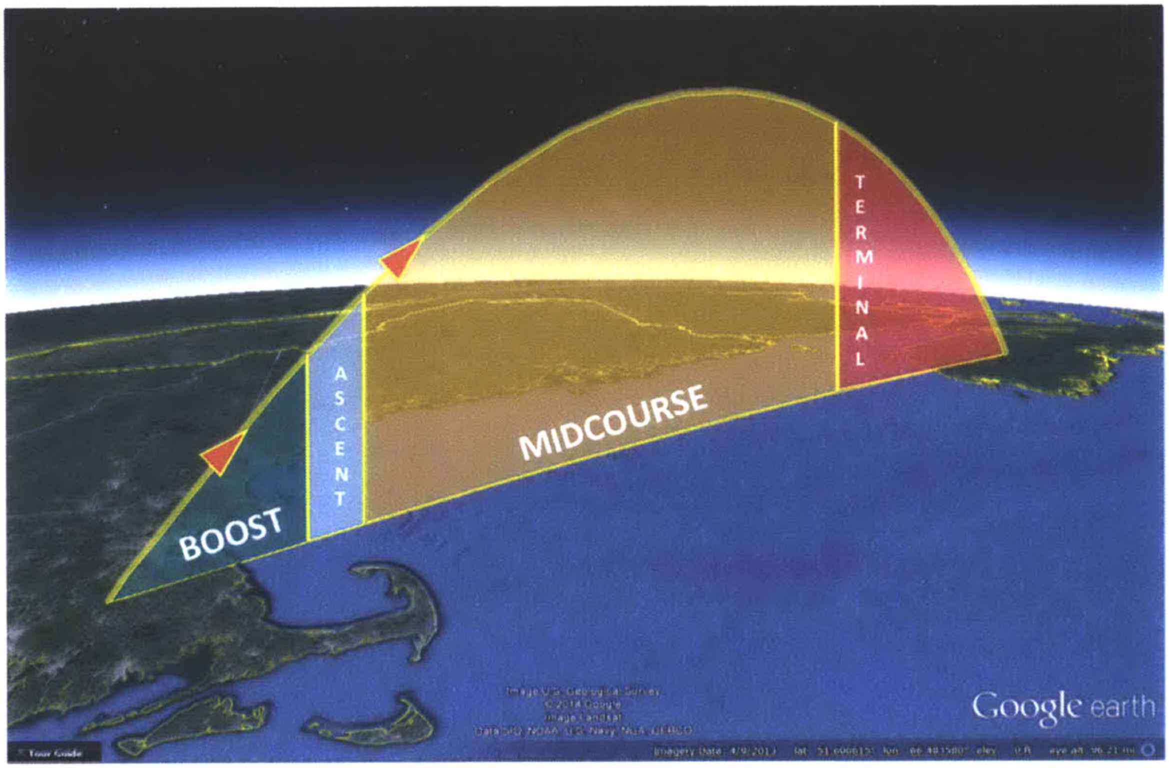

Figure 8 - Ballistic Trajectory Phases (Fulchino, 2014)

The typical phases of flight are depicted above and outlined below.

- Boost: The powered phase of flight lasting anywhere from a few seconds to minutes (Isaacson & Vaughan, 1996). Once the launch command is given, the rocket motor (liquid or solid) burns until its fuel supply is exhausted. The guidance computer aboard the missile corrects the missile's pitch, yaw, and roll angles to ensure the missile is on the correct trajectory at burn termination. During this phase, the missile behaves unpredictably as its acceleration forces and guidance algorithms compete to keep the missile on its intended trajectory.

- Ascent: Once the powered phase of flight has terminated, the missile may separate, jettisoning its rocket motor(s), and continuing on its way[13]. Typically there is a significant amount of debris generated during this process (National Research Council, 2012)

- Midcourse: During this period the missile behaves ballistically, obeying the law of gravity as it approaches apogee and descends back down to earth. It is during this period that the post-boost vehicle, which contains one or more re-entry vehicles (Hobgood, et al., 2009) deploy from the rocket body, if they have not done so already.

