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Integrated Electronic Warfare Systems aboard the United States Navy 21st Century Warship

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14. ABSTRACT
The current world geopolitical situation has resulted in an ever increasing number of third-world nations and terrorists states gaining access to advanced military technology and weaponry that was previously limited to first-world nations. The blue water and littoral areas that are the operational environments of the United States and Coalition naval forces are within range of capable enemy missile systems as was evident in the attacks on the United States Ship Stark by Iraq in 1987 and the Israeli Naval Ship Hanit by Hezbollah in July 2006 Given the increasing threat of Anti-Ship Cruise Missiles (ASCM), the complete integration of an effective Electronic Warfare system into the combat systems of U.S. and Coalition maritime forces is paramount. Research has shown that this integration must include a computer-aided human element in the decision process. The project objective was to develop an improved, advanced Electronic Warfare architecture with a complete range of automated operation using a Human-In-the-Loop that could be integrated into existing and future combat systems. A model was developed that demonstrates solutions that integrate hard-kill defensive systems with soft-kill subsystems, managed by a human, in order to provide a completely integrated capability to defend against land, air, and sea-launched ASCMs.

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ABSTRACT

The current world geopolitical situation has resulted in an ever increasing number of third-world nations and terrorists states gaining access to advanced military technology and weaponry that was previously limited to first-world nations. The blue water and littoral areas that are the operational environments of the United States and Coalition naval forces are within range of capable enemy missile systems as was evident in the attacks on the United States Ship *Stark* by Iraq in 1987 and the Israeli Naval Ship *Hanit* by Hezbollah in July 2006

Given the increasing threat of Anti-Ship Cruise Missiles (ASCM), the complete integration of an effective Electronic Warfare system into the combat systems of U.S. and Coalition maritime forces is paramount. Research has shown that this integration must include a computer-aided human element in the decision process.

The project objective was to develop an improved Electronic Warfare architecture with a complete range of automated operation using a Human-In-the-Loop that could be integrated into existing and future combat systems. A model was developed that demonstrates solutions that integrate hard-kill defensive systems with soft-kill subsystems, managed by a human, in order to provide a completely integrated capability to defend against land, air, and sea-launched ASCMs.

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EXECUTIVE SUMMARY

The current world geopolitical situation has resulted in an ever-increasing number of third-world nations and terrorists states gaining access to advanced military technology and weaponry that was previously limited to first-world nations. The blue water and littoral areas that are the operational environments of the United States and Coalition naval forces are within range of capable enemy missile systems missile systems originating from land, air, and sea platforms as was evident in the attacks on the United States Ship *Stark* by Iraq in 1987 and the Israeli Naval Ship *Hanit* by Hezbollah in July 2006

Given the increasing threat presented by Anti-Ship Cruise Missiles**,** the complete integration of effective Electronic Warfare systems into the current combat systems of United States and Coalition maritime forces is paramount. This integration must include a computer-aided human element in a decision process designed to engage and neutralize an Anti-Ship Cruise Missile.

The objective of this project was to develop an improved, advanced Electronic Warfare architecture with a complete range of automated operation using a Human-In-the-Loop (HITL) that could be integrated into existing and future combat systems.

Several models were developed simulating an integrated Electronic Warfare architecture. The integrated architecture incorporated a complete range of automation from total automation to manual operation using a Human-In-the-Loop to aid in Situational Awareness in combat. The model developed with Rockwell's Arena enabled evaluation of solutions that integrate hard-kill defensive systems with soft-kill Electronic Warfare subsystems in order to provide a completely integrated capability to defend against land, air, and sea-launched Anti-Ship Cruise Missiles.

Among the findings of the study was that only a few seconds of delay for HITL involvement can be tolerated. Based on estimated times for HITL actions, under the most stressing scenario, the system should present the human decision maker with only the option to veto or not veto continued operation before automatic threat prosecution takes place.

I. INTRODUCTION

Anti-ship cruise missiles (ASCMs) are an ever-increasing threat to both military and commercial shipping worldwide. In the last fifty years there have been several attacks on United States (US) and foreign ships by ASCMs. The first recorded lethal attack was on the Israeli Naval Ship (INS) *Eilat* in 1967 resulting in 47 deaths. Since the first use of Electronic Warfare (EW) in a battle between missile-equipped boats at the Battle of Latakia in 1973 (Anon. 12 2009), EW systems have evolved greatly, but have yet to become fully integrated into the overall ship's weapon systems. With ASCM capabilities improving, the need for more timely responses has become paramount. The evolution and integration of EW systems with existing weapon systems has become an increasingly important part of ship defensive capabilities. In his 1988 book *Naval Electronic Warfare*, Dr. D. G. Kiely wrote:

> Further evolution may lead to [EW] being absorbed into a complete ship weapons system, largely software controlled, which is designed from the outset as a single entity using as ingredients the capabilities of the separate sensors and weapons of today. This trend in system design is virtually inevitable. In the future there will not be enough time in major operations for men to assess the tactical situation from sensor information and then decide to commit weapons to individual threats. What is likely to occur is the creation of a total ship system where the sensor information is appraised by software and weapons, decoys, and other ECM measures are deployed automatically.

The objective of this endeavor is the development of a solution to improve the integration of EW systems into the weapons systems architecture onboard the United States Navy (USN) 21st Century Warship. Currently, EW systems must use one or more Human-In-The-Loop (HITL) in order for threats to be prosecuted. At times, this method can be slow and cumbersome. The proposed architecture will change the way the HITL is employed by further automating the threat resolution process and determining the method, whether soft-kill, hard-kill, or both to use that will defeat threats while meeting the current Rules of Engagement (ROE) for deployed units.

A. ASCM DEFENSE DEVELOPMENT BACKGROUND

At the tip of the spear, the USN protects national security by maintaining a high level of readiness to preserve freedom of the seas. A major threat to the survivability of our naval force is the ASCM. These can be generally categorized as either subsonic, with speeds up to Mach 0.9, or supersonic, with speeds of Mach 1.0 and above. These missiles typically fly at low altitudes to avoid detection and are the principle threat to the navies of the United States and her Coalition partners. These missiles are highly capable of destroying naval surface ships, as demonstrated in the attack on the United States Ship (USS) *Stark* in 1987, and can be deployed from air, surface, subsurface, and land units (Raytheon Company 2007, 2).

The decision to engage with the correct weapon must be made quickly once a threat has been detected. The situation on the USS *Stark* involved decision making that centered on multiple people in the engagement loop. Had the Electronic Warfare System (EWS) been completely integrated with the combat systems on the platform, the attack might have been averted. It was evident that the Navy needed a better way to combat the threat of ASCMs in littoral waters. In the early 1990's, the USN began research and development on systems that would change the current "Detect to Engage" (DTE) sequence that had been in use long before the attack on the USS *Stark*. The Navy needed a means of incorporating threat inputs from multiple on and off board sensors to neutralize those threats using currently deployed weapon systems. Parallel systems development took place in an effort to minimize the threat. The first objective of the new system was to identify and categorize the threat. Once identified as a positive threat, the system would use computerized doctrine to assign either a soft or hard-kill system to counter the threat.

B. PROBLEM ASSESSMENT

1. History of Anti-Ship Missile Attacks

a. INS *Eilat*

The first anti-ship missile attack recorded was on the INS *Eilat*. The INS *Eilat* was a Z-class destroyer, originally christened Her Majesty's Ship (HMS) *Zealous*. She served in the Royal Navy (RN) during World War II and was later sold to Israel in 1955 where she was re-commissioned as INS *Eilat*. During the Suez Crisis on 31 October 1956, *Eilat* participated in the attack on the Egyptian destroyer *Ibrahim al-Awal*. *Eilat* later served in the War of Attrition, which took place between Egypt and Israel between 1967 and 1970. Between 11 and 12 July 1967, *Eilat* attacked and destroyed two Egyptian torpedo boats in conjunction with two Israeli torpedo boats. On October 21 1967, while on routine patrol off of Port Said in the Mediterranean, *Eilat* came under attack by Egyptian missile boats that were still anchored in port.

The first attack came when an Egyptian *Komar*-class missile boat fired two Russian SS-N-2 *Styx* missiles at *Eilat*. The missiles were detected just prior to their impact with the ship, making defensive maneuvers impossible. The first missile struck just above the waterline, and the second missile struck two minutes later in the same location. The ship sustained heavy damage and began listing. *Eilat* was attacked by a second *Komar*-class missile boat approximately an hour to an hour and a half after the first attack, again with *Styx* missiles, and sank ten minutes later. Of her complement of 191 sailors, forty seven were killed as a result of the attack (Geller 2009).

Figure 1: The INS *Eilat* (Anon. 12 2008).
The Israeli destroyer INS *Eilat* steaming in an undisclosed location prior to the Egyptian Komar-class boat attacks that fired SS-N-2 *Styx* missiles and sank her.

b. The Falklands War

In 1982 three attacks were recorded. The first was an Argentinean attack on the RN destroyer HMS *Sheffield*. This is a prime example of the issues faced when confronting the anti-ship cruise missile threat. The HMS *Sheffield*, hull number D80, was a Type 42 guided missile destroyer, similar in function to the United States *Spruance* or *Arleigh Burke* class guided missile destroyers. Embarking with 287 sailors, the *Sheffield* was part of the British Task Force that took part in the Falklands War in 1982. On the morning of 4 May 1982, *Sheffield* was on station after relieving her sister ship, HMS *Coventry*. *Sheffield* and *Coventry* were communicating via

Ultra High-Frequency (UHF) radio when she detected incoming missiles on her Type 965 radar. The missiles were French designed *Exocet* anti-ship missiles. The launching aircraft, two Argentine *Super Étendards*, flying from Rio Grande, Tierra del Fuego Naval Air Base, were never detected. The missiles impacted the ship only seconds after being detected.

The first *Exocet* impacted *Sheffield* amidships, approximately 8 feet above the waterline on the second deck while the second missile fell short of the ship and landed in the ocean. It is unclear if the warhead detonated or not, but significant damage was caused. The unexpended rocket fuel in the missile was ignited, starting fires that ravaged the ship. Twenty sailors were killed as a result of the attack. The fires were successfully extinguished and the ship was taken into tow by HMS *Yarmouth* on 10 May; however, high seas caused slow flooding of the ship and the *Sheffield* finally sank later that day (Navy Command HQ 1982).

Figure 2: Damage to the HMS *Sheffield* (Anon. 02).
The HMS *Sheffield* engulfed in flames after being struck by two Argentine-launched *Exocet* missiles.

Another ship to fall to the power of the anti-ship missile was the Merchant Vessel (MV) *Atlantic Conveyor*. The *Atlantic Conveyor* was a British merchant navy ship requisitioned by the Ministry of Defence (MOD) during the Falklands War to function in a support role, ferrying supplies from the United Kingdom (UK) to the Falklands. Due to her not being a military ship, she was not fitted with any kind of active or passive defensive capability and relied on the ships around her for protection. On 25 May 1982, the *Atlantic Conveyor* came under attack by Argentine *Super Étendard* aircraft armed with *Exocet* anti-ship missiles in much the same way as the HMS *Sheffield* before her. However, unlike the *Sheffield*, *Atlantic Conveyor* was not the intended target of the attack. The Argentine *Super Étendards* had fired their *Exocet* missiles at ships in the adjoining task force. The targeted ships successfully deployed chaff countermeasures, which caused the missiles to break lock and look for a new target - the *Atlantic Conveyor*.

Having no ability to defend herself from the incoming threat, the ship was struck on the port quarter, and fires started aboard the ship. Again, it is unclear if the impacting missile's warhead detonated or not. The embarked cargo of several helicopters and fixed wing aircraft were largely destroyed. After the fires were extinguished, the damage to the ship was deemed too great and she was abandoned, later being intentionally sunk. Twelve sailors were killed as a result of the attack (Navy Command HQ 1982b).

Figure 3: Damage to the MV *Atlantic Conveyor* (Anon. 25).
The MV *Atlantic Conveyor* on fire after an Argentine *Exocet* strike during the Falklands war.

The final example from the Falklands War is that of the HMS *Glamorgan*, hull number D19. She was a County-class destroyer, also part of the British Task Force employed during the Falklands War. On the first of May, 1982, she was unsuccessfully attacked by four Argentine *Mirage* fighter aircrafts using 500 pound bombs, a method that was later successfully employed against the frigates HMS *Ardent* and HMS *Antelope*. On the evening of 25 May, after the attack on the MV *Atlantic Conveyor*, *Glamorgan* participated in retaliatory strikes against the city Stanley. She participated in several additional strikes against Stanley in the following days.

During the afternoon of 30 May *Glamorgan* came under attack by *Exocet* missiles, but escaped unscathed. She remained in the area supporting British warfighting efforts, and on the 12th of June, she again came under attack by *Exocet* missiles.

The attack was carried out by a shore-based *Exoce*t battery. The incoming missile was not detected by shipboard warning systems. However, seconds before impact, the *Exocet* exhaust plume was detected visually by the Officer of the Watch. The missile impacted the aft end of ship, blowing a hole in the deck outside the hangar, destroying the ships aircraft and the port *Seacat* anti-air missile launcher. As in other cases, the missile's warhead did not detonate. However, the fires it caused spread throughout the hangar and galley, which was situated below the area of impact. The ship's magazine and other nearby compartments were flooded, but the ship did not sink. She was temporarily repaired on site and steamed to port under her own power in late June. She continued in service until 1998. Of 471 embarked sailors, thirteen were killed as a result of the attack (Anon. 01; Anon. 03).

Figure 4: Damage to the HMS *Glamorgan* (Anon. 04 2008).
This is the result after an *Exocet* strike from a shore battery during the Falklands War.

c. USS *Stark*

The USS *Stark* was an *Oliver Hazard Perry*-class guided missile frigate (FFG) with the USN. With her embarked complement of approximately 230 sailors, she was one of several USN ships deployed to the Persian Gulf during the Iran-Iraq war in the late 1980s. Her mission was to protect Kuwaiti oil tankers that had been temporarily reregistered as US vessels in an attempt to legally offer them protection while the US remained neutral in the conflict. The US's neutrality would come at a steep price. On 17 May 1987, while on patrol in the Persian Gulf, *Stark* came under attack. *Stark* was fired on by an Iraqi *Mirage* F1 fighter aircraft operating out of Shaibah. Similar to previous incidences, the French *Exocet* missile was not detected on radar prior to impact. The ship's defensive systems were not made ready and as a result, there was no response to the incoming missiles from either the *Phalanx* Close-In Weapons System (CIWS) or onboard countermeasure dispensers. The first missile penetrated the port side hull and lodged itself in the ship, not detonating but starting fires from its still burning rocket motor. The second missile struck moments later, penetrating into the ship and detonating its warhead in crew quarters. While sustaining heavy damage, *Stark* was temporarily repaired onsite and was able to return to port under her own power. After refurbishment she continued in service until 1999. Iraq later stated that the USS *Stark* had been mistaken by the pilot as an Iranian frigate. Thirty seven sailors were killed as a result of the attack, which was a huge public relations disaster for US policy in the region (Sharp 1987; Manning 2001).

Figure 5: Damage to the USS *Stark* (Anon. 19 1987).
The USS Stark on fire in the Persian Gulf after being struck by an *Exocet* anti-ship cruise missile.

d. INS *Hanit*

The most recent attack was on the INS *Hanit*. The INS *Hanit* (translated to English as "Spear") is a Sa'ar 5-class corvette that entered service in February of 1995. She participated in operations during the 2006 Lebanon War (also known as the July War or the Second Lebanon War) between Lebanon and Israel. On 14 July 2006, *Hanit* was engaged in patrol operations in Lebanese waters approximately 10 nm off the coast of Beirut, Lebanon. She was attacked by at least one anti-ship missile, suspected to be a sea-skimming Chinese C-802. The missile impacted the ship under the aft superstructure causing damage to the flight deck and propulsion systems. However, *Hanit* was able to return to port for repairs under her own power. There is conjecture that the ship actually faced a multiple-missile threat, the first being a decoy that locked on to its intended target on a similar bearing as *Hanit* prior to passing over. It was initially believed that a weaponized unmanned aerial vehicle (UAV) had been used in the attack. Only later was it determined that a rather sophisticated anti-ship missile was the weapon used. The possibility of an anti-ship missile attack by Hezbollah militants was not believed likely, thus *Hanit's* anti-ship missile defenses were not online during the attack. Of her complement of 74 sailors, four were killed as a result (Pike 2006c; Katz 2006; Eshel 2006; Anon. 14 2008).

Figure 6: Damage to INS *Hanit* (Anon. 14 2008).
While on patrol operations in Lebanese waters INS *Hanit* was struck by a Hezbollah launched sea-skimming Chinese C-802. Damage was sustained to the flight deck and propulsion systems.

C. BACKGROUND AND PROBLEM ASSESSMENT

There are several lessons learned from the anti-ship cruise missile attacks evaluated above. In general, a combination of factors were in play, however, there are some specific factors that can be noted. In some of the cases, the incoming missiles were not detected in enough time to employ defensive measures. The timeline from detection to engagement, either by human or computerized system, was not sufficient to employ defensive systems aboard the targeted platform. In some of the cases, the automated systems that would have detected the incoming threats were disabled or operated in a reduced capacity due to interference from other shipboard systems. While the systems were present, they were not implemented in such a way that they were effective. In yet other cases, the defensive systems were not enabled due to intelligence suggesting such attacks were unlikely.

Each of the factors noted above is an issue to both a fully automated system and a system with a HITL. With regard to there not being enough time between detection and employment of countermeasures, a HITL will only serve to extend that timeline. In the case of the systems being disabled or operated in a reduced capacity due to interference, it was a human that made the decision to limit the system, because it was a human who became annoyed with the alarm bells, or flashing lights, alerting them to threats that were not there. Finally, it was a human who ultimately decided not to operate the defensive systems due to intelligence they were provided. Thus, a system is necessary that will: detect incoming threats at long range; quickly analyze incoming threats to categorize the threat and determine a response; employ countermeasures automatically or with limited human oversight; and be electromagnetically compatible with other ship systems.

D. RESULTS AND RECOMMENDATIONS

This study has shown that there is a great need for improvement of current Naval ASCM defensive techniques, in order to both defend against current threats and to maintain such a capability against emerging and evolving threats. The integration of an advanced electronic warfare system to existing surface combatant defensive systems will enable current and future Naval surface combatants to effectively combat the ASCM threat.

It is recommended that an integrated electronic warfare system be developed with a HITL in an oversight role. A significant output of this study was the development of a model for ASCM engagement. The model currently incorporates nominal unclassified parameters for both the ASCM threat systems and the necessary human performance parameters. It is further recommended that the model be expanded upon, both in fidelity and depth of detail.

E. REPORT OVERVIEW

The remainder of this report contains four sections; Literature Review, Technical Approach, Design and Analysis, and Conclusion. The background concerning the threat has been established the literature review section which provides information on current threat capabilities, ship capability gaps, and the importance of carefully considering the implementation of the HITL. The third section, Technical Approach, describes the team's work transforming stakeholder needs into functional needs and presents the systems engineering approach for the project. It describes how the team modeled and simulated the problem. The Design and Analysis chapter assessed current and projected system capabilities to define the potential battlespace. A conceptual design was proposed and evaluated against the current design. Finally, conclusions are presented and recommendations made in the final chapter.

II. LITERATURE REVIEW

The literature review portion of this report focuses on the ASCM threat and human systems integration. For the ASCM threat, past, present and future ASCMs are reviewed. Their performance characteristics, such as speed, terminal attack type, velocity, propulsion and guidance types, and typical launch platforms are presented. In addition, known future ASCM developments are discussed. When the past and present threats are combined with knowledge about future technologies and example attacks discussed in Chapter I, methods to counter the threats can be devised. Further, human systems integration (HSI) is also discussed. Integration of man and machine is imperative to achieve the response times necessary to counter the ASCM threat. Levels of computer automation will be explored, and historical information on human/machine interaction in similar combat systems will be examined.

A. ANTI-SHIP CRUISE MISSILE DEFENSE (ASCMD)

1. ASCM Threat Assessment

The primary driver for ship self defense is ASCMs. A comparison of some of those missiles and their capabilities is necessary to better understand the requirements of the Integrated EW on the ships. These capabilities include country of origin, propulsion type, velocity, guidance type and warhead type.

