ECONOMIC ASYMMETRY IN DRONE WARFARE A CASE STUDY OF IRAN'S SHAHED-136 OPERATION AGAINST ISRAEL'S IRON DOME DEFENSE SYSTEM

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Abstrak — *The advent of low-cost loitering munitions has revolutionized modern warfare, creating a profound economic imbalance between offensive and defensive capabilities. In the Middle East, the deployment of Iran's Shahed-136 drone against Israel's Iron Dome defense system serves as a prime example of a "cost-imposing" strategy in asymmetric warfare. Objective: This study aims to quantify the economic disproportion between the production and deployment costs of the Shahed-136 drone and the operational costs of the Iron Dome system. It explores how this cost ratio impacts long-term national defense budgets and strategic sustainability. Methodology: This study uses a qualitative-descriptive approach supported by comparative economic modelling. Data are synthesized from defense budget reports, estimates of the Shahed-136 manufacturing costs, and the unit cost of the Iron Dome Tamir interceptor missile. The analysis uses the Cost-Exchange Ratio (CER) to evaluate the economic efficiency of both sides. Results: The study's findings reveal a sharp economic asymmetry, with a single Shahed-136 estimated to cost between $20,000 and $50,000, depending on configuration, while a single Tamir interceptor missile costs approximately $40,000 to $100,000, depending on configuration. When factoring in "saturation attacks" (or drone swarms), defense costs increase exponentially, not only through missile expenditure but also through the economic disruption caused by airstrike warnings and collateral infrastructure damage if interceptions fail. Conclusion: The study concludes that while Iron Dome remains tactically effective in saving lives, its current economic trajectory is unsustainable against the threat of low-cost, mass-produced drones. The study suggests that to maintain strategic stability, the defense framework must transition to lower-cost interception technologies, such as directed energy weapons (lasers/Iron Beam), to neutralize the economic advantage currently held by offensive drone platforms.*

Keywords: *Drone Warfare, Shahed-136, Iron Dome, Economic Asymmetry, War of Attrition, Cost-Exchange Ratio, Defense Economics.*

1. *INTRODUCTION*

1.1. Background

Developments in military technology over the past two decades have seen a paradigm shift from expensive and complex conven tional weapons systems to the use of inexpensive yet lethal autonomous platforms. This phenomenon is most evident in the use of Unmanned Aerial Vehicles (UAVs), or drones, as primary instruments in asymmetric warfare. One of the dynamics that has attracted the most international attention is the use of the Shahed-136 *kamikaze drone by Iran and its proxies, which directly confronted Israel's most advanced air defense system, the Iron Dome. This conflict has become not only a showcase of technological might but also a battle of economic efficiency. In classic military strategy, defense success is measured by the number of threats successfully intercepted. However, in the context of modern defense economics, the indicator of success has shifted to the Cost-Exchange Ratio (CER). A key problem arises when the cost of maintaining an asset is far greater than the cost to the attacker of destroying it.*

1.2. The Problem of Economic Asymmetry

The economic asymmetry in drone warfare arises when there is a significant price gap between offensive weapons and defensive systems. The Shahed-136 drone is desig ned with a "low-cost, mass-produced" philosophy, using commercially available (COTS) electronic components and a simple piston engine, with an estimated production cost of only $20,000 to $50,000 per unit. In contrast, the Iron Dome uses Tamir interceptor missiles equipped with advanced heat-seeking sensors and active radar, with a cost per launch of $40,000 to $100,000. This imbalance creates a strategic dilemma for Israel. If the Iron Dome is not deployed, the damage to infrastructure and loss of life will be far greater economically. However, if it is used continuously against drone swarms, the interceptor stockpile will be depleted and the defense budget burden will balloon to a financially unsustainable point.

1.3. Cost-Imposing Strategy

This research argues that Iran's use of the Shahed-136 is not simply an attempt to penetrate airspace, but rather a cost-imposing strategy. This strategy aims to deplete the opponent's foreign exchange reserves and ammunition stocks, thereby weakening the defending nation's economic capacity in the long term. In a war of attrition, the party that can produce wea pons at the lowest cost while still posing a significant threat typically holds a strategic advantage.

1.4. Research Objectives

This research aims to analyse in-depth the cost structures of these two weapons systems and calculate their economic asymmetry ratios. Furthermore, this rese arch will explore the policy implications for countries facing similar threats and how new technologies, such as directed-energy weapons, are expected to reverse this economic asymmetry in the future.

1.5. Research Significance

This study is significant because it provides a new perspective: victory in future drone warfare will not be determined solely by the most advanced technology, but by the most sustainable economic model for defending its airspace.