- Terminal Phase: As the missile components begin to re-enter the atmosphere, they slow down due to the effects of drag, significantly heating up during the process. The threat is now only seconds away from impact. Defensive terminal weapon systems target the missile components during this period. (Hobgood, et al., 2009)

Though ballistic missiles possess vastly differing capabilities, there are some commonalities that defense planners can rely on as constants when determining efficacy of weapon systems, namely what occurs during the phases of flight outline above. (Isaacson & Vaughan, 1996)

### Missile Launcher Mobility

Technology that launches ballistic missiles takes one of two forms: fixed in garrisons and silos, or as part of a system that transports the missile, erects it to an appropriate angle for

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[13] Unitary threats, those that are modeled in this study, do not separate. The entire missile travels together to impact.

launch, and provides the final guidance for the missile prior to launch[14], commonly referred to as a Transporter-Erector-Launcher, or TEL, shown below.

Figure 9 - SCUD TEL at the National Museum of History, Bulgaria (Holt, 2010)

The only limitation of these TELs is the road infrastructure that they must utilize to travel from munitions depots to designated launch sites, though this limitation is also what enables the level of uncertainty that yields deterrence.

## Anti-Ballistic Missile Systems

As in other studies (Corbett, 2013), open sources describe the details of the modeling system, though typically the sensor and weapon components represent a system-of-systems, whereby information generated by the sensor is used by the weapon in order to

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[14] Also known as transporter, erector, launcher (TEL)

determine interceptor fly-out profiles, and therefore threat missile intercept points (if any exist).

In Zarchan's model, there are no time delays present in the system due to guidance computation, commander decision delay, or communications links, in order to reduce variability (Defense Science Task Force, 2004). In fact, all delays are eliminated in order to minimize performance variability based on non-kinematic parameters. As such, it is a kinematic assessment, only, where the weapon system is presumed to have an unlimited inventory of missiles at its disposal.

# Part 4: Measuring Mobility Uncertainty

Strategists and defense planners use many approaches to measure the performance of a given system or architecture in the face of a missile threat, yet these assessments are often performed independently, presuming either that launch site activity is fixed, or the assets being defended are fixed. The assessment of "defended area," defined in the following section, is a common method of determining the overall region that is protected from a threat originating from one (or many) fixed launch sites (Zarchan, 2012).

When presented with a highly mobile adversary, other methods may be effective at characterizing and evaluating the risk due to this uncertainty. "Launch area denied," the measure of performance which indicates whether or not specific assets are protected from threats originating *anywhere* in the threat region, is a good way to mitigate the uncertainty driven by road-mobile launchers, no pun intended.

By systematically analyzing the two measures of performance, and understanding how they are related, one can characterize the architectural performance against an adversary exploiting mobile equipment and infrastructure to generate uncertainty and drive up deterrence.

The methods used to determine defended area and launch area denied again follow Zarchan's framework (Zarchan, 2012). These two measures of performance have been examined with varying degrees of fidelity in the past (Corbett, 2013).

## Background

Defended area and launch area denied assessments focus on two fundamentally different regions, the former being where the threat will *originate*, with variation around where it will *land*, the latter focusing on where the threat will *land* with uncertainty regarding launch *origination.*

## Defended area

With respect to ballistic missile defense, *defended area* is the measure of performance (MOP) often cited to describe the area in which a given weapon system has some defensive capability against a specified threat coming from a limited set of launch areas[15] (Zarchan, 2012). Often, it is simply an assessment of the kinematic ability of an interceptor with predefined, notional parameters to cross an incoming missile's path before that threat impacts the ground.

This assessment does *not* necessarily consider the assets which the planner desires to defend. Instead, it determines whether or not the weapon system can kinematically[16] intercept the defined threat with the specified system parameters before it impacts a particular grid point. In some cases, such as defense of a broad region, an asset that the weapon system is assigned to defend may fall both in and out of the defended area.