There are currently six primary nations that produce ASCMs for sale to other countries; the United States, Russia, China, India, France, and North Korea. The US produces the A/R/UGM-84 *Harpoon*. The *Harpoon*, manufactured by Boeing (formerly McDonnell Douglas) Integrated Defense Systems in St. Charles, Missouri, achieved operational capability in 1977 and is employed by the USN, United States Air Force (USAF), and 27 foreign countries through foreign military sales. The *Harpoon* is available in the following variants: Air-to-Ground (AGM-84), Surface-to-Surface (RGM-84), and Subsurface-to-Surface Missile (UGM-84). Each is powered in flight by a liquid-fueled jet engine, with the surface and submarine-launched variants having an additional booster rocket engine. The *Harpoon* is a sea-skimming missile with a terminal pop-up maneuver utilizing an Inertial Navigation System (INS) and an active radar terminal seeker to locate its target. It cruises at high subsonic speeds with a range in excess of 67 miles and carries a conventional high explosive warhead of 488 lbs. The *Harpoon* Block II adds global positioning system (GPS) capability to complement the INS (Anon. 10 2009).

Russia produces three ASCM variants. The first is the P-15 *Termit*, alternatively known by its North Atlantic Treaty Organization (NATO) reporting name SS-N-2 *Styx* or 4K40. The *Styx* is manufactured by the MKB Raduga design bureau. It achieved operational capability in 1960 and is employed by many countries, including Algeria, Egypt, Iraq, and North Korea. It is available in air, surface, and ground-launched variants, and is as the basis for derivative weapons from several other countries, including China, Iran, and North Korea. The *Styx* is a rocket powered, sea-skimming missile that is capable of cruising at high subsonic speeds with a range in excess of 50 miles. It carries a conventional 1,100 lb high-explosive anti-tank (HEAT) warhead, as opposed to the more common semi-armor piercing warheads typical of anti-ship missiles. It uses active radar for terminal guidance with some variants having a supplemental infrared (IR) guidance system (Anon. 06 2009).

Another Russian ASCM is the P-270 *Moskit*, alternatively known by its NATO reporting name SS-N-22 *Sunburn*, which is designed by the same bureau as the *Styx*. The *Sunburn* achieved operational capability in the late 1970s and is also employed by China, Vietnam, and Iran. The *Sunburn* is available in air, surface, submarine and ground-launched variants. The *Sunburn* is a sea skimming missile that uses a ramjet with booster rocket for launch. It cruises at Mach 2 to 3, and has a range between 56 and 155 miles, depending on the particular variant. It carries a conventional 700 lb warhead and uses an active radar seeker for terminal guidance (Pike 2006d).

The final ASCM produced by Russia is the 3M54 *Klub*, alternatively known by its NATO reporting name SS-N-27 *Sizzler*. The *Sizzler* is manufactured by the Novator Design Bureau and was shown to the public in 1997 with variants known to be also employed by China, India, and Algeria. It is available in surface and submarine-launched variants, though an air-launched version may be in development. The *Sizzler* is a sea-skimming missile that cruises at high subsonic speed and has a supersonic dash capability for the terminal phase. It has a range of 140 miles and carries a 440 lb conventional warhead. The *Sizzler* uses inertial navigation with an active radar seeker for terminal guidance (Rakshak 2006).

Similarly to Russia, China produces several ASCMs. The C-801, alternatively known as the Ying-Ji (YJ) 1 or by its NATO reporting name CSS-N-4 *Sardine*, is a Chinese anti-ship missile manufactured by China Haiying Electromechanical Technology Academy (CHETA). It is known to be employed also by Iran. The *Sardine* is available in air, surface, submarine and ground-launched variants. The *Sardine* is powered by a rocket engine and uses a booster rocket for launch. The *Sardine* is a sea-skimming missile believed to be derived from the French *Exocet.* It cruises at high subsonic speeds and has a range of 26 miles. It carries a conventional 360 lb high explosive semi-armor piercing warhead and uses an active radar seeker for terminal guidance (Pike 2006a).

The C-802, alternatively known as the YJ-802 or by its NATO reporting name CSS-N-8 *Saccade*, is a Chinese anti-ship missile manufactured by CHETA. It achieved operational capability in 1989 and is employed by many other countries, including Algeria, Bangladesh, Iran, and Pakistan. The *Saccade* is available in air, surface, submarine and ground-launched variants. The *Saccade* is a jet engine powered, sea-skimming missile that attacks low on the target's waterline. It cruises at high subsonic speeds and has a supersonic terminal phase. The *Saccade* has a range of between 75 and 310 miles, and carries a conventional 363-lb high explosive semi-armor piercing warhead utilizing inertial navigation with an active radar seeker for terminal guidance. IR and electro-optical (EO) seeker upgrades are known to be available (Pike 2006b).

The Russian SS-N-2 *Styx* missile provided the basis for several Chinese anti-ship missiles, including the HY-1, CSS-C-2 *Silkworm*, HY-2, HY-3, CSS-C-3 *Seersucker*, and HY-4. They are in use by multiple countries including China, Iran, North Korea, Sudan, and the United Arab Emirates (UAE). This family of missiles is available in air, surface, and ground-launched variants. Variants are powered by rocket, ramjet (HY-3), or jet (HY-4) engines with booster rockets used for launch. They are sea-skimming missiles with a terminal dive attack and a range of 60 miles carrying a conventional 1,130 lb warhead. Guidance types vary from IR to active radar to monopulse radar (Anon. 11 2009).

India has one ASCM, the PJ-10 *BrahMos*. The PJ-10 *BrahMos* is a joint effort between the Indian Defense Research and Development Organization (DRDO) and Russian NPO Mashinostroeyenia. Achieving operational capability in 2006, it is employed by India and Russia. The *BrahMos* is available in air, surface, submarine and ground-launched variants. The *BrahMos* uses an integrated rocket and ramjet engine for launch and cruise. It is a sea-skimming missile, which carries a conventional 660 lb semi-armor piercing warhead, capable of cruising at supersonic speeds between Mach 2.8 and 3.0 with a range of 180 miles. A hypersonic, Mach 5.0 and above, variant is under development and has been demonstrated in a laboratory environment. It uses inertial navigation with GPS and has an active radar seeker for terminal guidance (Anon. 07).

The *Exocet* is a French anti-ship missile manufactured by the Aérospatiale division of MBDA. It achieved operational capability in 1972 and is employed by many different countries including Pakistan, Argentina, Egypt, and Iraq. It is available in air, surface and submarine-launched variants, and has been adapted for ground-based launches as well. It uses a booster rocket engine for launch and a rocket or jet engine for cruising. It is a sea-skimming missile that cruises at high subsonic speed and has a range of 110 miles. The *Exocet* carries a conventional 360 lb shaped-charge warhead and uses inertial navigation with active radar for terminal guidance (Anon. 09).

The KN-01 is a North Korean variant of the Russian SS-N-2 *Styx* anti-ship missile. It has been test fired extensively from 1993 to today. The KN-01 has been displayed at trade shows mounted to ground-launch vehicles and has a demonstrated range of 65 miles. Little is known about its warhead, engine, or range, though these are likely to be similar to the capabilities of the *Styx* (Pike 2005; Jane's Information Group 2008).

Nomenclature	Country of Origin	IOC	Launch Type	Propulsion Type	Velocity	Range (mi)	Warhead Type	Warhead Size (lbs)	Guidance Type
A/R/UGM-84 Harpoon	US	1977	Air / Land / Surface / Subsurface	Jet Engine with Rocket Booster	High Subsonic	67+	Conventional High Explosive	488	GPS/INS/Active Radar
SS-N-2 Styx / P-15 Termit / 4K40	Russia	1960	Air / Land / Surface / Subsurface	Rocket Engine with Rocket Booster	High Subsonic	50+	High Explosive Anti-Tank	1100	Active Radar / IR
SS-N-22 Sunburn / P-270 Moskit	Russia	1970s	Air / Land / Surface / Subsurface	Ramjet with Rocket Booster	Supersonic (Mach 2 - 3)	56 - 155	Conventional High Explosive	700	Active Radar
SS-N-27 Sizzler / 3M-54E Klub	Russia	1997?	Air (?) / Surface / Subsurface	Jet or Rocket Engines	High Subsonic with Supersonic Terminal	140	Conventional High Explosive	440	INS / Active Radar
C-801 / Ying-Ji-1 / CSS-N-4 Sardine	China	?	Air / Land / Surface / Subsurface	Rocket Engine with Rocket Booster	High Subsonic	26	Conventional High Explosive Semi-Armor-Piercing	360	Active Radar
C-802 / Ying-Ju-802 / CSS-N-8 Saccade	China	1989	Air / Land / Surface / Subsurface	Jet Engine	High Subsonic with Supersonic Terminal	75 - 310	Conventional High Explosive Semi-Armor-Piercing	363	INS / Active Radar
HY-1 / CSS-C-2 Silkworm / HY-2 / HY-3 / CSS-C-3 Seersucker / HY-4	China	?	Air / Land / Surface / Subsurface	Jet or Rocket Engines with Rocket Booster		60	Conventional High Explosive	1130	IR / Active Radar / Monopulse Radar
PJ-10 BrahMos	India / Russia	2006	Air / Land / Surface / Subsurface	Integrated Rocket / Ramjet	Supersonic (Mach 2.8 - 3) / Hypersonic (Lab)	180	Conventional High Explosive Semi-Armor-Piercing	660	GPS/INS/Active Radar
Exocet	France	1979	Air / Land / Surface / Subsurface	Jet or Rocket Engines with Rocket Booster	High Subsonic	110	Conventional High Explosive Shaped-Charge	360	INS / Active Radar
KN-01	North Korea	?	Land (?)	?	?	?	?	?	?

Table 1: Potential ASCM Threats.
A table of potential ASCMs that would have to be defended against and their respective attributes. Most of these missiles are operated by more than one country.

2. Future Developments

Future ASCM development is focused toward improving upon existing technologies and designs, rather than implementing revolutionary capabilities. The major areas for increased capabilities are seeker technology, range, speed, and stealth. Some capabilities are being improved in tandem, such as speed and range, while others are interrelated, such as the use of advanced passive sensors to improve stealth. There are upcoming weapons geared toward providing increased capabilities for conflicts in littoral waters. Such weapons will use advanced seeker hardware and algorithms to improve their performance in high-clutter environments (Defense Update 2007).

Other weapons are being developed with a focus on increased range, allowing attacking craft to employ their weapons at greater distances, outside of weapon and/or detection range of the target ship (Defense Update 2009; FBO Daily 2008).

In addition, systems are being developed with an eye on decreasing probability of detection. Through the use of composite materials, passive guidance technologies, and particular body shapes, weapons can be made increasingly stealthy, much as aircraft have become. This will allow the weapons to more readily be employed without being detected, and will lower the potential response time the target ship has available to employ countermeasures (Scott 2006).

Additional improvements are being made in propulsion, with mixed mode jet/rocket systems, higher sustained speeds, and terminal phase dash attacks all increasing probability of kill while decreasing probability of detection. In addition improvements to existing weapons are being made to increase flight speeds into the hypersonic regime. These potential improvements highlight the importance of eliminating ship defensive capability gaps (Anon. 18 2008).

Advancing technologies have led to four major types of weapons from a flight speed perspective. First, there are the subsonic missiles that cruise below Mach 1 for the duration of their flights. Next there are the supersonic missiles. These accelerate to and cruise in the Mach 1 to Mach 2 speed range for the duration of their flights. In addition, there are those weapons that have a terminal phase that is much faster than their cruise phase. To date these missile typically cruise at subsonic speeds and have a supersonic terminal phase. Finally, there are the hypersonic weapons, which are the newest class, of which none are known to be currently fielded. The *BrahMos II* is the first of these weapons, cruising at up to and over Mach 3. In order to defend against all these types of weapons, it is necessary to be able to defend against the fastest – those being the hypersonic class weapons.

B. HUMAN SYSTEMS INTEGRATION (HSI)

The International Council of System Engineering (INCOSE) defines HSI as the "interdisciplinary technical and management processes for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice" (HSI Working Group 2007).

In 2008 the Duncan Hunter National Authorization Act recognized the importance of including HSI in all DoD acquisition programs (Washington, DC: ODUSD(A&T), ODUSD(S&T) Director of Biological Systems 2009) The design of the Integrated Electronic Warfare Systems (IEWS) will incorporate HSI according to policy standards set forth in the DoD and Navy HSI management plans.

1. Levels of Automation

The original intent of the project team was to create a completely automated, integrated EW system that would be considered for the combat systems of the next generation of 21st Century warships. The initial thought was that a fully automated EW system, without HITL, was needed to minimize system response time. After much discussion it became apparent that Situational Awareness (SA), specifically the need to discriminate between friend or foe, was a considerable issue and that the human could not be disconnected from the process altogether. The level of human and machine interaction then became the central focusing issue. The question of how much human activity versus how much automation to employ became paramount to the research on the integration of the system as a whole. To characterize levels of HITL activity, we have selected the ten levels of automation, taken from the research of Parasuraman, Sheridan, and Wickens. Table 2 shows the ten levels of interaction that the human and the computer could have (Parasuraman, Sheridan, and Wickens 2000, 286). These levels span a range from only human decisions and actions to no human decision or actions taken during the DTE sequence.

LEVELS OF AUTOMATION OF DECISION AND ACTION SELECTION		
HIGH	10	The computer decides everything, acts autonomously, ignoring the human
	9	Informs the human only if it, the computer, decides to
	8	Informs the human only if asked
	7	Executes automatically, then necessarily informs the human
	6	Allows the human a restricted time to veto before automatic execution
	5	Executes the suggestion if the human approves
	4	Suggests one alternative
	3	Narrows the selection down to a few
	2	The computers offers a complete set of decision/Action alternatives
LOW	1	The computer offers no assistance; human must take all decisions and actions

Table 2: Recreation of Table 1, Levels of Automation of Decision and Action Selection. This table was taken from A Model for Types and Levels of Human Interaction with Automation (Parasuraman, Sheridan, and Wickens 2000, 286). These 10 levels indicate the amount of interaction between a human operator and the system. Low indicates that the human user will make all the decisions and take subsequent actions. High indicates that the human will have zero input into the DTE sequence and the system acts autonomously.

The human considerations of the system are every bit as important and challenging as the hardware and software portion of the system. The HSI domains found on the Naval Postgraduate School (NPS) website include human factors engineering, human survivability, system safety, health hazards, habitability, manpower, personnel, and training (Naval Postgraduate School 2009). The simulation has randomized small differences in reaction time to emulate the differences in skill and attention levels of personnel at any given time. During the development of the models, human factors engineering, human survivability, system safety concerns were addressed throughout the levels of human interaction. For the levels that require human interaction the degree and time of these interactions has been varied with the system. This variation could range from a simple query of the system to the human completing some or all decisions and actions. Each level of automation is assigned a specific time in the model simulating the delay time that would be expected if a human was a part of the kill chain. At the four second mark the operator may press a button to veto the automatic solution presented by the system. At 15 seconds, the operator may be given multiple alternatives to chose from. At 30 seconds, the system could be switched to a manual mode of operation. The design took into consideration the complete range of human interaction that may occur during the operation of the

IEWS that would improve the overall SA of the watch stander while conducting engagement support or counter targeting.

Three primary assumptions applied to the simulation presented in subsequent chapters concerned Manpower, Personnel, and Training. It was assumed that while the personnel maintaining the system may or may not be military, the HITL would be military. The second assumption involved the fact that increased automation would reduce the numbers of military personnel necessary to operate the system, but may also increase the need for regular testing and maintenance. The third assumption made was that the Navy would apply stringent qualifications to the training program for operators and would limit the position of operator to members in a supervisory position with the authority to release weapons. Health hazards and habitability domains were not addressed in this project.

2. Historical Example

There has been much attention called to HITL issues. Many published articles discuss the USS *Vincennes* incident on July 3, 1988 in the Persian Gulf. While most of the literature maintains that the incident could have been avoided, it focuses on the fact that in war time, life and death decisions must be made instantaneously without clear or available information. The question asked after this incident by the press was phrased very well by a writer for Time magazine. "The central question is whether technology may be pushing the fallible humans who operate it beyond their ability to make wise judgments instantly on the basis of what, with even the most sophisticated systems, will often be ambiguous info" (Church, Jackson/Tehran, and Peterzell/Washington 1988). The factors that led to the incident include Geopolitical situations, ROE, the fog of war, as well as the lack of experience with the system and system failure. All but one of these factors could be considered human factors. This is why it is so important to explore human factors.

3. Ethical and Political Implications

As stated previously, a discussion on SA drove critical changes to the direction of the project. Political and ethical implications also weighed heavily on those decisions. America is bound by the Geneva Convention as well as other international laws of war. These laws demand that there is a limit to collateral damage. It is paramount to determine combatants from non-combatants in order to limit collateral damage. Because of the difficulty of accountability, completely autonomous weapons are seen as problematic. As a result, there is a political impetus to keep a HITL, meaning that a human controller must authorize weapons release (Lazarski 2001).

The project team was also aware of the ethical implications of automated systems, as was Thomas Sheridan, a noted researcher in the field of supervisory behavior and automation. He has expressed concern that operators interfacing with technology could have the tendency to trust technology without question and abandon responsibility for their own actions. Because of the design of computers and the associated interfaces with peripheral equipment, the tendency of the operator is to implicitly trust the output of the computer.

This leads to a dilemma for program managers during development of weapons systems. How much automation is politically acceptable? The tendency is to remove human failure by completely automating the system. The most acceptable solution may be to automate the weapon system while maintaining a human override capability. For this to work, the operating personnel would need to be well versed in the functionality of the system. This option is understood as an alternative; however, it is not considered in the modeling approach in this study.

III. TECHNICAL APPROACH

The technical approach section of the report presents the project stakeholders and their applicable requirements, the capability gap the project aims to fill, the assumptions that went into the project and the associated computer based models, and the systems engineering processes followed over the course of the project. First, the stakeholders will be defined, and their individual system functional requirements discussed. Next, the capability gaps the system is aiming to fill are explored. Then, the assumptions used to bound the system and translate the system functional requirements into a system capable of being modeled are laid out. Finally, the systems engineering design process will be surveyed.

A. STAKEHOLDERS

1. Definitions and Customers

The literal definition of a stakeholder is, "Any party that has an interest (stake) in a project, firm or enterprise" (Calvano 2008). However, adhering strictly to this definition when dealing with systems intended to be used in combat would produce a massive list of stakeholders. When considering the different viewpoints concerning both strategy and tactics, not only amongst the services, but even between members of the same service, comprehensive requirements definition at any level would become impossible to accomplish in a reasonable amount of time. Therefore, it is prudent to narrow the scope of stakeholders by only considering those that are most relevant. The team has defined a relevant stakeholder as any organization or individual with a *direct interest* in actions or decisions concerning this project. The interest may be because they will have a role in *implementing* the decisions, or because they will be *directly affected* by the decision (Calvano 2008). Given this scope, the relevant stakeholders can be further stratified by identifying those who are implementing the decisions, those that are being affected by the decisions, or both.

Those who both make the decisions and are directly affected by them are our most important stakeholders. There are two categories of these, with each individual within in a category being equally important. The first category of stakeholders is the Combatant Commanders (CCDRs) who are charged by the President with effectively planning and executing operations in their area of responsibility. This includes defining the capabilities needed to execute operational plans. If the system we are designing is intended to support these operations, it must meet CCDR requirements. The second category is the Fleet Commanders whose Title 10 responsibilities are to man, train, and equip the naval forces for the CCDR. These persons are the vital link between fielded equipment, operators and the CCDR's requirements to execute operations. If a Fleet Commander cannot support our system as designed, it cannot be fielded.

The second stratum of stakeholders includes those that are directly affected by the decisions. Although these are all tactical operators charged with physically using the system, they can be broken down further according to the level of war fighting integration required at their level of command. There are four categories with each individual within a category being equally important; Commander, Carrier Strike Group (CCSG), ship captains assigned air defense responsibilities, tactical system operators, and tactical system maintainers. CCSGs exercise tactical control and coordination of multiple units in support of an assigned mission. These commanders must integrate and utilize the fielded system as part of a larger force that may contain many dissimilar platforms. Our system must be able to integrate with other units tactically. Ships in an air defense posture must operate the physical system and do so in a manner that is consistent with the intentions of the CCSG. They must set the operational parameters for the system within its operating limits. Tactical system operators are the button pushers. If the fielded system is to be operated effectively, the input of those that must physically operate it is essential. Even the most elegant EW solution to the ASCM problem will be useless if it cannot be effectively operated in a high stress environment. Tactical system maintainers work to keep the system up and running. No matter how well designed, the fielded system will require maintenance. The proposed design must include input from personnel performing these actions.