2. *METHODOLOGY*

2.1. Previous Research

To assess the originality of this research, a review of several thematically relevant studies was conducted. The following is a summary of previous research and its differences from this study:

Researchers and Years	***Research Focus***	***Key Findings***	***Differences with This Research***
Binnendijk & Banasik (2020)	*The evolution of drones in asymmetric warfare in general.*	*Drones lower the threshold for conflict involvement for non-state actors.*	*The focus is on general military tactics, while this research focuses on quantifying the asymmetry of economic costs.*
Dall'Agnol & Gilli (2022)	*Analysis of missile-based air defense system technology.*	*The cost of developing air defense systems continues to increase exponentially.*	*Reviewing the engineering-manufacturing aspects, while this research focuses on operational cost efficiency (CER) in specific scenarios..*
Rubin (2023)	*Iron Dome's tactical effectiveness GAZA Conflict*	*Iron Dome has a success rate of over 90% against short-range rockets.*	*The focus is on the interception of unguided rockets, while this research focuses on kamikaze drones (loitering munitions) which have a different threat profile.*
Watling (2024)	*The use of Shahed drones in the Ukraine-Russia conflict.*	*The Shahed drones are being used as a tool of attrition to deplete Western air defenses.*	*The focus is on the European theater (Ukraine), while this research focuses on the geopolitics of the Middle East and its interaction with the Iron Dome.*

2.2. Specific Differences (Novelty)

This study has several fundamental differences that provide added value (novelty) compared to existing literature:

- *Specific Cost-Exchange Ratio (CER) Analysis: Unlike general studies on drones, this study performs in-depth mathematical calculations on the*

estimated cost per unit of the Shahed-136 (offensive) compared to the cost per intercept of the Tamir missile (defensive). This study explicitly calculates the financial saturation point for defense providers.
- *Focus on the Dynamics of Guided Munitions vs. Layered Defense Systems: Most previous studies on Iron Dome have focused on its ability to intercept unguided rockets (such as Qassam/Grad rockets). This study fills this gap by analyzing how the same system responds to loitering munitions, which have more advanced manoeu vrability and sensors than conventional rockets.*
- *Long-Term Strategic Sustainability Perspective: This research looks not only at tactical success (whether the drone is shot down or not), but also at strategic success (whether the cost of downing the drone will be devastating to the surviving country's economy in the long term).*
- *Integration of Future Solutions (Iron Beam): This research connects the analysis of current economic losses with the urgency of transitioning to laser technology (Direct Energy Weapon), which has not been compre hensively discussed in the context of defense economics in older journals.*

2.3 Shahed-136 Technical Specifications

Pic source : NBC news

2.3.1.Dimensions and Weight
- *Length: 3.5 meters.*
- *Wingspan: 2.5 meters.*
- *Total Weight: Approximately 200 kg.*
- *Warhead Weight: 40-50 kg (High Explosive/Fragmentation Type).*

2.3.2.Flight Performance
- *Maximum Speed: 185 km/h (Relatively slow, equivalent to the speed of a car on the highway).*
- *Range: Estimated 1,000 km to 2,500 km (Highly dependent on fuel load and wind conditions).*
- *Flight Altitude: 60 - 4,000 meters (Frequently flies low to avoid radar/LOAL detection).*
- *Endurance: Up to 10-12 hours of flight.*

2.3.3. Propulsion & Navigation System
- *Engine: Mado MD-550 with 50 horsepower (HP).*
- *Propeller: Wooden/composite propel ler ler at the rear (pusher configu ration).*
- *Navigation System: Combination of INS (Inertial Navigation System) and Multi-constellation GNSS (GPS, GLONASS). Some later versions reportedly use an Anti-jamming unit to counter electronic warfare.*

2.4 Iron Drome Technical Specifications

Pic Source : CSIS

2.4.1. Interceptor Missile Technical Specifications (Tamir)
The Tamir missile is a kinetic component tasked with destroying airborne targets.
- *Missile Length: Approximately 3meters.*
- *Diameter: 160 mm.*
- *Weight: 90 kg.*
- *Speed: Mach 2.2 (approximately 2,700 km/h).*
- *Operational Range: 4 km to 70 km.*
- *Seeker: Equipped with electro-optical sensors and active radar for high precision in the final stages of pursuit.*

- *Warhead: Uses a proximity fuse. The missile does not have to directly impact; it will detonate near the target, destroying it with shrapnel.*
- *Unit Price: Estimated $40,000 – $100,000 (depending on source and system operating costs).*