In the past, these assessments have worked well because there is significant uncertainty associated with where the threat missile will *land* – less so from where it will originate as a function of the test itself (the garrison location is fixed) (Corbett, 2013).

Defense planners must first perform a rough, high level assessment of "enageability" to determine whether the system may be effective (irrespective of various engagement success probabilities) at the specific location. This helps to place outer bounds on the design for the defense planner, and is one of the first tests used to determine where the weapon system should be located, though it is important to note again that this is an asset-independent test.

The area defended by a ballistic missile defense system is analogous to that region above "home plate" in American Baseball where the batter must swing to hit an incoming pitch. Without speaking of the probabilities of hitting the ball based on hand/eye coordination, strategy, or other external influences, a batter must perform the following assessment as

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[15] For the purposes of this study, Defended Area outside of the weapon system footprint is uniformly disregarded

[16] In this case, this is a physics-only assessment, which is to say that an analysis is performed to determine whether or not the time and distance requirements for intercept can be met given the specified average velocity of the interceptor.

the ball leaves the pitcher's hand: is the ball seen early enough, can the swing occur fast enough, and is the ball moving slow enough for there to be a physical connection?

The principles are the same when dealing with the intercept of a missile. The very basic kinematic questions one asks when determining whether or not a system can defend against a threat are, in this order:

1. When is the target [baseball] "seen" by the system [batter] (if at all)?
2. How fast is the target [baseball] going?
3. If an intercept attempt [swing] were to start right now or at any time in the future, would the interceptor [bat] be able to travel the distance required to meet the target [baseball] prior to ground impact [catcher]?

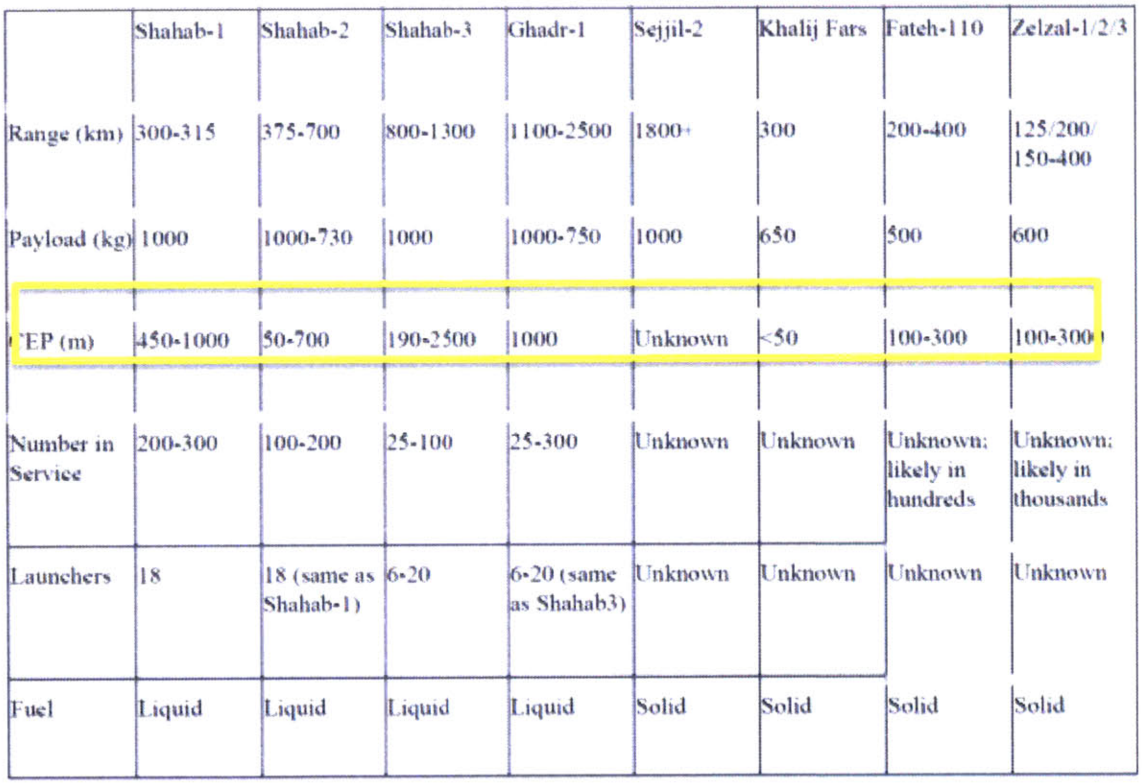
Designers of defense plans must perform assessments of weapon and overall system efficacy against a host of adversarial threat tactics, techniques, and procedures, yet when computing defended area, and indeed when attempting to hit a baseball, planners and pitchers "know where to look." At a fundamental level, the batter *knows* where the ball is coming from.