The third stratum of stakeholders consists of those that have a role in implementing the decisions but are not directly affected by the outcome; the system producers and the producers of other ASCMD systems. "Directly affected by the outcome" indicates that the fielded system will be an integral part of the day-to-day routine of the individual. It does not mean that an individual will experience ancillary effects, such as a loss of position. Ranked first by the monetary risk involved are the system producers. If we cannot design a system that will be profitable to produce, there will be no fielded system. The number of stakeholders and their ranking in this category will change dependent on the final system configuration. Second are the producers of other (i.e., hard kill) ASMD systems. If the fielded system is to be an integrated solution, it will require input from these producers.

2. Stakeholder Requirements

Discussion with Commander Cerovsky and information warfare operators from Carrier Strike Group Twelve and amongst the team has produced the following requirements. These requirements have been compiled, categorized, and placed into table 3 shown below.

Category	Requirement
Performance	System must be responsive enough to counter Hypersonic missiles detected at close range.
	System must provide 360-degree engagement capability for each platform on which it is installed.
	System must have capability of engaging multiple threats at once.
	System must be able to route engagements to other defensive systems in the event of target saturation.
	System must be able to assume engagement from other defensive systems on command or as a result of doctrinal requirement.
	System must be scalable to different size platforms.
Interoperability	System must be integrated with other defensive weapons on the platform.
	System must not interfere with communications or navigation systems.
	System must be interoperable with other defensive systems operating in a joint or coalition environment.
	System must not interfere with flight operations at sea during normal operation (missile engagement excepted).
	System must utilize military standard communications protocols and paths.
	System must be capable of being retrofitted to existing platforms.
Oversight	System must allow human intervention at time of the operational commander’s choosing, i.e. it cannot be designed to be completely autonomous.
	System must contain kill chain breaks (such as keys or firing pins) that may be removed or inserted at the discretion of the operational commander.
	System must capable of being shut down immediately.
Operation and Maintenance	System must be operable by a typical watch stander (no excessive training requirements compared to currently fielded systems).
	System must be operable in port (special operating mode allowed).
	System must be maintainable by typical personnel at sea.
	System must have redundancy in the event of battle damage or power loss.
	System must conform to current display standards on Navy combatants.
	System must be upgradable.
	System must be operable by typical naval combatant power systems.

Table 3: Stakeholder Requirements.
The table displays system functionality requirements generated from the stakeholders.

B. SHIP DEFENSIVE CAPABILITY GAPS

When it comes to defense of naval combatants, the best option from an operational standpoint is early detection and elimination of the threat. Shooting the archer, not the arrow, is a fundamental tenet of defensive warfare. In naval missile warfare, that means early detection and discrimination to achieve engagement criteria. In modern operating environments cluttered with non-combatants, both detection and discrimination are hard to achieve. Picking out the archer from the crowd of white shipping, air traffic, and land-based clutter is a complex problem at best and is near impossible in the case of a terrorist threat.

To mitigate this problem, one approach is to both expand and increase the resolution of the sensor horizon by the networking of all available sensors as is done with the Cooperative Engagement Capability (CEC). In fact, network-centric operation as it is called, is well down the path to becoming the default doctrine by which the armed forces operate. Unfortunately, it has done remarkably little to enable the early detection of an ASCM before the active seeking terminal phase.

Even if technology progresses to the point that allows the complete integration of every sensor in a theater, the problem of recognizing the archer among the crowd persists, something that certainly requires a HITL to solve. Additionally, the defense of one ship is completely reliant on both ubiquitous communications and other platforms in relatively close proximity. Neither of these scenarios is a current reflection of real world operating environments. Additionally, once launched, the simple truth is that the probability of radar detection of a sea-skimming missile at range is unacceptably low.

The most consistent unambiguous indication of a missile attack is the detection of a missile’s active radar seeker. The signal is unique from other radar signals and is generally pointed directly at its target. Current U.S. capabilities are relatively robust in this area. However, the use of passive Radio Frequency (RF) sensors for missile warnings creates a situation vulnerable to exploitation by missile designers as explained below.

If one assumes that a naval combatant’s first indication of an inbound missile will be the detection of the missile seeker, the time from detection to impact is a straightforward function of missile speed and seeker turn on time. The most serious threats utilize a combination of inertial or GPS guidance with an active seeker only for the terminal phase.

Missile speed also affects the response time available to the defense. Cappacio (2007) notes that:

> Charts prepared by the Navy for a February 2005 briefing for defense contractors said the *Sizzler*, which is also called the SS-N-27B, starts out flying at subsonic speeds. Within 10 nautical miles of its target, a rocket-propelled warhead separates and accelerates to three times the speed of sound, flying no more than 10 meters (33 feet) above sea level.

A Mach 3.0 missile detected at 10 nm will result in a detect-to-engage timeline of less than one minute, and that assumes perfect sensor coverage. Choosing this as the “design to” case raises the question of how best to defeat the inbound missile once it is detected. Current tactics emphasize hard-kill options with countermeasures and current systems have the capability of both automatically deploying chaff/flares as decoys and shooting. In this situation, shooting something that is misidentified or not shooting because of a very restrictive doctrine would have enormous military and political consequences.

Most operational commanders chose to insert a human in the decision making loop, resulting in a situation where sensors only provide inputs to human operators and a human must choose how to deploy a response. This required human involvement limits the timeline of responses to unacceptably long periods when presented with a sophisticated missile such as the SS-N-27B. Cappacio (2007) states that:

> The Defense Department's weapons-testing office judges the threat so serious that its director, Charles McQueary, warned the Pentagon’s chief weapons-buyer in a memo that he would move to stall production of multibillion-dollar ship and missile programs until the issue was addressed.

Lastly, the increased timeline resulting from human involvement is not even the most serious problem. Cappacio (2007) also mentions that:

> The Navy’s ship-borne AEGIS system, deployed on cruisers and destroyers starting in the early 1980s, is designed to protect aircraft-carrier battle groups from missile attacks. But current and former officials say the Navy has no assurance AEGIS, built by Lockheed Martin Corp., is capable of detecting, tracking and intercepting the *Sizzler*.

Because the AEGIS system was designed to be used in blue water battles, platforms with that system of defense could be susceptible to littoral terrorist attacks from “friendly” surface platforms using modified ASCM systems. Even if the Navy’s most advanced hard-kill defensive system does get a warning early enough, it may not be able to do anything about it.

C. GENERAL ASSUMPTIONS

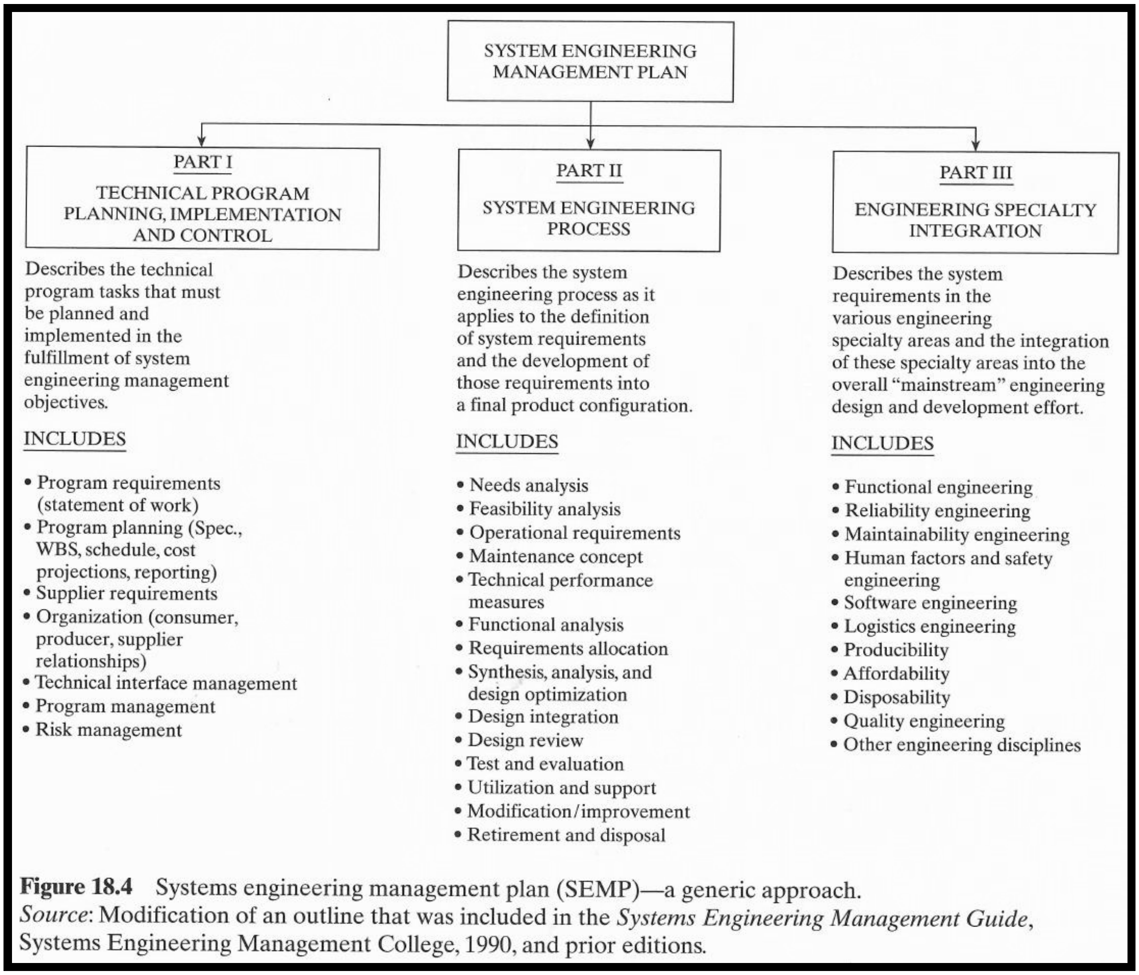
For assessment of the bounds and scoping of the project, the team made several specific assumptions in defining the baseline scenario:

- The EW will not interfere with the Target Illuminators.
- The Fire Control System (FCS) will operate as the server for the queuing system.
- The system radar can track multiple targets.
- Targets will be treated as discrete events and not a swarm. Each event is discrete even if multiple events occur at the same time. The model is designated in the form A/B/S, where A is the arrival distribution, B is the Service Time Distribution, and s is the number of servers. The model chosen for this study has a Markov distribution (M), a general service time distribution (G), and a single server (1). Thus, the model is designated M/G/1.
- Arrival rates are unknown.
- Threats shall have the performance characteristics indicated in table 1. Other parameters shall be estimated.
- Surface combatants shall have nominal values for their parameters.
- The ability to radiate Electro-Magnetic (EM) energy is unrestricted – no Emission Control (EMCON).
- Weather conditions shall be average (rather than extreme), with sea state between zero and two. There shall be good visibility, low humidity, low clutter, and no precipitation.
- The battlespace shall be in blue water areas outside of shipping lanes.
- When a HITL is present, only one person will act and that person will be in a supervisory position.

D. SYSTEMS ENGINEERING DESIGN PROCESS

The main objective of the systems engineering design process as applied to this problem is to investigate how the HITL affects the overall performance of the IEW, hard-kill, and soft-kill systems onboard a 21st century warship. The investigation will provide information concerning the level of automation that is acceptable. One extreme would be to allow the HITL to make all the decisions and have no automation. Without any automation the HITL would have to detect, classify, track and engage the target along with each respective sub-function as shown in Figure 8. Another extreme would be to have no HITL and have a completely automated process in which an onboard computer receives all the information and makes all the decisions. Hence, a systems engineering design process is needed that allows and enables the simulation and evaluation of such a system and which provides insight into acceptable alternatives.

The systems engineering design process includes: an initial research of literature, stakeholder analysis, requirements generation, an Analysis of Alternatives (AoA) approach, modeling and simulation, risk management and human factors integration. This project is considered a science and technology effort; not a complete DoD acquisition project that would require a more comprehensive systems engineering design process as described on page 664 in Blanchard & Fabrycky's book *Systems Engineering and Analysis* (2006). Figure 7 shown below illustrates the full range of tasks that make up the systems engineering process. Because of the limited time available for the project, the team was only able to perform selected tasks.



SYSTEM ENGINEERING MANAGEMENT PLAN

PART I

TECHNICAL PROGRAM PLANNING, IMPLEMENTATION AND CONTROL

Describes the technical program tasks that must be planned and implemented in the fulfillment of system engineering management objectives.

INCLUDES

- Program requirements (statement of work)
- Program planning (Spec., WBS, schedule, cost projections, reporting)
- Supplier requirements
- Organization (consumer, producer, supplier relationships)
- Technical interface management
- Program management
- Risk management

PART II

SYSTEM ENGINEERING PROCESS

Describes the system engineering process as it applies to the definition of system requirements and the development of those requirements into a final product configuration.

INCLUDES

- Needs analysis
- Feasibility analysis
- Operational requirements
- Maintenance concept
- Technical performance measures
- Functional analysis
- Requirements allocation
- Synthesis, analysis, and design optimization
- Design integration
- Design review
- Test and evaluation
- Utilization and support
- Modification/improvement
- Retirement and disposal

PART III

ENGINEERING SPECIALTY INTEGRATION

Describes the system requirements in the various engineering specialty areas and the integration of these specialty areas into the overall "mainstream" engineering design and development effort.

INCLUDES

- Functional engineering
- Reliability engineering
- Maintainability engineering
- Human factors and safety engineering
- Software engineering
- Logistics engineering
- Producibility
- Affordability
- Disposability
- Quality engineering
- Other engineering disciplines

Figure 18.4 Systems engineering management plan (SEMP)—a generic approach.
Source: Modification of an outline that was included in the *Systems Engineering Management Guide*, Systems Engineering Management College, 1990, and prior editions.

Figure 7: Excerpt from Systems Engineering and Analysis, Fourth Edition.
This excerpt was taken from page 664 of Blanchard and Fabrycky's book (2006). This page displays a breakdown of the three parts of the Systems Engineering Management Plan. Had the project not been a Science and Technology effort the team would have had to follow this plan more closely.

The systems engineering design process began with the initial research of literature by which it was determined that the HITL was a main contributor in failures to neutralize the incoming ASCM threat as previously discussed. The stakeholder analysis led to the development of requirements as in table 3, and the DTE system as illustrated in figure 8 in Chapter IV. An selection process was conducted to determine which simulation emulator software would be used to develop the simulation models. The results are provided in Appendix C. Six different emulation software packages were considered: Excel, Rockwell's Arena version 10, SIMIO, Matlab, ExtendSim, and OPEmCSS. The software selection was based on 10 attributes (categories) each of which received a respective weight based on importance. Each category then received a subjective score from 0-10 for each emulation software package. Excel and Rockwell's Arena received the highest scores of 951 and 805 respectively. Rockwell's Arena was chosen to be the primary emulation tool. Excel was the secondary emulation tool, and it was also used to verify and validate the simulation results from Rockwell's Arena. Arena's Input Analyzer was used to determine how to set the parameters for the different simulation processes. Arena's Output Analyzer was used to set the model's warm-up period parameters and to evaluate the simulation's overall response behavior.

The Base Case Model was developed as a basis to evaluate the IEW, hard-kill, and soft-kill systems without a HITL. The parameters of the Base Case Model are described in Chapter IV. After evaluating the Base Case Model, it was modified by inserting a HITL process. There was much discussion on where to insert the HITL, ultimately it was decided to insert the HITL before the IEW queue and hard-kill, soft-kill queue. A third model, the Integrated Base Case/HITL Model, was developed to simulate a more comprehensive simulation of the HITL, IEW, hard-kill and soft-kill systems. Through a series of model runs and sensitivity analysis the models provided much insight into how the HITL affected the response performance of the overall onboard ship defense systems.

DoD risk management tools and techniques were used to evaluate and mitigate various risks throughout the system design process. As risks were identified a risk category was assigned as well as the severity and likelihood of the respective risk. Project risks were monitored and evaluated on a weekly basis and received risk status updates at the weekly project team meetings.

The consideration, evaluation, and implementation of human factors was instrumental in the Engineering Design Process as it enabled the team to conduct the core analysis on the HITL effects on the overall onboard ship defense systems. HITL average reaction times and minimum and maximum reaction times were assigned for the various levels of automation. and were simulated by the HITL models. These times are shown in table 8 in Chapter IV.

A good understanding of systems engineering principles is critical in the planning, design, implementation, sustainment, and retirement of any project. Applying these principles early on and consistently throughout the duration of a project will ensure a more manageable project and higher likelihood of success.

Incorporating the stakeholders early in the technical approach a more relevant solution can be obtained and user operational requirements met. Ship defensive capability gaps have been identified and a notional solution provided to bridge these current gaps. A list of general assumptions were then generated to bound and define the scope of the project which led to the generation of a baseline HITL model. A systems engineering design process was used to create the HITL models and design an implementation of a variety of levels of automation as described in table 2. After which, an analysis of the baseline HITL was conducted and appropriate recommendations made.

IV. DESIGN AND ANALYSIS

The design and analysis section of the report presents the project key capabilities, battlespace definition and scenarios, design parameters for each model, the conceptual design for each model and current and proposed solution analyses. The project key capabilities are characterized by the functional breakdown of the DTE sequence. The battlespace definitions and scenarios are characterized by the OV-1 system operational concept. The design parameters provide detailed design constraints and functionality for each model that was developed. The conceptual design is explained and shown for each model developed. Finally each model is used to develop a detailed analysis for each proposed solution and is presented with and over view of the respective results. Representative modeling and simulation results are shown in appendix D.

A. KEY CAPABILITIES

Based on an analysis of the requirements and threat timelines, the current need is for a system that is capable of detecting incoming threats at ranges greater than ten nautical miles, quickly analyzing incoming ASCM threats to characterize them, and determining an appropriate response. The system must be capable of employing countermeasures automatically or with limited human oversight, and it must have electromagnetic compatibility with other ship systems.

The following paragraphs describe how the functions of the IEW and the defensive system were modeled using the selected Arena software in order to gain insight into the effects of various levels of human involvement in the operation of the systems.

Detection is defined as the process of discovering the presence of a target using the existing shipboard sensor suite. This sensor suite includes infrared, electro-optical, radar, and human observers. For the purposes of the system model; detection will be modeled by a pre-determined arrival rate.

Post-detection threat categorization (or classification) happens once the threat has been given a designation. Parameters are recorded and evaluated against a pre-populated database of threat parameters. If a system matches a particular threat system in the database, or displays properties characteristic of ASCMs such as altitude, velocity, and radar return, it will be designated a threat and an initial response will be determined. For the purposes of the system model, the entities arriving into the system queue are assumed to already be properly classified as ASCM threats. The entities will have randomly assigned parameters which govern whether the model selects the initial response to be a hard- or soft-kill regime.

Employment of responses after threat classification consists, for example, of launching missiles such as the Standard Missile or firing the Phalanx Close-In Weapons System. It might also consist of soft-kill measures such as the employment of a controlled high energy RF emission, or the employment of decoys such as flares or chaff. Countermeasures employment is modeled by routing of the threat based on its randomized characteristics to either hard- or soft-kill subsystems.

Electromagnetic compatibility is a design feature or attribute rather than a functional capability; however, its inclusion is critical. The system will be designed in such a way to limit production of signals that might interfere with other ship systems. Accordingly, it will also be designed to reject incoming signals that might interfere with its own systems. Through the use of subsystem design principles, topside design principles, and electromagnetic environmental effects evaluation, both at the subsystem and system level, the system will operate successfully in the highly RF cluttered shipboard environment. This parameter is not included in the model of the system. Within the DTE sequence shown in figure 8 the HITL-automated system interaction takes place at function block 4.4, “Command/Initiate Response.”