Specification	Shahed-136 (Attacker)	Iron Dome / Tamir (Bertahan)
Fungtion	Kamikaze Drone (Disposable))	Interceptor Missile
Velocity	185 km/jam (Slow)	2.700 km/jam (Very fast)
Navigation	GPS/GNSS (Static Target)	Radar Aktif (Moving Target)
Estimasi Harga	$20.000 - $50.000	$40.000 - $100.000
Karakteristik	Attack massively/swarm	Selective (Urban/vital areas only)

3. *RESEARCH RESULT AND DISCUSSION*

3.1. Research Design

This research uses a qualitative-descriptive approach supported by defense economic analysis modeling. The primary focus of this methodology is calculating the Cost-Exchange Ratio (CER) between an offen sive platform (Shahed-136) and a defensive platform (Iron Dome). The research was conducted through a syste matic literature review and analysis of secondary data derived from strategic think tank reports, public defense budgets, and open-source intelligence (OSINT) data.

3.2. Research Variables

To calculate economic asymmetry, this study defines the following variables:

- *Offensive Cost* (C_O)*: Estimated produc tion cost per Shahed-136 drone (inclu ding materials, engines, and navigation systems).*
- *Defensive Cost* (C_D)*: Estimated cost per Tamir missile interception (including missile, radar operations, and personnel).*
- *Interception Ratio* (P_k)*: The probability of successful interception (Kill Probability), which influences the number of missiles that must be launched per target.*
- *Value of Assets Protected* (V_A) *: The economic value of infrastructure or human lives saved to calculate the defense benefit.*

3.3. Mathematical Analysis Framework (CARA Model)

Economic analysis is carried out using the basic Cost-Exchange Ratio (CER) formula as follows:

$$CER = \frac{\sum(C_D \times n)}{\sum(C_O \times m)}$$

Where:

- *n = Number of interceptor missiles launched.*
- *m = Number of drones deployed in one attack wave. If CER > 1, the defense strategy is economically disadvan tageous (financial attrition). If CER < 1, the defense is economically efficient. Furthermore, this study uses the concept of the Economic Attrition Index (EAI) to measure long-term economic sustainability:*

$$EAI = \frac{C_D \cdot (\text{Rasio Tembakan})}{C_O}$$

Note: Typically Iron Dome launches 2 Tamir missiles for 1 target to ensure security $(P_k$ *tinggi)* *so the defensive cost is often effective* $2 \times C_D$*.*

3.4. Data Collection Techniques

Data was collected through data triangula tion from the following sources:

- *Official secondary data: Congres sional Research Service (CRS) reports on Iron Dome funding.*
- *Expert analysis: Cost data from the Center for Strategic and International Studies (CSIS) and the International Institute for Strategic Studies (IISS).*
- *Field reports: Drone debris analysis by Conflict Armament Research to verify the use of low-cost (COTS) compo nents.*

3.5. Analysis Stages

- *Unit Cost Identification: Determine the lowest and highest prices for each weapon.*
- *Saturation Attack Scenario Simulation: Calculate the total cost of a mass attack (swarm) involving 100 drones simulta neously.*
- *Comparative Analysis: Compare total defense costs with estimated infrastruc ture losses if drones are not intercepted.*
- *Strategic Synthesis: Evaluate the point at which laser technology (Iron Beam) becomes an economic imperative.*

3.6. Results and Discussion

3.6.1. Unit Cost Identification and Data Sources

Based on a review of secondary data and open source intelligence (OSINT) reports, the cost variables for both weapon systems are defined as follows:

Weapon Instruments	*Estimated Cost Per Unit*	*Primary Reference Source*
Shahed-136 (Iran)	*$20.000 - $50.000*	*IISS (2024), Conflict Armament Research (2023), Prana Network (Leak).*
Rudal Tamir (Israel)	*$40.000 - $100.000*	*Congressional Research Service (2023), CSIS Missile Defense Project (2022).*

Source Analysis:

- *Shahed-136: This low cost is confirmed by Conflict Armament Research (2023), which found the use of Commercial Off-the-Shelf (COTS) components such as hobbyist-based thrusters (MD550) and civilian GPS modules. An IISS report (2024) states that mass production at the Alabuga facility (Russia-Iran) has driven the price down to around $20,000.*
- *Iron Dome: A Congressional Research Service (CRS) report (2023) for the US Congress lists the production cost of the Tamir missile at around $40,000-$50,000. However, CSIS (2022) emphasizes that total operational costs (including radar maintenance and battery standby) can reach as high as $100,000 per launch.*