When determining when to swing, the "best guess" of ball position location is made, which is better than no guess, and not nearly as good as evaluating all possibilities. This works in a baseball game with only one threat geometry (generated by the pitcher), from which the attack originates, but is inapplicable in a game like European Football. The goal defender does not presuppose the angle of attack, speed, or player from which the ball will originate. In fact, he prepares for all possibilities by focusing on the defense of the single goal, handling balls from whatever direction in which they arrive, be it high, low, fast, or slow. This has profound effects on the outcome of the defensive mission.

The goal defender may always be able to block an oncoming shot, in which case his defense percentage is 100%, though if the majority of shots are high-velocity and off-angle, and he is a slow runner, his performance against those attacks may be truly low, in which case his overall performance is also truly low.

The defended area measure of performance, however, is the only assessment logic that allows a defense planner to adequately deal with the problem of *impact point* uncertainty.

The table below lists open assessments of impact point uncertainty associated with known ballistic missile systems, referred to as the "circular error probable (probability)," or CEP. The Air Force defines CEP as "… a circle, centered about the mean, whose boundary is expected to include exactly 50% of the population within it." (Nelson, 1988)



| | Shahab-1 | Shahab-2 | Shahab-3 | Ghadr-1 | Sejjil-2 | Khalij Fars | Fateh-110 | Zelzal-1/2/3 |
|---|---|---|---|---|---|---|---|---|
| Range (km) | 300-315 | 375-700 | 800-1300 | 1100-2500 | 1800+ | 300 | 200-400 | 125/200/ 150-400 |
| Payload (kg) | 1000 | 1000-730 | 1000 | 1000-750 | 1000 | 650 | 500 | 600 |
| CEP (m) | 450-1000 | 50-700 | 190-2500 | 1000 | Unknown | <50 | 100-300 | 100-300 |
| Number in Service | 200-300 | 100-200 | 25-100 | 25-300 | Unknown | Unknown | Unknown; likely in hundreds | Unknown; likely in thousands |
| Launchers | 18 | 18 (same as Shahab-1) | 6-20 | 6-20 (same as Shahab3) | Unknown | Unknown | Unknown | Unknown |
| Fuel | Liquid | Liquid | Liquid | Liquid | Solid | Solid | Solid | Solid |

Figure 10 - CEP Table (Hildreth, Iran's Ballistic Missile and Space Launched Programs, 2012)

What is immediately apparent from this table is that impact point uncertainty ranges from the size of a few football fields, to an area so large, it would take four minutes to drive through at highway speed. This area is likely even higher when modification to the missile's airframe are made to improve range, as was done by the Iraqi Army during the first Gulf War (Rosenau, 2002).

If the goal of the defense planner is anti-terror related, then it may be crucial to prevent *all* missile impacts in a defended area (such as a city), even those that are between military assets. If this is truly the case, and the launch sites are known, assessment of defended area alone is satisfactory. However, if there is even a shred of launch location uncertainty, this uncertainty must be characterized to assess the resulting system performance.

### Launch Area Denied

While defended area assessments work well when you *know* where a target will originate, the result is less efficacious when an adversary is mobile, and therefore launch location is uncertain. If the defense planner must know, with certainty, how a weapon system will perform when assigned to defend specific assets, a launch area denied assessment must be performed.