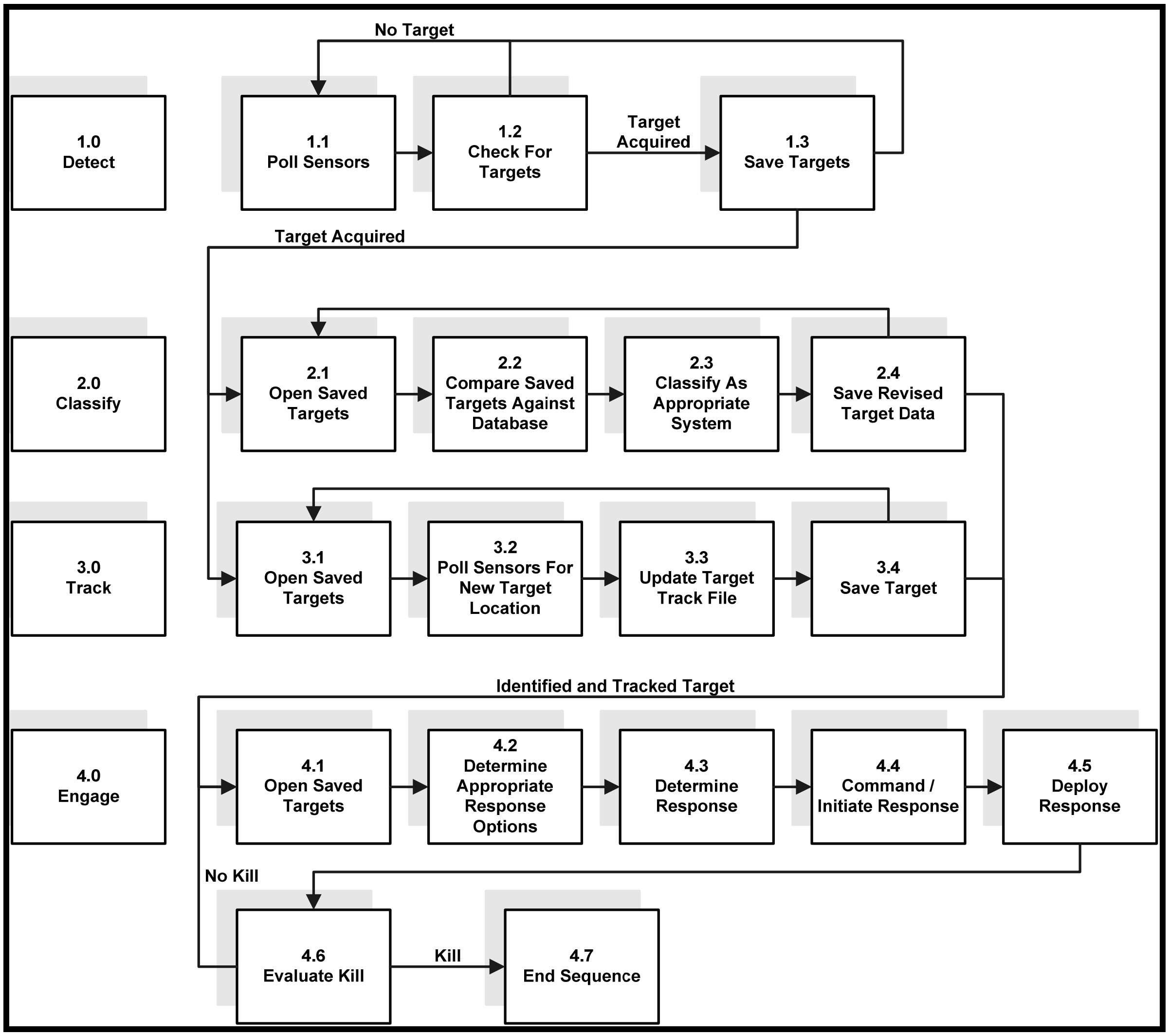


Figure 8: DTE Sequence.
This is a functional breakdown of the DTE sequence that the system is being modeled to. The first step is to detect an incoming threat. Step two will classify the threat and store the data. Step three will track the target and save a current track field. Step two and three operate concurrently and feed into step four. Step four is where the system decides a course of action, evaluates whether it was a successful engagement, and either reengages the target or ends the sequence.

B. BATTLESPACE DEFINITION

1. Definitions

Although the battlespace for an EW engagement includes the EM spectrum, when countering an inbound missile time and distance are paramount. The IEW model is primarily concerned with the time delays incurred before a response, either hard-kill or soft-kill, can be deployed. The complexities of different EW techniques (both offensive and defensive) are not investigated in this study; hence the electromagnetic spectrum is not a variable in the model.

As previously discussed, the early detection and elimination of the threat is highly desirable in ASCMD. Aimed at achieving this, the expansion of the sensor horizon by the networking of different platforms increases the physical volume of space that must be considered. However, a large physical volume of space containing many intelligent entities is difficult to model.

In order to mitigate this, the simulated battlespace must be constrained to an area that can be analyzed accurately. At the same time, "It must be large enough to include all of the locations that will be occupied by the players in the simulation (threats and EW protected platforms)" (Adamy 2006). To accomplish this, we have chosen to limit the scope of the battlespace to the sensor horizon of a single combatant (one EW protected platform). This approach highlights two important assumptions of the model. First, the most dangerous scenario that the system must counter is the case where detection of an ASCM can occur only at seeker turn-on using only sensors on the defended platform. Second, as a practical matter, EW is most effective when employed from the targeted platform itself.

For the purposes of our simulation, the battlespace will be defined as a generalized three-dimensional space surrounding a surface combatant. The shape and limits of this volume of space will be dependent on the available sensors. The areas at and below the surface of the water are excluded due to the obvious fact that ASCM's do not fly on or under water.

2. Battlespace Scenarios

Predicting the myriad of tactical scenarios that will be faced by a weapon system during operational use is complex. The problem of multiple ASCM launch platforms, as portrayed in figure 9, and large numbers of entities contained in the modeling space allows the perturbations to become extraordinarily large. The one constant in all scenarios, however, is an ASCM airborne and targeting a defended platform. By bounding the model battlespace, the tactical scenarios have been reduced to the common problem of countering a missile once airborne. Because of this, the model is valid for every scenario resulting from an ASCM launched from any platform at any distance. The primary objective is to study a quick reaction engagement and the limited decision timeline associated with it. This particular scenario can be considered typical of every other scenario.

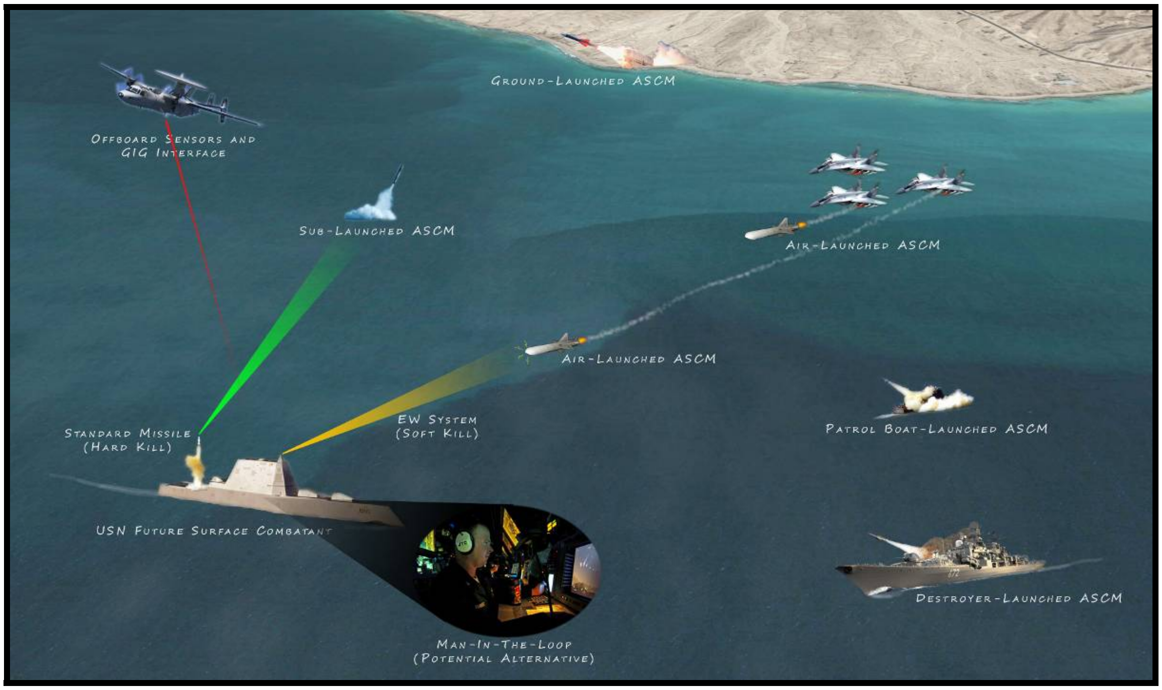


Figure 9: OV-1 System Operational Concept.
This picture captures the typical scenarios that the system is expected to encounter. The system can face ASCM threats from air, land, and sea based platforms.

3. Design Parameters

a. Base Case Model

The objective of the Base Case Model is to demonstrate the base case relationship between the IEW engagement response performance with no human in the loop given a specified Engagement Service Request (ESR) arrival schedule. The expected result for the Base Case Model is a statistical output for the model for the parameters as listed in table 4 below.

Parameter Category	Parameter Name
System	Number Out
Entity	ESR Wait Time
	ESR Transfer Time
	ESR Other Time
	ESR Total Time
Other	ESR Number In
	ESR Number Out
Process—Time Per Entity	IEW Charge Time
	IEW Engagement Time
	IEW Transition Time
Process-Accumulated Time	IEW Charge Time
	IEW Engagement Time
	IEW Transition Time
Queue—IEW	Waiting Time
	Number Waiting
Resource—Usage	Instantaneous Utilization IEW 1 and IEW 2
	Number Busy IEW 1 and IEW 2
	Number Scheduled IEW 1 and IEW 2
	Scheduled Utilization IEW 1 and IEW 2
	Total Number Seized IEW 1 and IEW 2
Counter	Count Rerouted ESR

Table 4: Base Case Parameters.

These parameters make up the base case EW Arena Model.

The model was evaluated using a warm-up period of 1,000 seconds to ensure steady state conditions had been reached. The number of replications was set to 1,000 to ensure variability reaches a steady state as well. Replication Length was arbitrarily set to 10 hours to generate results over time. The base time units were set to seconds for analysis purposes.

The model used a number of processes and associated parameters to produce the results. The different model processes are described in table 5 below. The probabilistic distributions associated with the model parameters were estimated values representative of actual systems.

Process Name	Description
Receive (Engagement Service Request) ESR	Schedule, Discrete Probability Distribution with a probability of 1 for a specified set of entities per arrival
Sample Number of Tgts in ESR	The Sample Number of Tgts in ESR process tallies the number of ESR received for record keeping and statistical calculations.
Enter IEW Queue	Is a 2-way by Condition process with the following criteria: ((IEW CHARGE.WIP + IEW Engagement.WIP + IEW Transition.WIP)<8), which basically only allows for 8 ESR entities to be served in a dual server queue. If the queue is greater than 8 the ESR will be balked and rerouted to an alternate hard-kill system for engagement.
IEW System Queue (2 IEW Radars)	
IEW CHARGE	The IEW CHARGE process has a Seize delay action with the following criteria: (Expo(.3))*No. of tgts. This expression shows an exponential distribution to represent the Poisson memory-less process of charging the IEW as part of the engagement process.
IEW Engagement	The IEW Engagement process has a Standard Delay action with the following criteria: (NORM(1, .3))*No. of tgts. This expression shows a normal distribution with the required engagement response time for the IEW to effectively neutralize an ASCM threat.
IEW Transition	The IEW Transition process has a Delay Release action with the following criteria: (WEIB(.5,.6))*No. of tgts. This expression shows a Weibel distribution with the required parameters for the IEW to transition to a ready state to service a new ESR.
Completed ESR	The Completed ESR process tallies the number of ESR completed by the IEW System Queue for record keeping and statistical calculations.
Count Rerouted ESR	The Count Rerouted ESR process tallies the number of ESR rerouted by the IEW System Queue for record keeping and statistical calculations.
Reroute to Alt Engagement Support	The Reroute to Alt Engagement Support process finalizes the process for rerouted ESRs.

Table 5: Base Case Model Processes.
The table lists the processes involved in the base case model and describes their properties and functionality.

b. HITL Models

The objective of the HITL Model is to demonstrate the relationship between the IEW engagement response performance with a HITL given a specified ESR arrival schedule and HITL reaction time. The expected result for the modified Base Case Model is a statistical output for the model for the parameters listed in table 6 below.

Parameter Category	Parameter Name
System	Number Out
Entity	ESR Wait Time
	ESR Transfer Time
	ESR Other Time
	ESR Total Time
Other	ESR Number In
	HITL Delay
	ESR Number Out
Process—Time Per Entity	IEW Charge Time
	IEW Engagement Time
	IEW Transition Time
Process-Accumulated Time	IEW Charge Time
	IEW Engagement Time
	IEW Transition Time
Queue—IEW	Waiting Time
	Number Waiting
Resource—Usage	Instantaneous Utilization IEW 1 and IEW 2
	Number Busy IEW 1 and IEW 2
	Number Scheduled IEW 1 and IEW 2
	Scheduled Utilization IEW 1 and IEW 2
	Total Number Seized IEW 1 and IEW 2
Counter	Count Rerouted ESR
Time Persistent	HITL Average Delay
	HITL ESR Total Time
	HILT ESRs in System
Output	HITL Percent Balk Out

Table 6: HITL Model Parameters.
This table lists the HITL ARENA simulation model parameter categories and their respective parameters.

The model was evaluated using a warm-up period of 1,000 seconds to ensure steady state conditions had been reached. The number of replications was set to 1,000 to ensure variability reaches a steady state as well. Replication Length was arbitrarily set to 10 hours to generate results over time. The base time units were set to seconds for analysis purposes.

The model used a number of processes and associated parameters to produce the results. The different model processes are described in table 7 below. The probabilistic distributions associated with the model parameters were again estimated to be representative of actual systems. Comparison of table 7 to table 5 reveals where in the model the HITL processes were inserted.

Process Name	**Description**
Receive (Engagement Service Request) ESR	Schedule, Discrete Probability Distribution with a probability of 1 for a specified set of entities per arrival
Sample Number of Tgts in ESR	The Sample Number of Tgts in ESR process tallies the number of ESR received for record keeping and statistical calculations.
Human In The Loop Delay X sec	The Human In The Loop Delay X sec has a Transfer action that with the following criteria: TRIA(min reaction time, mean reaction time, maximum reaction time). This expression shows a triangular distribution with a minimum, mean and maximum response time reprinting the different levels of Automation for HITL.
Enter IEW Queue	Is a 2-way by Condition process with the following criteria: ((IEW CHARGE.WIP + IEW Engagement.WIP + IEW Transition.WIP)<8), which basically only allows for 8 ESR entities to be served in a dual server queue. If the queue is greater than 8 the ESR will be balked and rerouted to an alternate hard-kill system for engagement.
IEW System Queue (2 IEW Radars)	
IEW CHARGE	The IEW CHARGE process has a Seize delay action with the following criteria: (Expo(.3))*No. of tgts. This expression shows an exponential distribution to represent the Poisson memory-less process of charging the IEW as part of the engagement process.
IEW Engagement	The IEW Engagement process has a Standard Delay action with the following criteria: (NORM(1, .3))*No. of tgts. This expression shows a normal distribution with the required engagement response time for the IEW to effectively neutralize an ASCM threat.
IEW Transition	The IEW Transition process has a Delay Release action with the following criteria: (WEIB(.5,.6))*No. of tgts. This expression shows a Weibel distribution with the required parameters for the IEW to transition to a ready state to service a new ESR.
Completed ESR	The Completed ESR process tallies the number of ESR completed by the IEW System Queue for record keeping and statistical calculations.
Count Rerouted ESR	The Count Rerouted ESR process tallies the number of ESR rerouted by the IEW System Queue for record keeping and statistical calculations.
Reroute to Alt Engagement Support	The Reroute to Alt Engagement Support process finalizes the process for rerouted ESRs.

Table 7: HITL Model processes.
This table lists the HITL processes and gives a description of their respective functionality.

The HITL reaction times were estimated for each level of human involvement. The estimated delay times and their distributions are shown in table 8 below.

Number	Description (Low to High)	Minimum Reaction Time Delay Introduced in Seconds	Mean Time Delay Introduced in Seconds	Maximum Reaction Time Delay Introduced in Seconds
1	The computer offers no assistance; human must take all decisions and actions.	2	30	36
2	The computer offers a complete set of decision/action alternatives	2	15	21
3	Narrows the selection down to a few	2	10	16
4	Suggests one alternative	2	8	14
5	Executes the suggestion if the human approves	2	6	12
6	Allows the human a restricted time to veto before automatic execution	2	4	10
7	Executes automatically, then necessarily informs the human	0	0	0
8	Informs the human only if asked	0	0	0
9	Informs the human only if it, the computer, decides to	0	0	0
10	The computer decides everything, acts autonomously, ignoring the human	0	0	0

Table 8: HITL Reaction Times.

This table shows the estimated values for mean, minimum, and maximum reaction times that a HITL will have depending on the level of human involvement. These values were used in the team’s modeling and simulations. The definitions of the ten levels of automation are from Parasuraman, Sheridan, and Wickens (2000).

c. Integrated Base Case/HITL Model

The objective of the Integrated Base Case/HITL Model is to demonstrate the interrelationships of the onboard sensors, hard-kill systems, soft-kill systems, the IEW system and HITL interaction, and the respective performance responses, given a randomly specified Firing Service Request (FSR) over time. The expected result for the Base Case Model is an output from the model for the parameters listed in table 9 below. The model also provides statistical measures for the parameters. The actual model results can be seen in Appendix D.

Parameter Category	Parameter Name	Sub-Parameters
System	Number Out, the number of Fire Service Request (FSR)	
FSR Wait Time		
FSR Transfer Time		
FSR Other Time		
FSR Total Time		
FSR Number In		
FSR Number Out		
Total Time per Entity	EW Engage Time	
	HITL Delay Time	
	Hard Kill (HK) Assess	
	HK Engage	
Accumulated Time	EW Engage	
	HITL Delay	
	HK Assess	
	HK Engage	
Process Number In/Out	EW Engage	
	HITL Delay	
	HK Assess	
	HK Engage	
Queue	Number Waiting	
Resource	Usage (Instantaneous, Number Busy, Number Scheduled, Scheduled Utilization, Total Number Seized)	HK System 1
		HK System 2
		System 1
		System 2
Counter	Count EW Balk	
	Count EW Engagement	
	Count EW FSR	
	Count HK Hit	
	Count HK Miss	
Time Persistent	Base FSR in System	
	Base FSR Wait Time	
Output	Base Pct (percent) Balk	
	Base Pct Hit	

Table 9: Integrated Base Case / HITL Model Parameters.
This table lists the category, name, and sub parameters of the integrated base case and HITL ARENA simulation model.

The model was exercised using a warm-up period of 200 seconds to ensure steady state conditions had been reached. The number of replications was set to 1,000 to ensure variability reaches a steady state as well. Replication Length was arbitrarily set to 8 hours to generate results over time. The base time units were set to seconds for analysis purposes.

The model used a number of processes and associated parameters to produce the results. The different model processes are described in tables 10 and 11 below. The probabilistic distributions associated with the model parameters were estimates considered to be representative of actual systems.

Process Name	Description
Receive FSR	Receive FSR is a random process with the following parameters: Random(Expo), with a value of 7 and the Entities per Arrival set to DISCRETE(0.2,0,0.4,1,0.6,2,0.8,3,1,4). The Received FSR simulates the service loading for the system to engage an ASCM threat.
Detect Target Characteristics	Detect Target Characteristics is assumed to be an instantaneous process with no time delay. The assumption can be made that the target characteristics have been assessed through on-board ship sensors and that this information is received along with the FSR. The following attributes are associated with this process:
	Range: UNIFORM(0.5,25), range is in nautical-miles
	Velocity: NORMAL(450,25), velocity is in nautical-miles per hour.
Hardkill or Softkill?	Is a 2-way by Condition process decides whether a threat enters the Hardkill or Softkill Queue and is set to the following parameters: (Range>10)&&(Velocity<500)&&(NC(Count HK Hit)+ NC(Count HK Miss) < 50). Where Range is in nautical-miles, Velocity is in nautical-miles per hour, the number of threats to be engaged by the onboard hardkill system is less than 50.
HITL Delay	The HITL Delay process has a Standard Delay type action with the following criteria: TRIA(min reaction time, mean reaction time, maximum reaction time). This expression shows a triangular distribution with a minimum, mean and maximum response time reprinting the different levels of Automation for HITL. The following parameters have been arbitrarily set for the different levels of Automation for HITL.
	TRIA(2,4,8)—for 4 second HITL delay
	TRIA(3,6,12)—for 6 second HITL delay
	TRIA(4,8,16)—for 8 second HITL delay
	TRIA(5,10,20)—for 10 second HITL delay
	TRIA(7.5,15,30)—for 15 second HITL delay
	TRIA(15,30,60)—for 30 second HITL delay

Table 10: Integrated Base Case/ HITL Model Processes and Parameters Part 1.
This table shows the first half of the processes of the Base Case and HITL model. It lists the process name, the parameters, and a description of what each process does.