3.6.2. Saturation Attack Scenario Simulation

To understand this asymmetry, we use a swarm attack scenario involving 100 Shahed-136 missiles. Standard procedure is for Iron Dome to launch two interceptor missiles per target to ensure a high probability of kill.
Simulation Calculations:

- *Total Offensive Cost:*

o 100 missiles x $30,000 (average) = $3,000,000 (USD 3 million)

- *Total Defensive Cost:*

o 200 Tamir missiles x $50,000 (average) = $10,000,000 (USD 10 million)

CER Result (Cost-Exchange Ratio):

$$CER = \frac{\$10.000.000}{\$3.000.000} = 3,33$$

Analysis: A ratio of 3.33:1 indicates that the defender must spend 3.3 times as much as the attacker. From a defense economics perspective, this figure represents a significant level of financial attrition for Israel.

3.6.3. Comparison of Economic Benefits (Value of Assets Protected)

Although the defending side loses in terms of the arms-to-weapons ratio (CER), the calculation must consider the Value of Assets Protected (VA). According to Bank of Israel data, damage from a single drone hitting an urban area or energy infrastruc ture can cause direct and indirect losses (production downtime, physical damage, insurance claims) worth $10,000,000 to $50,000,000. Therefore, tactically, spending $100,000 to protect an asset worth $10,000,000 is a logical decision. However, the issue is not the value of the asset, but rather the long-term fiscal capacity to withstand thousands of similar repeated attacks.

3.6.4. Technology Transition: Iron Beam as an Asymmetric Solution

This economic imbalance was the primary driver for the development of the Iron Beam (a high-energy laser system). According to official statements from Rafael Advanced Defense Systems, the cost per laser shot is estimated at only $2 to $10.

If this technology were implemented, the CER ratio would change drastically:

- *Attack Cost: $30,000*
- *Defense Cost (Laser): $10*
- *New CER: 0.00033*

With this ratio, the economic advantage shifts entirely to the defender, effectively ending the "cost-bearing" strategy of cheap drones.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusions

Based on the data analysis and economic simulations presented, this study conclu des several critical points as follows:

- *Cost Asymmetry: There is a significant economic gap between attackers and defenders. With an average Cost-Exchange Ratio (CER) of 3.3:1, the defender (Israel) is systematically forced to expend significantly more financial resources than the attacker (Iran). This proves that the Shahed-136 is not simply a kinetic weapon, but an instrument of economic warfare.*
- *Tactical Effectiveness vs. Strategic Sustainability: Although Iron Dome, using the Tamir missile, has a very high interception success rate (above 90%), the system faces the threat of a "financial saturation point." Tactical success in downing drones does not necessarily translate into strategic victory if the cost of such defense is an unsustainable drain on the national budget.*
- *The Paradox of COTS Components: The Shahed-136's use of civilian (Commercial Off-the-Shelf) components provides advantages in production speed and low cost that military-grade technology in conventional interceptor missiles cannot match. This shifts the power equation, where quantity (drone mass) begins to outweigh quality (missile precision) in terms of cost efficiency.*

4.2. Recommendations

To address the economic imbalance in future drone warfare, this study recom mends several strategic steps:

- *Accelerate the Transition to Laser Technology (Iron Beam). Israel and countries with similar threats should prioritize the operationalization of directed-energy weapons (DEMs). With an estimated cost per shot of only $2 to $10, this technology is the only way to reverse the CER from 3.3 to near-zero, while providing unlimited ammunition as long as power is available.*

- *Implement Layered Air Defense: Optimize the use of less expensive defense systems for low-level threats. The use of anti-aircraft cannons (such as the Gepard or the bullet-based C-RAM system), which have a much lower cost per round than Tamir missiles, should be considered to intercept drones that escape the outer shell, in order to conserve precision missile stocks.*

- *Supply Chain Disruption: Given the Shahed-136's heavy reliance on global electronic components (such as GPS modules and microprocessors sourced from abroad), strengthening interna tional export controls and economic intelligence* *is necessary to disrupt attackers' access to these critical COTS components.*

- *Utilization of Electronic Warfare: Increase investment in jamming and spoofing systems that can disrupt drone navigation signals. This method is much more economically efficient because it does not require physical ammunition to take down targets, but only electromag netic energy.*
- *This research confirms that in the era of modern asymmetric warfare, the economy is the primary line of defence. Without adapting technologies that can reduce defence costs (such as laser energy), developed nations will remain vulnerable to financial attrition strate gies launched through cheap drone plat forms.*

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