This measure of performance affords defense planners with an opportunity to determine what parts of a threat launch region are negated by the evaluated architecture, which is valuable when you do not know where the threat will originate. It is typically not computed for fixed sites, because it does not convey much novel information.

The problem of not knowing with certainty where the target will originate can be managed by accepting the reality exposed earlier in this study, that an unstable, threatened adversary will exploit geographic area in order to launch from any, and potentially every, location available.

With the reality of geo-dispersal in mind, defense planners can instead choose to assess the defendability of predefined assets with respect to *all* possible launches from within a specified threat region, in this case, the State's borders. Said another way, the defense planner assumes nothing about where the launch will originate and concerns him or herself only with assets the must be defended.

This type of assessment works well when you are not trying to defend a region (e.g., the City of Cambridge), but are instead trying to protect a critical asset (e.g., Fenway Park) from all attack geometries.

Back to our goalie analogy from earlier. The concept of launch area denied is similar to the role of goal defenders on a European football squad. These goalies have a fixed area in which they must defend against any oncoming threat geometry, without respect to where the threat will originate, similar to what an interceptor may do as part of a ballistic missile defense system.

The goalie, and indeed the ballistic missile defense system, never know with 100% certainty when the threat will arrive, and from what geometry. All that is known is that the goal must be defended. With this perspective, one can test the goalie to determine what geometries can be defended, and therefore which attack shots highlight a systematic limitation. This same principle is true for ballistic missile defense systems. Performing a launch area denied assessment against an uncertain ballistic missile threat, one in which the origin of attack and attack geometry is unknown, is a valuable utility to determine the boundary conditions for effective defense of a specific point.

Launch area denied, however, has its limitations, too. One impact point may be defendable at all times, but the reality is that weapon systems are emplaced to protect multiple assets at a given time. In short, defense planners must be able to characterize and adapt to this uncertainty, lest they lose the game because of a blooper kicked from the sideline.

## Conclusion

Whether evaluating the asymmetry between Germany and France, or the modulation of symmetry to vary deterrence, parity, and stability in the Middle East, opponents have predictably generated uncertainty through the utilization of alternative technology, tactics, techniques, and procedures, most notably though the deployment of mobile systems.

Adversarial goals have been the same through recent history, namely to force a change by an opponent with respect to the calculus used to determine future courses of action. However, those looking to defend interests and protect blood and treasure now have a way to rebalance the equation. A systematic combination of analytical methods may now be employed to effectively plan and adjust ballistic missile defense operations for all threats.

As exposed by this assessment, evaluation of defended area is an appropriate tool to use with respect to a state-stable adversary using fixed garrisons, irrespective of non-kinematic variables, such as command and control, engagement decision time, and link latency, etc. However, state-stable actors are typically concerned with mutually assured destruction, not regime survival, and do not often take asymmetric actions in order to achieve an objective (in this context).

When presented with an unstable state utilizing asymmetric tactics such as the deployment of mobile missile systems, threat location uncertainty modulates system performance, requiring a more robust assessment of architecture performance. This problem is complicated by adversaries who desire strength and precision but do not have the technological competency to achieve either, thereby yielding a threat that is both terroristic and schizophrenic in nature. With these issues in mind, defense planners may now also assess the defendability of assets with respect to *all* possible launches from a specified threat region, in this case, the adversarial state's borders.

It is clear from this assessment that a systematic approach to ballistic missile defense system performance, which presumes uncertainty regarding threat location, is the most comprehensive way to assess the value of an architecture.