Process Name	Description
HK Engage	The HK Engage process has a Standard Delay type action with the following criteria: Expo(MeanHKEngageTime). This expression shows a random process with and exponential distribution based on the mean Hardkill engage time.
HK Assess	The HK Assess process has a Standard Delay type action with the following criteria: UNIF(MinAssessTime,MaxAssessTime). This expression shows a uniform distribution with the minimum and maximum time as the defining parameters. The HK Assess process determines what HK system is best suited to engage the ASCM threat target.
Target Hit?	Is a 2-way by Condition process decides whether a threat was defeated by the HK system with the following criteria: UNIF(0,1)<HK_P_hit. This expression shows a uniform distribution with the HK P_hit probability defining parameter.
Count HK Hit	The Count HK Hit process tallies the number of direct hit hardkill engagements used for record keeping and statistical calculations.
FSR Tgt Hit	FSR Tgt Hit process finalizes the target hit process and calculates the respective entity statistic.
Count HK Miss	The Count HK Miss process tallies the number of missed hardkill engagements used for record keeping and statistical calculations.
FSR Tgt Miss	FSR Tgt Miss process finalizes the target miss process and calculates the respective entity statistic.
Count EW FSR	The Count EW EFR tallies the number of FSRs that enter the EW queue
EW Available?	Is a 2-way by Condition process that decides whether the EW system is available to engage an ASCM threat and has the following criteria: (EW Engage.WIP<EWEngageLimit). This expression shows that the EW system will be ready if the EW Engagement is less than the EW Engage limit. The EW engage limit is arbitrarily set.
EW Engage	The EW Engage process has a Standard time delay action with the following criteria: EXPO(MeanEWEngageTime). This expression shows the random process based on an exponential distribution with the mean EW engagement time as the defining parameter.
Count EW Engagement	The Count EW Engagement process tallies the number of EW engagements used for record keeping and statistical calculations.
EW FSR Engage	EW FSR Engage process finalizes the EW Engage process and calculates the respective entity statistic
Count EW Balk	The Count EW Balk process tallies the number of EW engagements that have balked for record keeping and statistical calculations.
EW FSR balked	EW FSR balked process finalizes the EW balk process and calculates the respective entity statistic

Table 11: Integrated Base Case/ HITL Model Processes and Parameters Part 2. This table shows the second half of the processes of the Base Case and HITL model. It lists the process name, the parameters, and a description of what each process does.

C. CONCEPTUAL DESIGN

1. Base Case Model

For the Base Case IEW model the main objective was to demonstrate the base case relationship between the IEW engagement response performance with no HITL given a specified ESR arrival schedule. The model is a high level representation of the ship's IEW, hard-kill and soft-kill systems without a HITL.

The model receives an ESR based on a predetermined schedule and then assesses the number of targets in the ESR. It then determines which targets in the ESR can enter the IEW Queue based on predefined criteria. If it can enter the IEW Queue the IEW system charges up, engages the target and finally transitions to a ready state. It is assumed that once the IEW system engages the target that it has a 100 percent probability of kill. If a target in the ESR cannot enter the IEW Queue it balks to an Alternate Engagement Support process which consists of hard-kill and soft-kill systems. It is assumed that the Alternate Engagement Support process occurs instantaneously and that it has a 100 percent engagement regardless of effectiveness. Kill probability is not assumed for the Alternate Engagement Support. It is solely assumed that the Alternate Engagement Support path will successfully process each ESR/FSR (i.e. there are no balks from that portion of the queue). The model calculates various statistics as discussed in the design parameters section of this chapter.

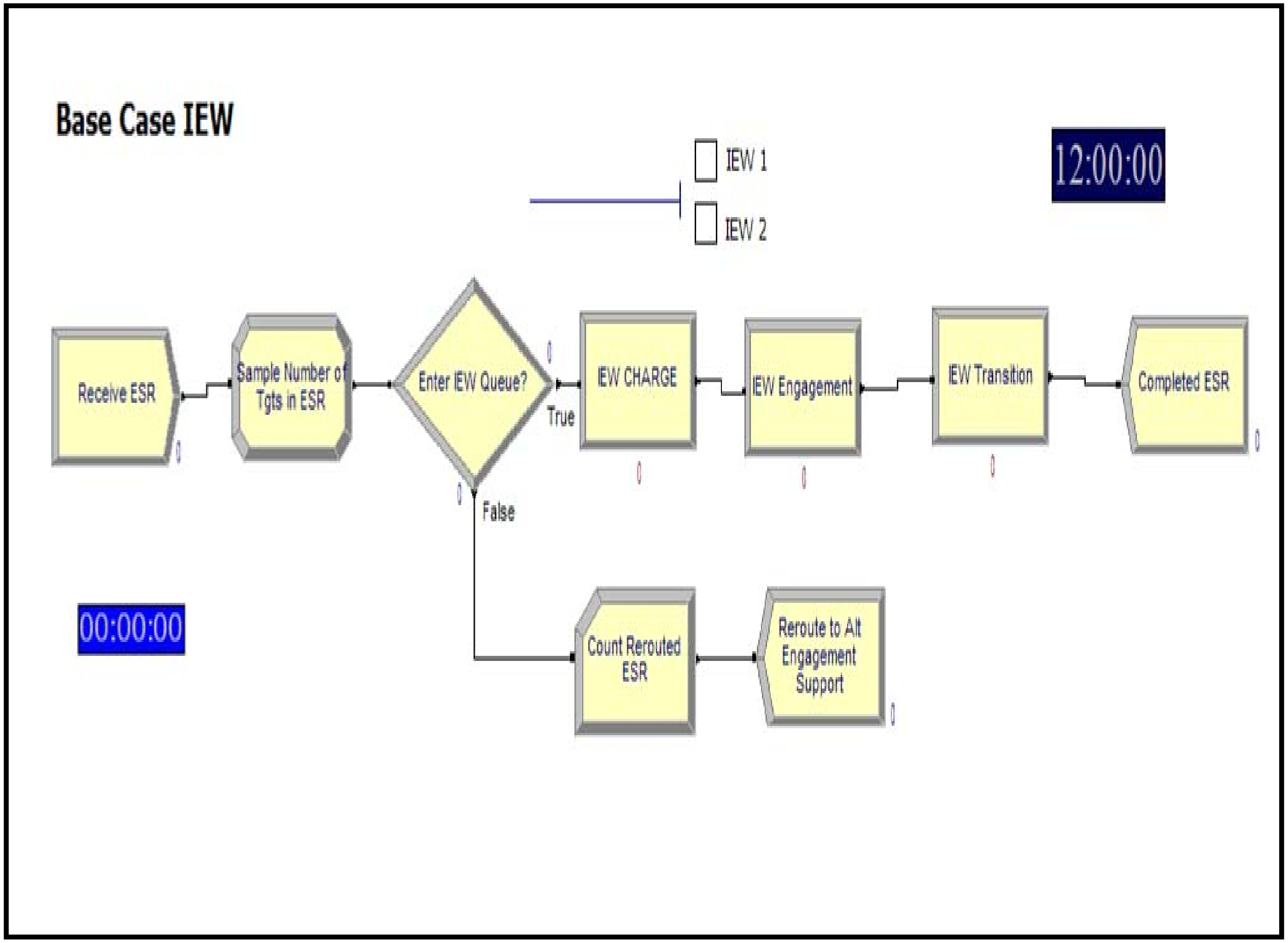


Figure 10: Base Case Model.

This ARENA simulation model demonstrates the base case relationship between the IEW engagement response performance without HITL. The model is a high level representation of the ship's IEW, hard-kill and soft-kill systems without a HITL.

2. HITL Models

The objective for the Base Case IEW model with a HITL is to demonstrate the base case relationship of the IEW engagement response performance given a specified ESR arrival schedule. The model is a high level representation of the ship’s IEW, hard-kill and soft-kill systems with a HITL.

The model receives an ESR based on a predetermined schedule and then assesses the number of targets in the ESR. The model contains a HITL process which determines which targets in the ESR will be engaged by the IEW, hard-kill and soft-kill system. Introducing the HITL process causes a delay based on a predetermined level of automation. The model then determines which targets in the ESR can enter the IEW Queue based on predefined criteria. If it can enter the IEW Queue the IEW system charges up, engages the target and finally transitions to a ready state. It is assumed that once the IEW system engages the target it has a 100 percent probability of kill. If a target in the ESR cannot enter the IEW Queue it balks to an Alternate Engagement Support process which consists of hard-kill and soft-kill systems. It is assumed that the Alternate Engagement Support process occurs instantaneously and that it has a 100 percent engagement regardless of effectiveness. Kill probability is not assumed for the Alternate Engagement Support. It is solely assumed that the Alternate Engagement Support path will successfully process each ESR/FSR (i.e. there are no balks from that portion of the queue). The model calculates various statistics as discussed in the design parameters section of this chapter.

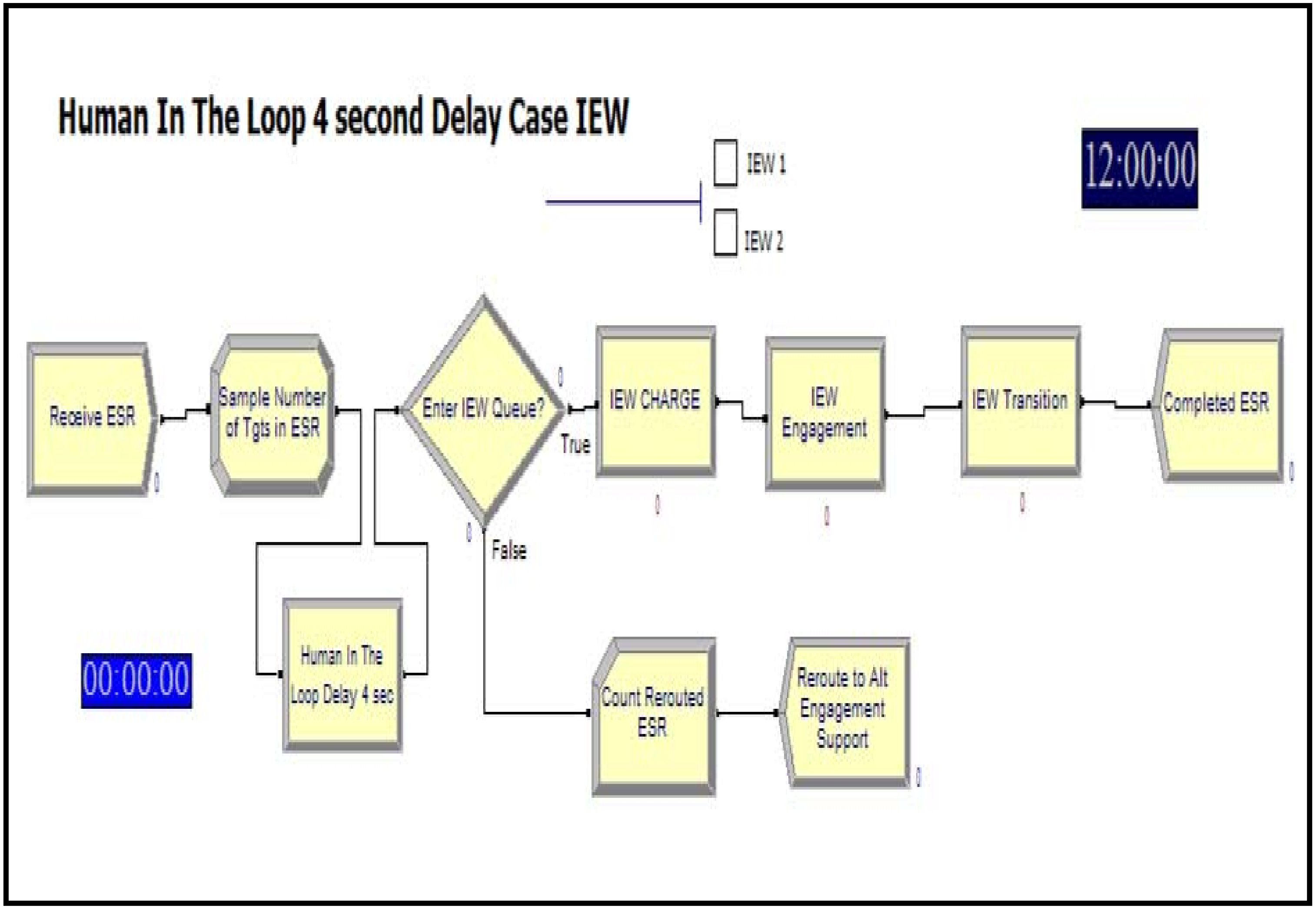


Figure 11: Base Case HITL Model.
This ARENA simulation model demonstrates the base case relationship between the IEW engagement response performance with a HITL. The model is a high level representation of the ship's IEW, hard-kill and soft-kill systems with a HITL.

For the Integrated Base Case/HITL Model the main objective is to demonstrate the interrelationships of the onboard Sensors, hard-kill systems, soft-kill systems, the IEW system and HITL interaction and the respective performance responses given a randomly specified FSR over time. The model is a high level representation of the ship's IEW, hard-kill and soft-kill systems with a HITL. The model is the first incremental redesign of the Base Case IEW with the HITL process and integrates more functionality such as the Target Hit assessment process.

The model receives a FSR based on a predetermined random process and then characterizes targets in the FSR. The model then determines whether a target in the FSR will be engaged by a hard-kill system or soft-kill system based on predefined criteria. If it is determined that a target in the FSR will be engaged by the hard-kill system it then enters the HITL process which introduces a time delay based on a predefined level of automation. The target in the FSR is then engaged by a hard-kill system, the model then assesses if the target was hit or not. If it is determined that a target in the FSR will be engaged by a soft-kill system it enters the IEW Queue. If the IEW system is available the target in the FSR is engaged by the IEW system. If the IEW system is not available the target in the FSR balks out of the overall system.

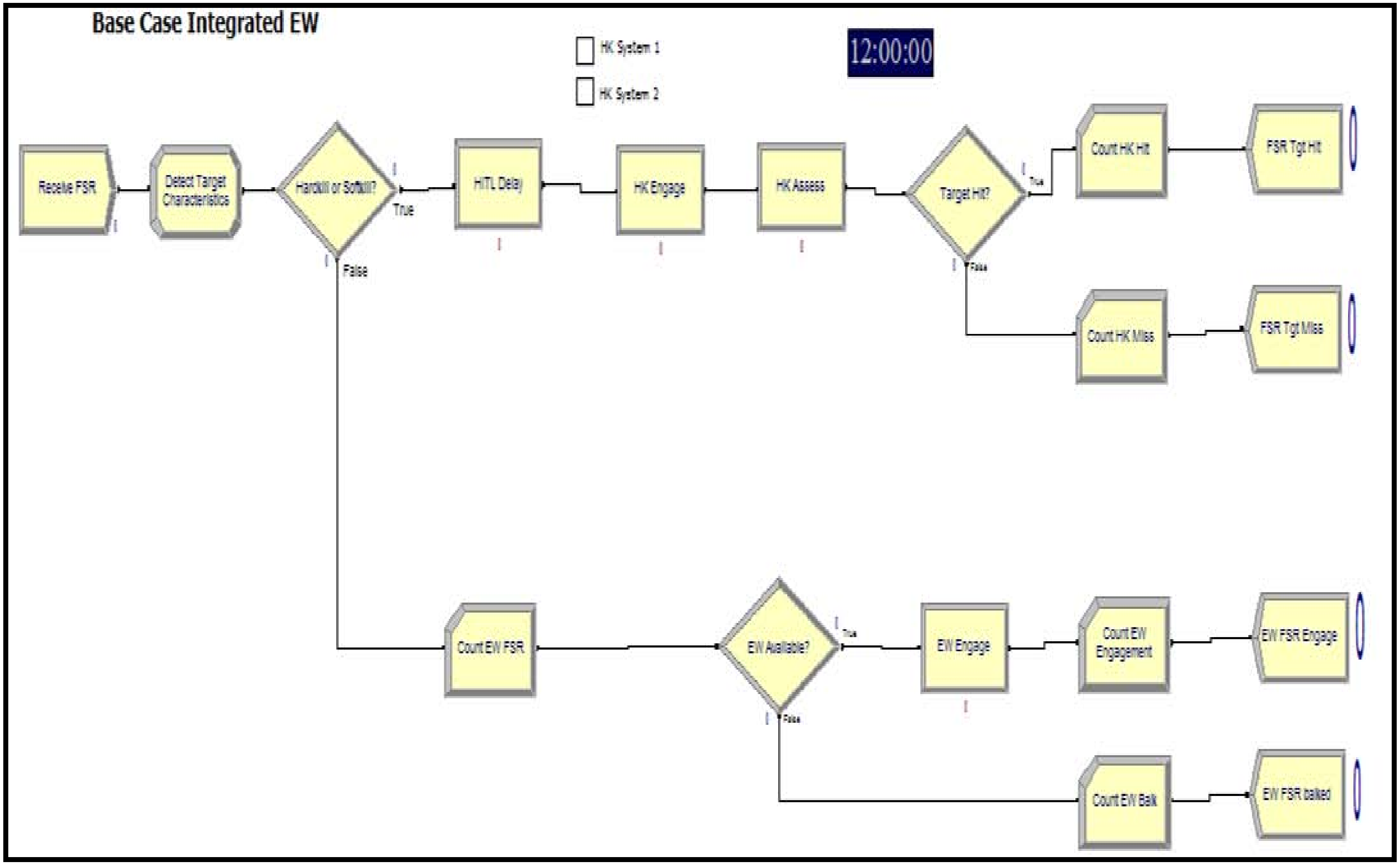


Figure 12: Integrated Base Case/HITL Model.

This ARENA simulation model's main objective is to demonstrate the interrelationships of the onboard sensors, hard-kill systems, soft-kill systems, the IEW system and HITL interaction and the respective performance responses. The model is a high level representation of the ship's IEW, hard-kill and soft-kill systems with a HITL. This is the first incremental redesign of the Base Case IEW with the HITL process and integrates more functionality such as the Target Hit assessment process.

D. CURRENT AND PROPOSED SOLUTION ANALYSIS

1. Analysis of Models Outputs

The model outputs are the response times to process an ESR or FSR. The model's outputs were used to analyze individual process performance and overall response performance to provide insight on the effects of modification in employment or hardware or software upgrades. By comparing model times to the times available to intercept threats, it was also possible to evaluate the effect of HITL delays on the overall system performance.

Miles	Nautical Miles	Mach Speed	Speed mi/hr	Speed nm/hr	Arrival time sec	Notes:
10	8.7	0.8	609	529	59	Most Likely Engagement
10	8.7	1.5	1142	992	32	Likely Engagement
10	8.7	3.0	2284	1984	16	Worst Case Engagement

Table 12: System Response Performance.
This table captures the response time that the system needs to accomplish given specific ASCM variables.

Given the types of ASCM threats shown in table 1, Potential Anti-ship Cruise Missile threats, it is evident that most ASCM threats are subsonic and thus the most likely to be encountered. However, with the advent of ASCMs capable of Mach 3+ speeds, it is necessary to be able to defend against such a threat as a worst-case scenario. Based on timeline analyses, the objective response time to neutralize an ASCM threat has been set to 12 seconds upon detection at 8.7 nautical miles and a threshold response time of 14 seconds upon detection at 8.7 nautical miles.

					ESR Total Time in Seconds					
Replications	Warm up Period	Duration	Entities Per Arrival	Type	Maximum Average	Minimum Average	Average	Half Width	Minimum Value	Maximum Value
1000	1000 sec	10 hr	2	Base Case Light Attack	5.40	3.76	4.45	< 0.02	0.04	87.83
1000	1000 sec	10 hr	4	Base Case Moderate Attack	5.40	3.76	4.45	< 0.02	0.04	87.83
1000	1000 sec	10 hr	7	Base Case Heavy Attack	11.49	9.39	10.31	< 0.02	-	134.15
1000	1000 sec	10 hr	2	4 sec HITL Delay Light Attack	10.77	8.81	9.71	< 0.02	2.65	84.95
1000	1000 sec	10 hr	4	4 sec HITL Delay Moderate Attack	10.77	8.81	9.71	< 0.02	2.65	84.95
1000	1000 sec	10 hr	7	4 sec HITL Delay Heavy Attack	12.02	10.30	11.07	< 0.02	2.53	88.62
1000	1000 sec	10 hr	2	6 sec HITL Delay Light Attack	12.17	10.06	11.03	< 0.02	2.72	86.06
1000	1000 sec	10 hr	4	6 sec HITL Delay Moderate Attack	12.17	10.06	11.03	< 0.02	2.72	86.06
1000	1000 sec	10 hr	7	6 sec HITL Delay Heavy Attack	16.34	14.08	15.05	< 0.02	2.66	144.04
1000	1000 sec	10 hr	2	8 sec HITL Delay Light Attack	13.53	11.32	12.36	< 0.02	2.87	88.23
1000	1000 sec	10 hr	4	8 sec HITL Delay Moderate Attack	13.53	11.32	12.36	< 0.02	2.87	88.23
1000	1000 sec	10 hr	7	8 sec HITL Delay Heavy Attack	14.29	12.50	13.37	< 0.02	2.79	111.72
1000	1000 sec	10 hr	2	10 sec HITL Delay Light Attack	14.96	12.50	13.68	< 0.02	2.94	89.89
1000	1000 sec	10 hr	4	10 sec HITL Delay Moderate Attack	14.96	12.50	13.68	< 0.02	2.94	89.89
1000	1000 sec	10 hr	7	10 sec HITL Delay Heavy Attack	18.15	15.89	16.97	< 0.02	2.43	146.05
1000	1000 sec	10 hr	2	15 sec HITL Delay Light Attack	18.14	15.36	17.00	< 0.02	3.10	94.14
1000	1000 sec	10 hr	4	15 sec HITL Delay Moderate Attack	18.14	15.36	17.00	< 0.02	3.10	94.14
1000	1000 sec	10 hr	7	15 sec HITL Delay Heavy Attack	18.83	16.44	17.63	< 0.02	2.88	116.10
1000	1000 sec	10 hr	2	30 sec HITL Delay Light Attack	28.83	24.69	26.98	< 0.04	3.38	107.22
1000	1000 sec	10 hr	4	30 sec HITL Delay Moderate Attack	28.83	24.69	26.98	< 0.04	3.38	107.22
1000	1000 sec	10 hr	7	30 sec HITL Delay Heavy Attack	29.82	26.86	28.32	< 0.03	3.10	129.88

Table 13: Base Case HITL Model Analysis.

This table captures the ESR Total time in seconds of each variation of HITL delays.

To conduct the sensitivity and performance analysis, 21 iterations of the Base Case-HITL model were run. Each iteration consisted of 1,000 replications. The entities per arrival were varied, simulating a light attack (2 entities per arrival), a moderate attack (4 entities per arrival) or a heavy attack (7 entities per arrival). The model produced no change in performance between the light attack and moderate attack scenarios. It can also be noted that the heavy attack scenarios had the greatest response time. This was due to a higher entity wait time in the IEW Service Queue. The model output ESR Total Time to engage an ASCM threat is shown in table 13. The highlighted light-blue cells indicate output values that are greater than the objective response time, but less than the threshold response time of 14 seconds. The tan highlighted cells indicate scenarios in which system performance as determined by the model was insufficient to defend against the incoming threat – the response time was too great. It is evident that the greater the HITL delay, the greater the response time. Based on the initial findings it is recommended that under light or moderate attack scenarios human involvement be such as to limit HITL delay to 8 seconds or less.. This implies that the system must be designed to present only one alternative to the HITL for a decision (see table 8). Further, in heavy attack scenarios it is recommended that a 4 second HITL delay be implemented which implies that the system will only allow the HITL a restricted time of about 4 seconds to veto continued operation before automatic threat prosecution takes place.

	ESR Total Time in Seconds						Base Pct Balk Out			
Type	Maximum Average	Minimum Average	Average	Half Width	Minimum Value	Maximum Value	Average	Half Width	Minimum Average	Maximum Average
Base Case Light Attack	5.40	3.76	4.45	< 0.02	0.04	87.83	0.00%	0.00%	0.00%	0.00%
Base Case Moderate Attack	5.40	3.76	4.45	< 0.02	0.04	87.83	0.00%	0.00%	0.00%	0.00%
Base Case Heavy Attack	11.49	9.39	10.31	< 0.02	-	134.15	1.83%	0.00%	0.00%	6.56%
4 sec HITL Delay Light Attack	10.77	8.81	9.71	< 0.02	2.65	84.95	0.00%	0.00%	0.00%	0.00%
4 sec HITL Delay Moderate Attack	10.77	8.81	9.71	< 0.02	2.65	84.95	0.00%	0.00%	0.00%	0.00%
4 sec HITL Delay Heavy Attack	12.02	10.30	11.07	< 0.02	2.53	88.62	0.01%	0.00%	0.00%	1.15%
6 sec HITL Delay Light Attack	12.17	10.06	11.03	< 0.02	2.72	86.06	0.00%	0.00%	0.00%	0.00%
6 sec HITL Delay Moderate Attack	12.17	10.06	11.03	< 0.02	2.72	86.06	0.00%	0.00%	0.00%	0.00%
6 sec HITL Delay Heavy Attack	16.34	14.08	15.05	< 0.02	2.66	144.04	1.02%	0.00%	0.00%	4.19%
8 sec HITL Delay Light Attack	13.53	11.32	12.36	< 0.02	2.87	88.23	0.00%	0.00%	0.00%	0.00%
8 sec HITL Delay Moderate Attack	13.53	11.32	12.36	< 0.02	2.87	88.23	0.00%	0.00%	0.00%	0.00%
8 sec HITL Delay Heavy Attack	14.29	12.50	13.37	< 0.02	2.79	111.72	0.00%	0.00%	0.00%	0.87%
10 sec HITL Delay Light Attack	14.96	12.50	13.68	< 0.02	2.94	89.89	0.00%	0.00%	0.00%	0.00%
10 sec HITL Delay Moderate Attack	14.96	12.50	13.68	< 0.02	2.94	89.89	0.00%	0.00%	0.00%	0.00%
10 sec HITL Delay Heavy Attack	18.15	15.89	16.97	< 0.02	2.43	146.05	0.78%	0.00%	0.00%	3.30%
15 sec HITL Delay Light Attack	18.14	15.36	17.00	< 0.02	3.10	94.14	0.00%	0.00%	0.00%	0.00%
15 sec HITL Delay Moderate Attack	18.14	15.36	17.00	< 0.02	3.10	94.14	0.00%	0.00%	0.00%	0.00%
15 sec HITL Delay Heavy Attack	18.83	16.44	17.63	< 0.02	2.88	116.10	0.00%	0.00%	0.00%	0.56%
30 sec HITL Delay Light Attack	28.83	24.69	26.98	< 0.04	3.38	107.22	0.00%	0.00%	0.00%	0.00%
30 sec HITL Delay Moderate Attack	28.83	24.69	26.98	< 0.04	3.38	107.22	0.00%	0.00%	0.00%	0.00%
30 sec HITL Delay Heavy Attack	29.82	26.86	28.32	< 0.03	3.10	129.88	0.16%	0.00%	0.00%	1.95%

Table 14: Percent Balk.

This table captures the percentage of balks based upon various HITL delays.

In table 14 the light-green highlighted cells indicate a Percent Balk out of ESRs greater than 0%. Balking is defined as the failure of an ESR or FSR to be engaged by either EW or hard-kill. This is typically a result of exceeding maximum queue length. The higher number of entities per ESR is directly related to a higher percentage of ESRs balking out of the IEW Service Queue. This indicates that under a heavy attack scenario, the IEW system as modeled herein will not be able to successfully respond to all incoming ESRs regardless of the level of HITL; thus, if a “perfect” system is required, alternate hard- and soft-kill systems will need to be employed.

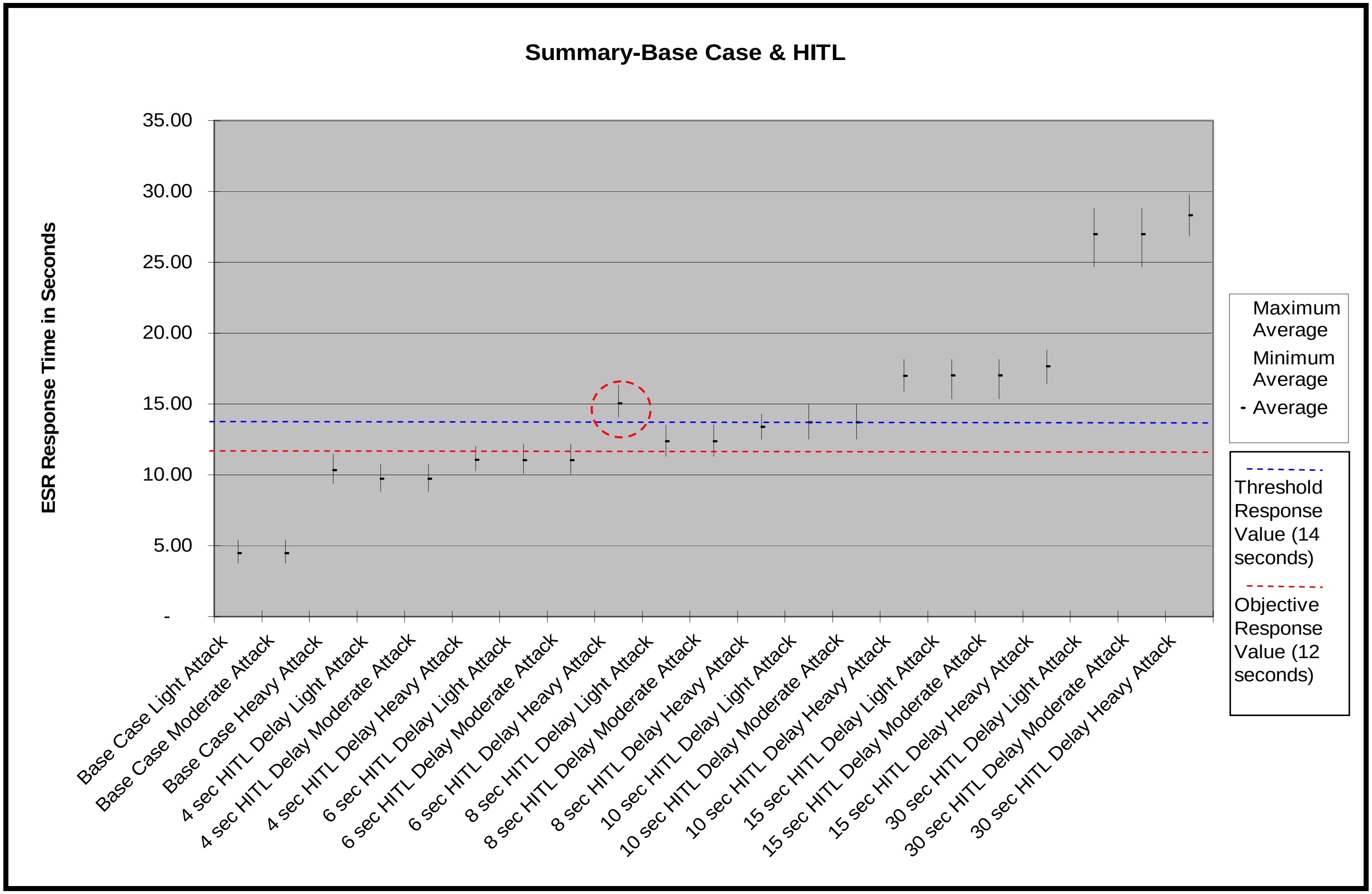


Figure 13: Base Case and HITL response time summaries.
This figure shows the various response times summarized based upon different HITL response times and severity of the attack numbers.

In figure 13 the objective response time of 12 seconds is indicated by the red line and the threshold response time of 14 seconds is indicated by the blue line. There appears to be an outlier in the results as indicated by the red circle. The "6 sec HITL Delay Heavy Attack" iteration had a higher average response time than the other scenarios. It also had the highest maximum response time value of 144.04 seconds. This is primarily due to the IEW charge and transition times being abnormally high (60.83 seconds and 130.14 seconds, respectively).

	Integrated Base Case/HITL Model Results						
Parameter	Base Case	4 Sec HITL Delay	6 Sec HITL Delay	8 Sec HITL Delay	10 Sec HITL Delay	15 Sec HITL Delay	30 Sec HITL Delay
Average FSR Number Out	136	137	137	137	136	136	136
Average HITL Delay (s)	0.00	4.66	6.98	9.32	11.64	17.47	34.91
Average FSR Total Time (s)	46.37	47.83	48.68	49.58	50.68	52.88	59.63
Average HK Number Hit	35.64	35.68	35.67	35.63	35.67	35.68	35.68
Average HK Number Miss	15.10	15.07	15.11	15.13	15.10	15.12	15.17
Average EW Number Hit	64.21	65.00	64.98	65.06	64.60	64.62	64.57
Average EW Number Balked	20.82	21.00	21.18	21.11	21.01	20.91	20.87
Percent Engaged by the HK	37%	37%	37%	37%	37%	37%	37%
Percent Engaged by the EW	63%	63%	63%	63%	63%	63%	63%
Percent Successful HK	70%	70%	70%	70%	70%	70%	70%
Percent Successful EW	76%	76%	75%	76%	75%	76%	76%

Table 15: Integrated Base Case/HITL Model Analysis.
This is an analysis of the outputs generated by the model.

Five main outputs were selected for analysis of the overall performance of the Integrated Base Case/HITL Model as shown in tables 14 through 20. The outputs are discussed in more detail in the section below.

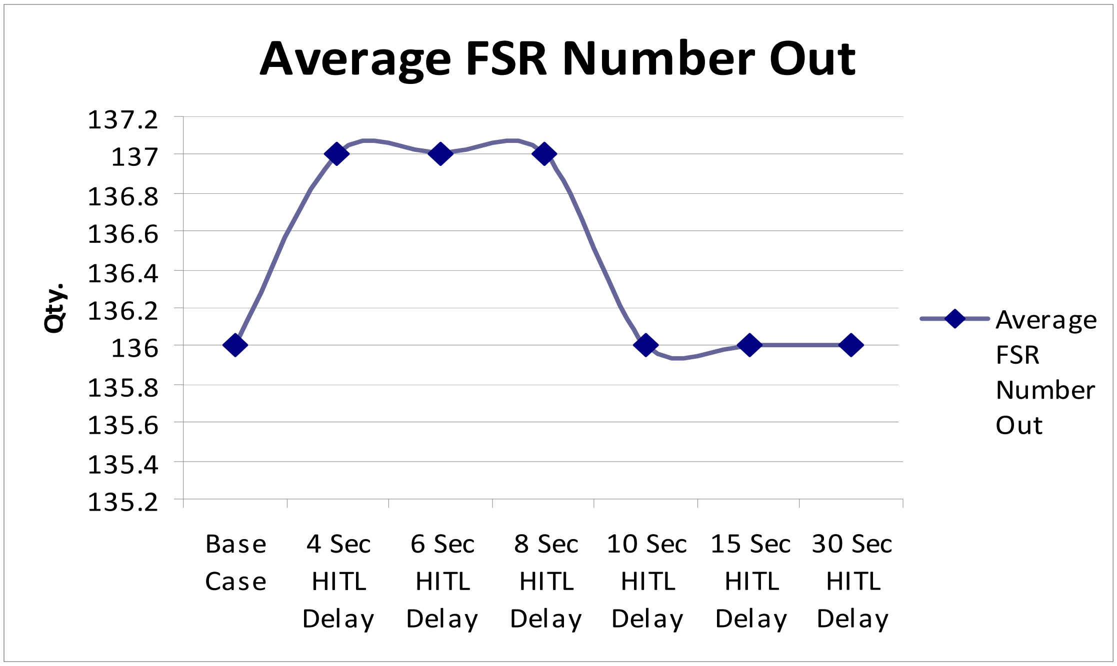


Figure 14: Average FSR Number Out.
This figure shows the various response numbers based upon different HITL response times.

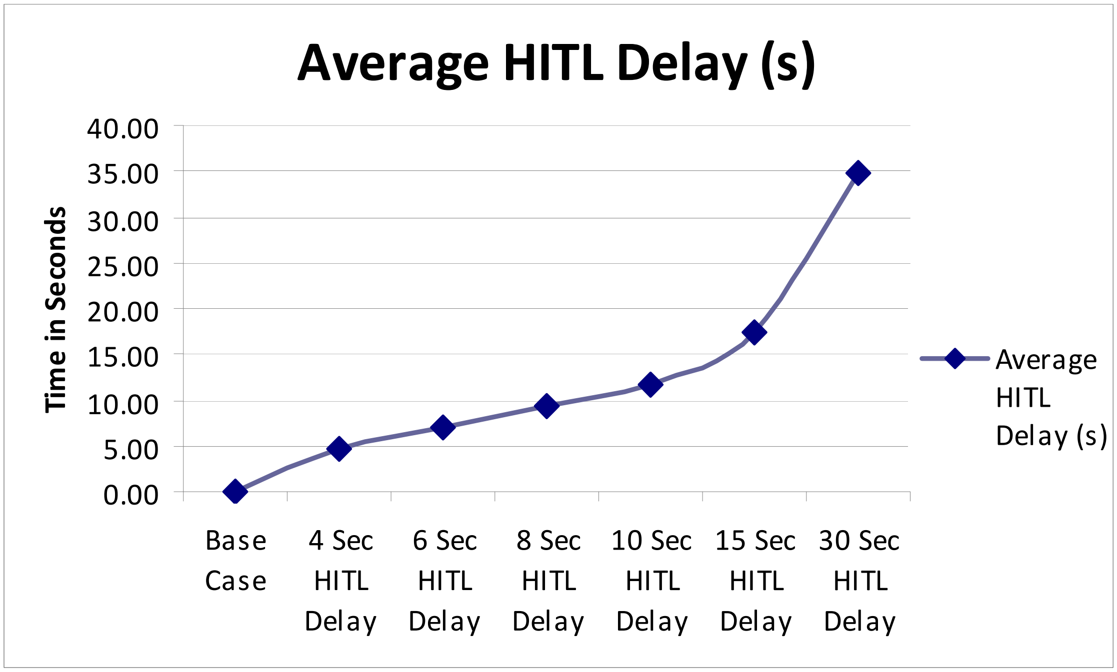


Figure 15: Average HITL Delay times in seconds.
This figure shows the average delay times produced by the various HITL scenarios.