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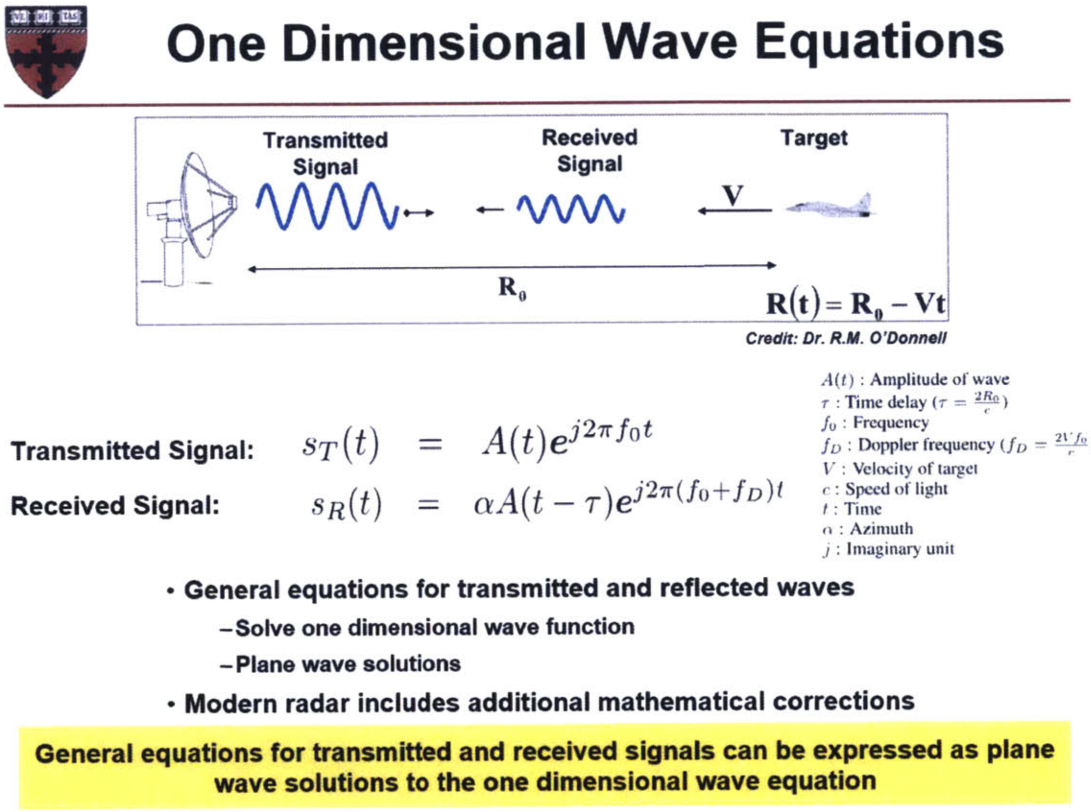
# Appendices

## Appendix A: Radar Range Equation (Fulchino, 2014)



### One Dimensional Wave Equations

$$R(t) = R_0 - Vt$$

*Credit: Dr. R.M. O'Donnell*

**Transmitted Signal:** $$s_T(t) = A(t)e^{j2\pi f_0 t}$$

**Received Signal:** $$s_R(t) = \alpha A(t-\tau)e^{j2\pi(f_0+f_D)t}$$

$A(t)$ : Amplitude of wave
$\tau$ : Time delay ($\tau = \frac{2R_0}{c}$)
$f_0$ : Frequency
$f_D$ : Doppler frequency ($f_D = \frac{2Vf_0}{c}$)
$V$ : Velocity of target
$c$ : Speed of light
$t$ : Time
$\alpha$ : Azimuth
$j$ : Imaginary unit

- **General equations for transmitted and reflected waves**
  - **Solve one dimensional wave function**
  - **Plane wave solutions**
- **Modern radar includes additional mathematical corrections**

**General equations for transmitted and received signals can be expressed as plane wave solutions to the one dimensional wave equation**

## Appendix B: Launch Area Denied vs. Defended Area: An Assessment

This appendix provides an analytical evaluation of the differences between launch area denied and defended area assessments using specific architectures. Based on Zarchan's framework, it utilizes notional sensor, weapon, and ballistic missile system parameters in order to compare and contrast these measures of performance in a novel way.

It is available upon request from the author.

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