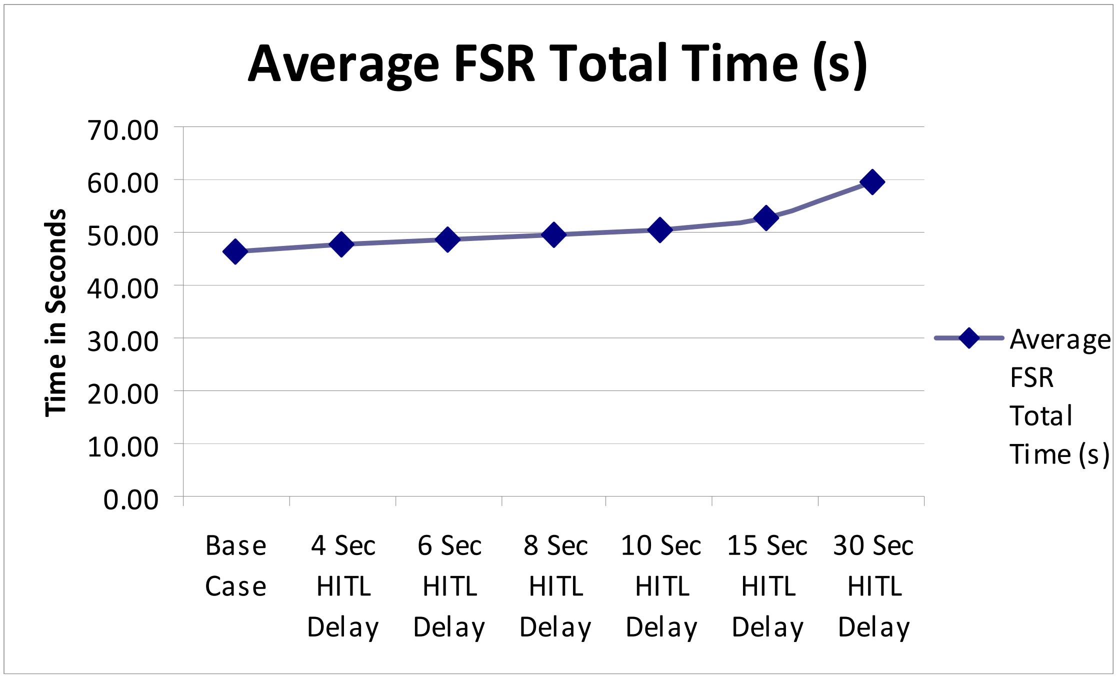


Figure 16: Average FSR Time Totals in seconds.
This figure shows the various average response times summarized based upon different HITL response times.

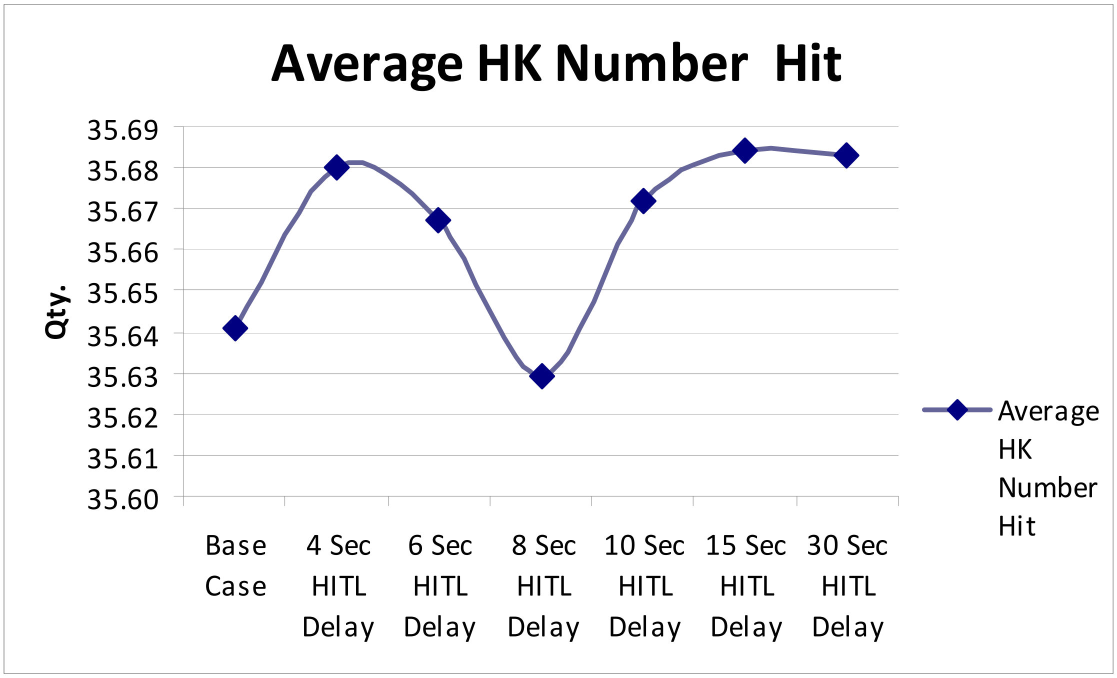


Figure 17: Average hard kill numbers hit.
This figure shows the average number of hard kill targets that were hit based on the HITL delay times.

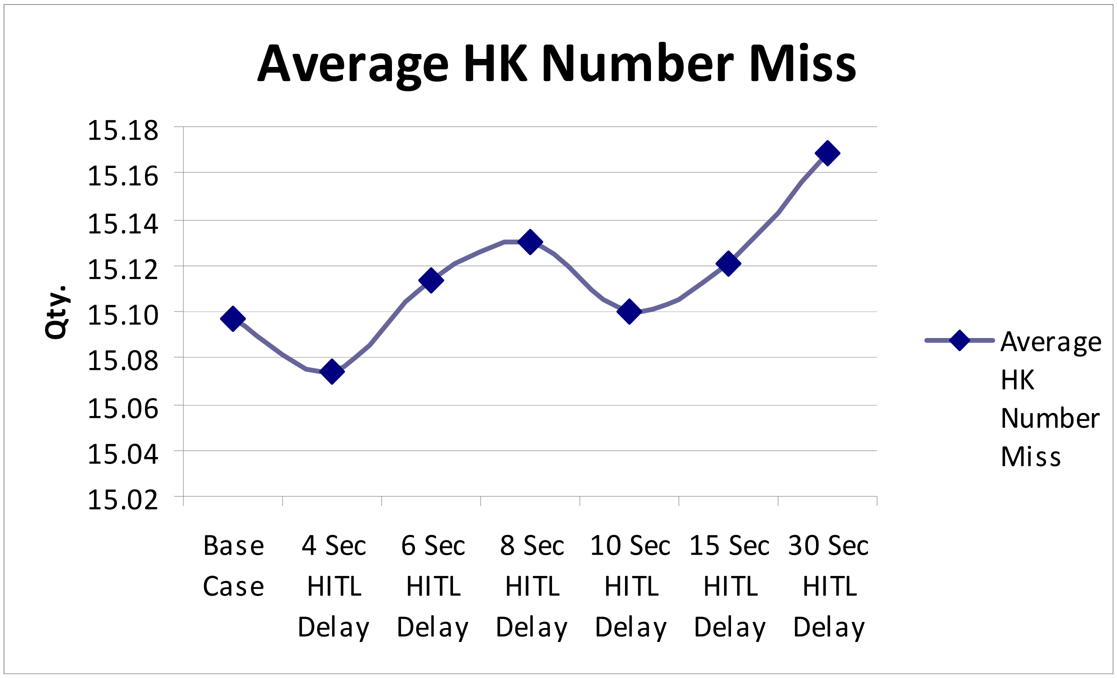


Figure 18: Average hard kill numbers missed.
This figure shows the average number of hard kill targets that were missed based on the HITL delay times.

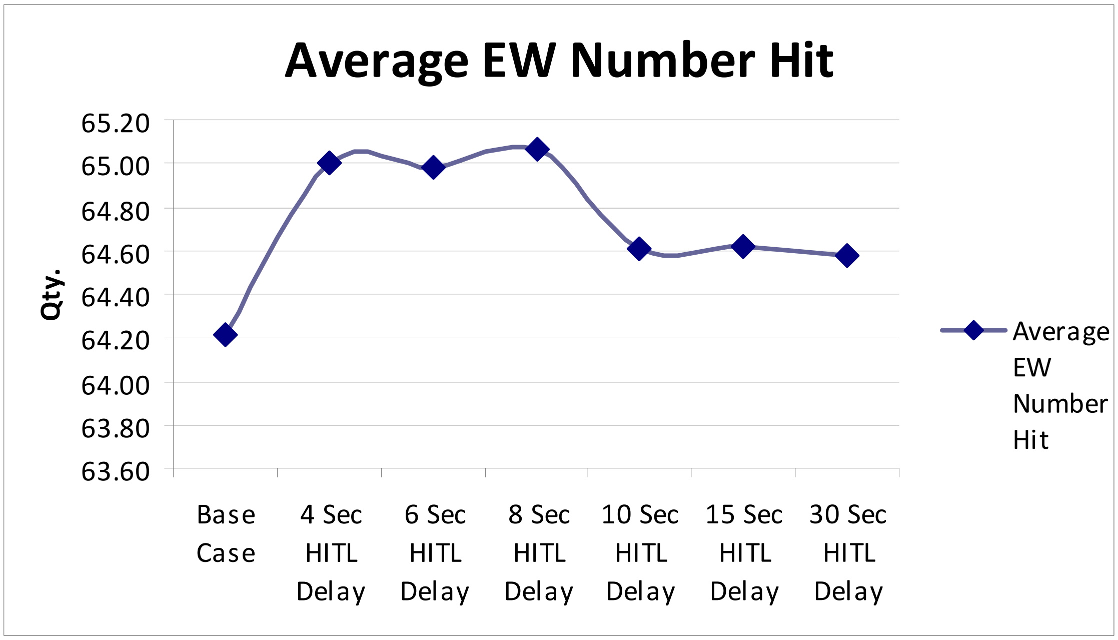


Figure 19: Average EW numbers hit.
This figure shows the average number of EW targets that were missed based on the HITL delay times.

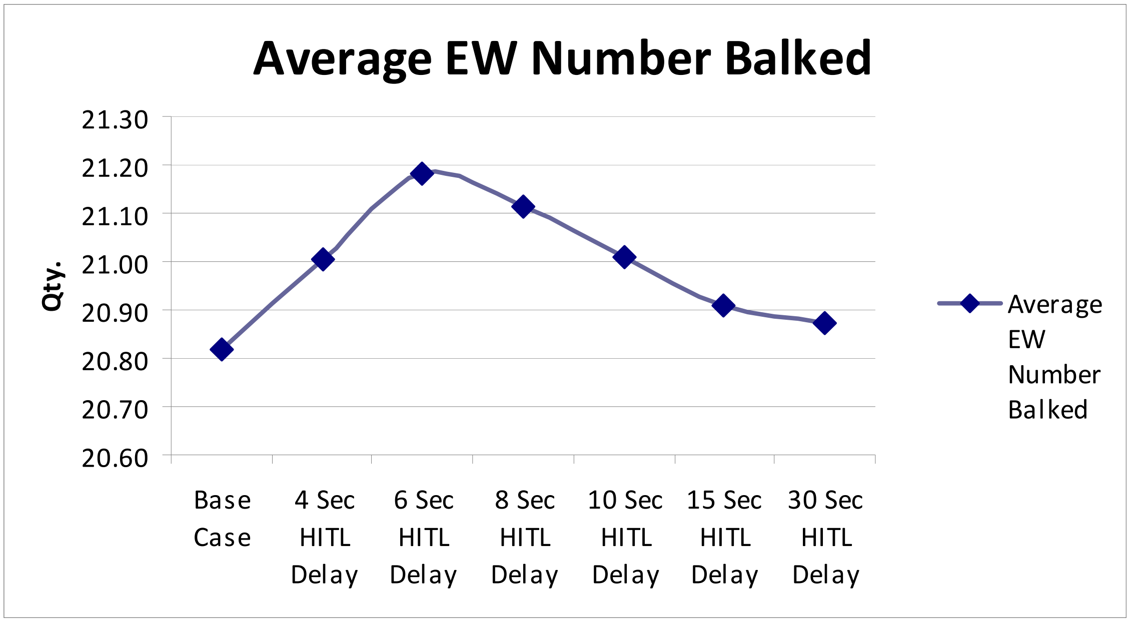


Figure 20: Average EW numbers balked.
This figure shows the average number of EW targets that were missed based on the HITL delay times.

The Average FSR Number Out, shown in figure 14, shows that the system received between 136 and 137 FSR in a given 8 hour simulation period regardless of what HITL delay was involved. The Average HITL Delay, shown in figure 15, shows the increasing HITL delay trend which is correlated with the Average FSR Total Time, figure 16, and the Average HK Number Miss, figure 18. The greater the HITL delay observed, the longer it takes for an FSR to be processed by the system. Because the HITL delay directly affects the performance of the hard-kill engagements, a greater Average of HK Number Miss was observed as the HITL delay increased. This was due to a slower response time to engage the ASCM threat. On average, 37 percent of the FSRs received were engaged by a hard-kill system with an average probability of hit (P-hit) of 0.70, or 70 percent. Similarly an average of 63 percent of the FSRs received were engaged by the IEW with an average P-hit of 0.76 or 76 percent. In the modeled defensive system, the soft-kill EW systems have a better performance than the hard-kill systems because the IEW systems serve more FSRs and have a greater P-hit than the hard-kill systems.

The comparison of Integrated Base Case/HITL Model engagement times to the Base Case-HITL Model—IEW only engagement times bring to light the challenges associated with hard-kill systems defending against supersonic threats. The Integrated Base Case/HITL Model had average FSR process times between 46.37 seconds and 59.63 seconds, which are very much greater than even the threshold engagement time of 14 seconds, to say nothing of the objective engagement time of 12 seconds. This indicates an "EW engagement first" approach may be warranted in the Integrated model, in which hard-kill defined as the secondary option in order to assure some form of engagement within the threshold time.

For the Integrated Base Case/HITL Model, functionality should be included for scenarios wherein a re-engagement is necessary due to an initial hard-kill miss. The HITL delay could also be placed in different or multiple locations in the model, depending on the number and type of decisions left open to the HITL (for example, if a HITL is making the final determination as to the type of response being employed vs. if a particular sensor return is or is not a threat).

The implementation of automation for a tactical system can be either Semi-Automatic (see figure 21), or Automatic (see figure 22). In the case of the Semi-Automatic system, the HITL needs to assess much of the sensor data and provide sensors feedback on their future operation. In the case of the Automatic system, the sensor management is handled by the machine and not the HTIL allowing for more efficient situation assessment. Machine generated options are presented to the HITL which can then be controlled by a veto or negation of the automatic machine generated decision. The higher the demand for sensor management the more an Automatic system is required because the HITL will be overwhelmed with the amount of sensor data received. The Automatic system is more costly to develop and maintain but will be needed in systems where the intended battlespace scenarios warrant a higher demand of sensor management and situation assessment.

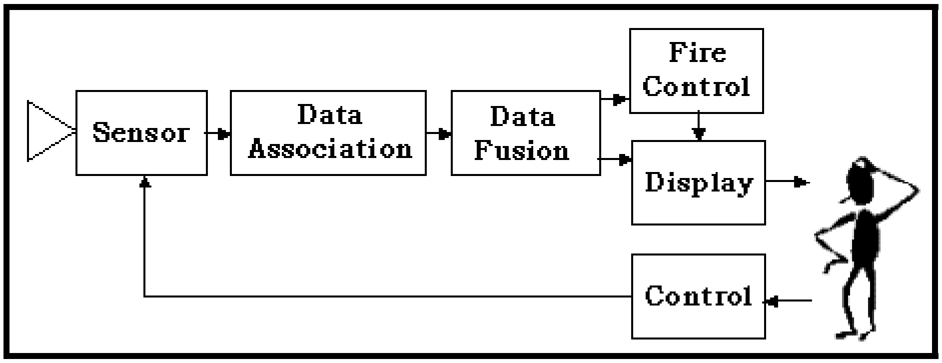


Figure 21: Semi-Automatic Sensor System.
This figure is a partial excerpt of figure 9 from Naval Network-Centric Sensor Resource Management (Green, Johnson, 2002, 13). This figure shows a semi-automatic implementation for a sensor system with a HITL.

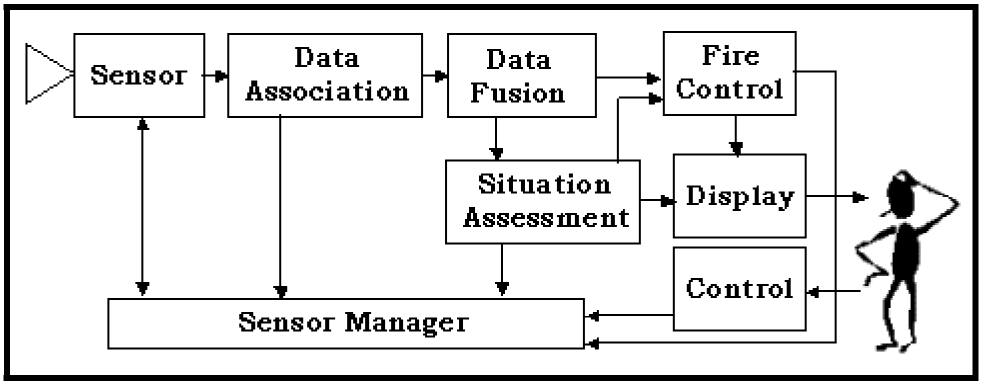


Figure 22: Automatic Sensor System.
This figure is the second part of figure 9 from Naval Network-Centric Sensor Resource Management (Green, Johnson, 2002, 13). This figure shows an automatic implementation for sensor systems with a HITL.

With additional time and effort the model developed in this project could include functionality allowing hard-kill systems to be used for re-engagement in addition to EW, based on availability of the EW system and the hard-kill systems. Finally, functionality could be added to the model to incorporate the presence and characteristics of other defensive soft-kill systems like onboard countermeasures.

Finally, the expansion of the model to include flexible HITL positions in the decision chain, re-engagement, and more specific parameters for hard-kill and soft-kill systems could be undertaken. Doctrinal requirements, specific defensive system parameters, and threat system parameters based on actual system data could also be included.

V. CONCLUSION

1. Findings

This study has demonstrated that an increasing level of threat from Anti-Ship Cruise Missiles (ASCMs) calls for improvement to current ASCM defensive techniques. In the past 50 years of warfare, there have been many incidents of ASCMs being employed in a number of combat scenarios. In each case examined herein there was a failure of existing tactics, techniques, or procedures that resulted in significant damage to the ship under attack and significant injury and loss of life to the ship's crew. There have been demonstrated failures in threat detection, threat discrimination and employment of defensive measures.

This project's objective was to improve the effectiveness of shipboard defensive systems through better integration of EW with hard kill systems. The research performed by the team indicated that a major factor influencing effectiveness was the degree of human involvement in decision-making and operation of the systems. Following requirements and functional analyses, the team's systems engineering approach was to develop a baseline model simulating an integrated Electronic Warfare architecture. Using the model, the team examined options with levels of Human-In-the-Loop (HITL) involvement ranging from total automation to fully manual operation.

The system was modeled both at the system level and the system of systems (SoS) level. At the system level, external factors were assumed in order to concentrate on the effect of the HITL. It was shown that a minimal HITL influence was preferred as this lowered the potential delay in deploying a hard- or soft-kill response to an incoming threat to an acceptable level. When considered at the SoS level, the simulation allowed for factors such as a limited number of hard-kill assets, and performance of the incoming threat. Here again it was shown that a lower HITL influence was better for the success of the overall engagement from the perspective of the defending platform.

The models developed in this project used assumed and estimated but realistic values for the effects of HITL delays. The results indicated that under light or moderate attack scenarios human involvement in defensive system operation should be such as to limit HITL delay to 8 seconds or less. This implies that, for this scenario, the system must be designed to present only one alternative to the HITL for a decision, not multiple alternatives. Further, in heavy attack scenarios it was found that a maximum 4-second HITL delay could be tolerated. This implies that under this condition, the system should be designed to limit the HITL role to deciding whether to veto continued operation before automatic threat prosecution takes place.

The system-related findings of this study aim to eliminate the gaps in performance demonstrated in the historical examples discussed above. The proposed system features provide for integration of ship sensor systems with both the Command and Control (C^2) personnel and the hard- and soft-kill defensive systems in existing and future USN ship designs. While the proposed features can be implemented with existing systems, it has been demonstrated that the existing systems might not provide for optimal defensive performance. Instead, new or improved systems, which reduce or eliminate the need for human operators and decision makers are preferred.

2. Recommendations

The ASCM threat will likely only increase over time. The proliferation of ASCMs and the advancement of technologies employed within them will only serve to make both blue water and littoral engagements more dangerous for future surface combatants. For success in future engagements, it is imperative that the U.S. and her allies implement an effective system to enable defense against this evolving threat.

It is recommended that the modeling and simulation effort begun under this study be continued both in more detail using more refined estimates and assumptions. Additional details to be added to the model might include additional threat parameters such as typical fly-out paths, terminal engagement types, seeker parameters, launch platform behavior, and own-ship sensor performance. Future efforts could include usage of actual threat parameters, such as information on particular known threat ASCMs, and higher fidelity human performance information.

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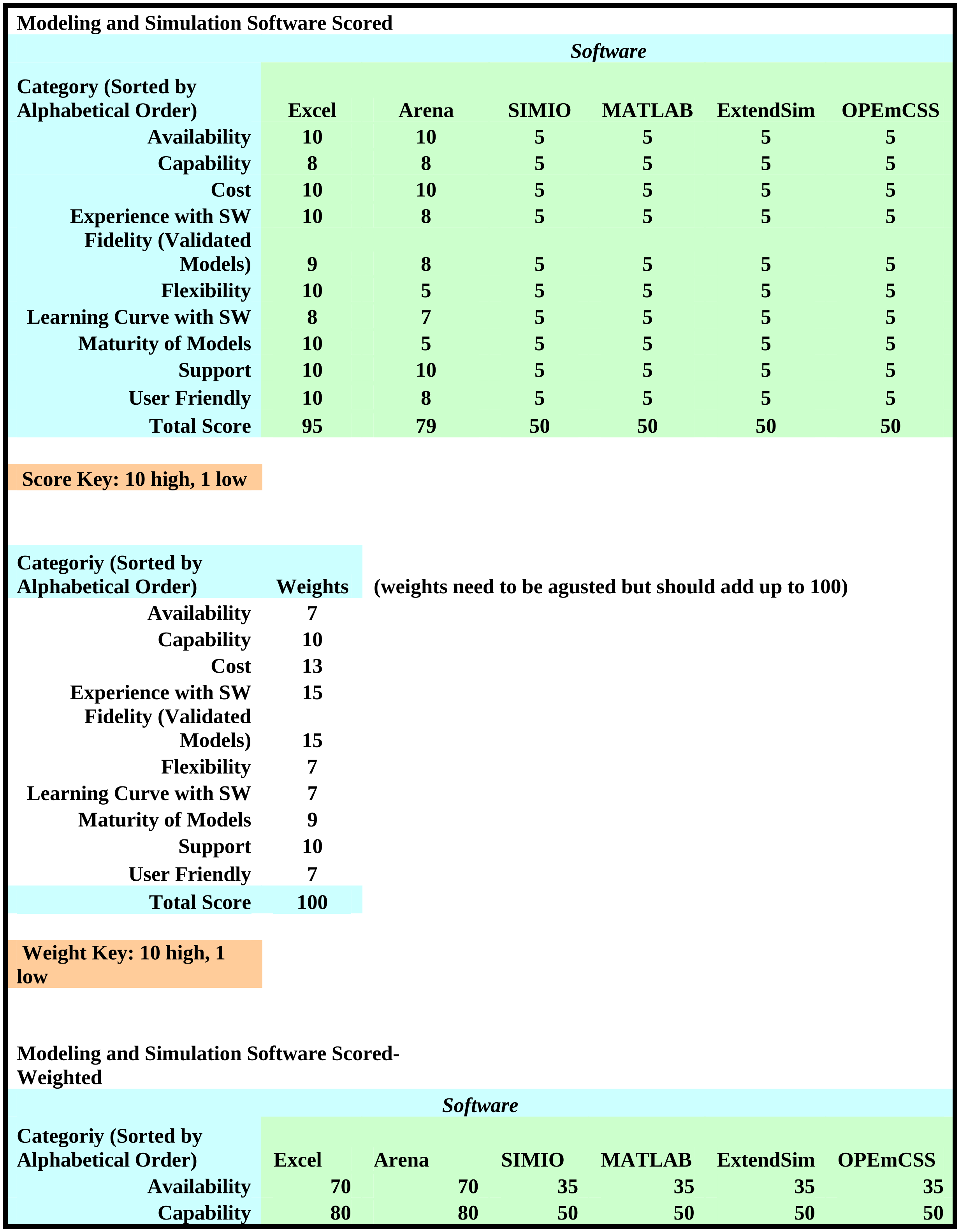
Appendix B - Acronyms

AGM	**Air-to-Ground Missile**
AoA	**Analysis of Alternatives**
ASCM	**Anti-Ship Cruise Missile**
ASCMD	**Anti-Ship Cruise Missile Defense**
AWS	**AEGIS Weapon System**
C^2	**Command and Control**
CHETA	**China Haiying Electromechanical Technology Academy**
CIC	**Combat Information Center**
CCDR	**Combatant Commander**
CCSG	**Commander, Carrier Strike Group**
CEC	**Cooperative Engagement Capability**
CIWS	**Close-In Weapons System**
COTS	**Commercial Off The Shelf**
CNO	**Chief of Naval Operations**
CSG	**Carrier Strike Group**
DTE	**Detect To Engage**
DoD	**Department of Defense**
DRDO	**Defense Research and Development Organization**
EMCON	**Emission Control**
EM	**Electro-Magnetic**
EO	**Electro-Optical**
ESM	**Electronic Support Measure**
EW	**Electronic Warfare**
EWS	**Electronic Warfare System**
ESR	**Engagement Service Request**
FCS	**Fire Control System**
FSR	**Firing Service Request**
FFG	**Guided Missile Frigate**
GPS	**Global Positioning System**
HEAT	**High Explosive Anti-Tank**
HITL	**Human-In-The-Loop**
HMS	**His/Her Majesty's Ship**
HSI	**Human Systems Integration**
IEWS	**Integrated Electronic Warfare System**
IFF	**Identification, Friend or Foe**
INCOSE	**International Council on System Engineering**
INS	**Inertial Navigation System**
INS	**Israeli Naval Ship**
IR	**Infrared**
JETT	**Joint Electronic Warfare Task Team**
LOS	**Line of Sight**

MOD	**Ministry of Defence**
MOSA	**Modular Open System Architecture**
M&S	**Modeling and Simulation**
MSSE	**Master of Science in Systems Engineering**
MV	**Merchant Vessel**
NATO	**North Atlantic Treaty Organization**
NDI	**Non-Developmental Item**
NPS	**Naval Postgraduate School**
NM	**Nautical Mile**
OA	**Open Architecture**
PATRIOT	**Phased Array Tracking Radar to Intercept Of Target**
RF	**Radio Frequency**
RGM	**Radar Guided Missile**
RN	**Royal Navy**
ROE	**Rules of Engagement**
SA	**Situational Awareness**
SoS	**System of Systems**
SAG	**Surface Action Group**
SSDS	**Ship Self-Defense System**
UAE	**United Arab Emirates**
UAV	**Unmanned Aerial Vehicle**
UGM	**Underwater Guided Missile**
UHF	**Ultra High-Frequency**
UK	**United Kingdom**
US	**United States**
USS	**United States Ship**
USAF	**United States Air Force**
USN	**United States Navy**
YJ	**Ying-Jo**

Appendix C - Emulator Software Selection



Modeling and Simulation Software Scored

Category (Sorted by Alphabetical Order)	*Software* Excel	Arena	SIMIO	MATLAB	ExtendSim	OPEmCSS
Availability	10	10	5	5	5	5
Capability	8	8	5	5	5	5
Cost	10	10	5	5	5	5
Experience with SW	10	8	5	5	5	5
Fidelity (Validated Models)	9	8	5	5	5	5
Flexibility	10	5	5	5	5	5
Learning Curve with SW	8	7	5	5	5	5
Maturity of Models	10	5	5	5	5	5
Support	10	10	5	5	5	5
User Friendly	10	8	5	5	5	5
Total Score	95	79	50	50	50	50

Score Key: 10 high, 1 low

Categoriy (Sorted by Alphabetical Order)	Weights
Availability	7
Capability	10
Cost	13
Experience with SW	15
Fidelity (Validated Models)	15
Flexibility	7
Learning Curve with SW	7
Maturity of Models	9
Support	10
User Friendly	7
Total Score	100

(weights need to be agusted but should add up to 100)

Weight Key: 10 high, 1 low

Modeling and Simulation Software Scored-Weighted

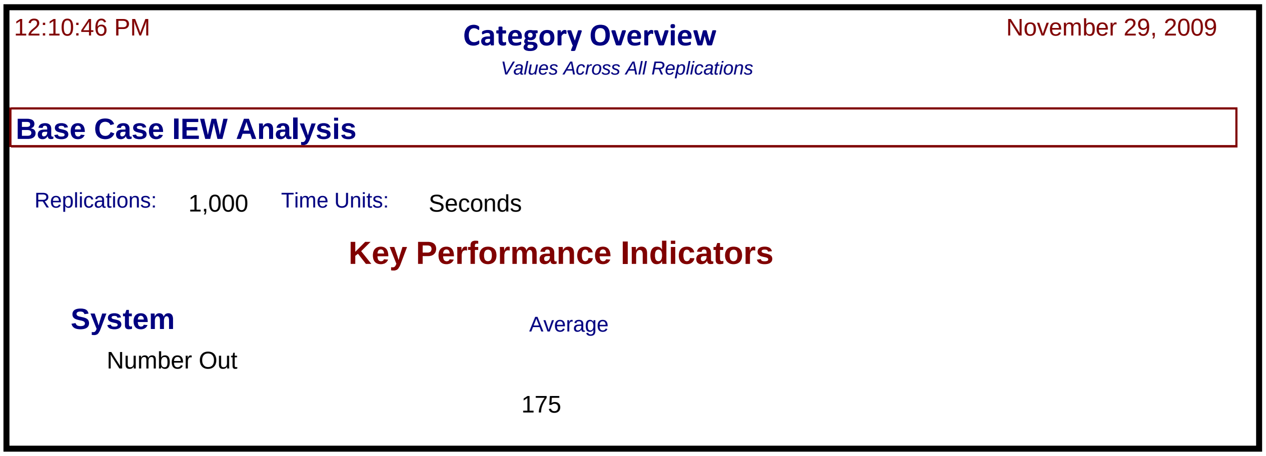
Categoriy (Sorted by Alphabetical Order)	*Software* Excel	Arena	SIMIO	MATLAB	ExtendSim	OPEmCSS
Availability	70	70	35	35	35	35
Capability	80	80	50	50	50	50

Cost	**130**	**130**	**65**	**65**	**65**	**65**
Experience with SW	**150**	**120**	**75**	**75**	**75**	**75**
Fidelity (Validated Models)	**135**	**120**	**75**	**75**	**75**	**75**
Flexibility	**70**	**35**	**35**	**35**	**35**	**35**
Learning Curve with SW	**56**	**49**	**35**	**35**	**35**	**35**
Maturity of Models	**90**	**45**	**45**	**45**	**45**	**45**
Support	**100**	**100**	**50**	**50**	**50**	**50**
User Friendly	**70**	**56**	**35**	**35**	**35**	**35**
Total Score	**951**	**805**	**500**	**500**	**500**	**500**

Since Excel and Arena received the highest scores, they were selected as the primary emulation software packages for the development of the simulation models.

Appendix D – Modeling and Simulation Results

1. Base Case Light Results



12:10:46 PM

Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	175

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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.2637	< 0.02	3.5988	5.2492	0.03420432	86.9003

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.1855	< 0.00	0.08650194	0.3627	0.00	16.9788

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.4491	< 0.02	3.7581	5.4031	0.03739759	87.8258

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
ESR	174.71	1.18	122.00	236.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
ESR	174.70	1.18	122.00	236.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.02221170	< 0.00	0.01505450	0.03146172	0.00	6.0000

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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.6240	< 0.00	0.4785	0.7814	0.00000725	10.9273
IEW Engagement	2.0820	< 0.00	1.8798	2.2821	0.00	6.8520
IEW Transition	1.5576	< 0.01	0.9852	2.4667	0.00000007	83.6874

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.1855	< 0.00	0.08650194	0.3627	0.00	16.9788

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.8095	< 0.00	0.6367	1.0330	0.00000824	17.8759
IEW Engagement	2.0820	< 0.00	1.8798	2.2821	0.00	6.8520
IEW Transition	1.5576	< 0.01	0.9852	2.4667	0.00000007	83.6874

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	108.99	0.91	73.3816	158.98
IEW Engagement	363.71	2.57	252.29	499.09
IEW Transition	272.22	3.10	151.73	492.68

Category Overview

Values Across All Replications

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

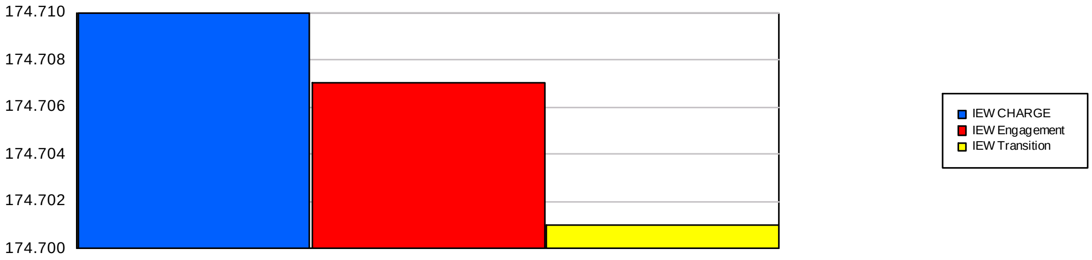
Process

Accumulated Time

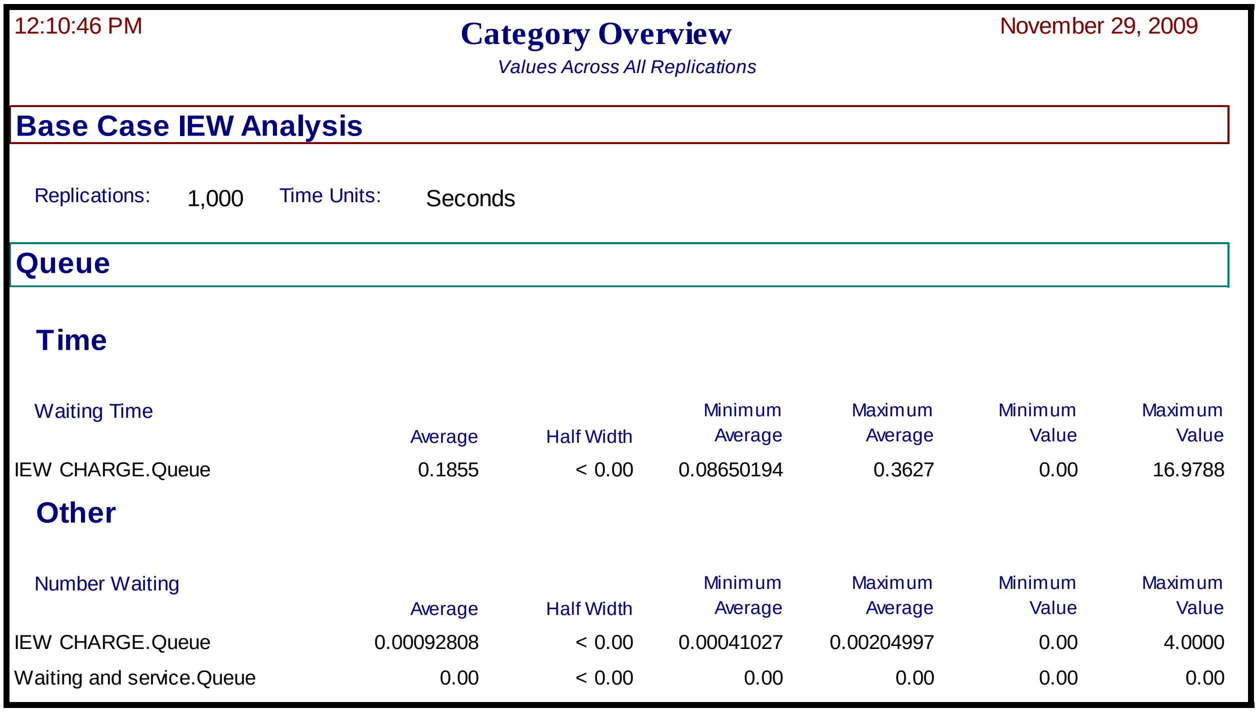
Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	32.4820	0.54	14.3593	71.7490

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	174.71	1.18	122.00	236.00
IEW Engagement	174.71	1.18	122.00	236.00
IEW Transition	174.70	1.18	122.00	236.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	174.71	1.18	122.00	236.00
IEW Engagement	174.70	1.18	122.00	236.00
IEW Transition	174.70	1.18	122.00	236.00



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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Queue

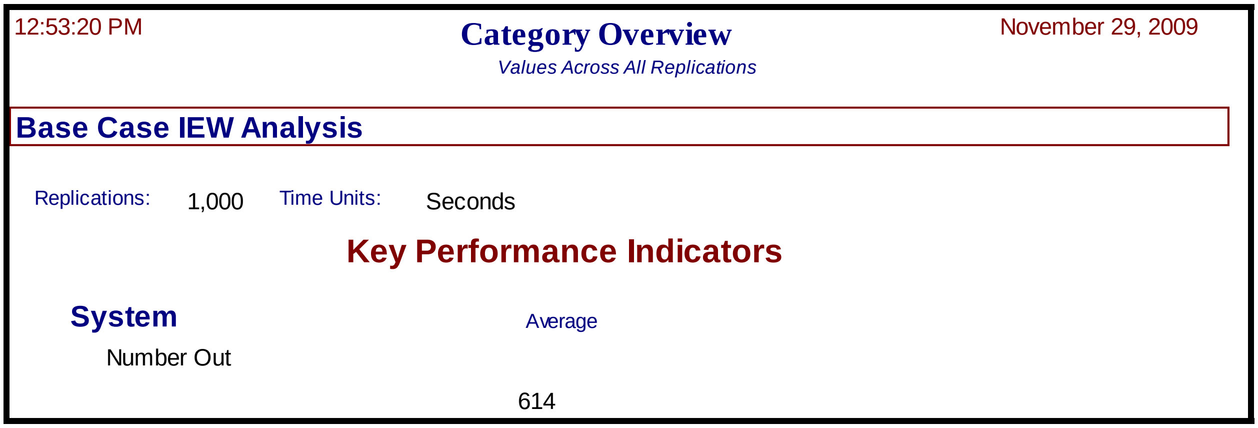
Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.1855	< 0.00	0.08650194	0.3627	0.00	16.9788

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.00092808	< 0.00	0.00041027	0.00204997	0.00	4.0000
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

2. Base Case Heavy Results



12:53:20 PM

Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	614

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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.1890	< 0.01	3.7318	4.7624	0.00	121.51

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	6.1233	< 0.01	5.5944	6.7883	0.00	56.9701

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	10.3123	< 0.02	9.3931	11.4913	0.00	134.15

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
ESR	614.17	4.01	441.00	791.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
ESR	614.18	4.01	441.00	791.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.1809	< 0.00	0.1240	0.2315	0.00	15.0000

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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.6246	< 0.00	0.5299	0.7038	0.00000313	11.6606
IEW Engagement	2.0779	< 0.00	1.9418	2.2192	0.00	6.7579
IEW Transition	1.5646	< 0.01	1.1925	2.0114	0.00000000	118.87

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	6.2380	< 0.01	5.6177	7.0631	0.00	56.9701

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	6.8625	< 0.01	6.2011	7.7203	0.00000518	57.8794
IEW Engagement	2.0779	< 0.00	1.9418	2.2192	0.00	6.7579
IEW Transition	1.5646	< 0.01	1.1925	2.0114	0.00000000	118.87

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	376.43	2.60	250.63	528.16
IEW Engagement	1252.57	8.18	902.06	1629.51
IEW Transition	942.95	7.52	616.26	1347.19

Category Overview

Values Across All Replications

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

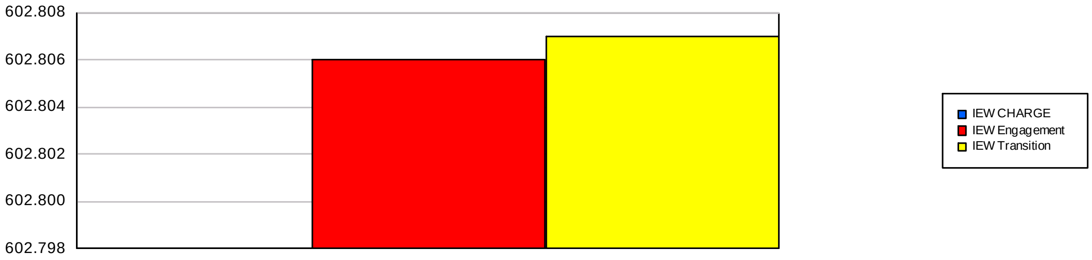
Process

Accumulated Time

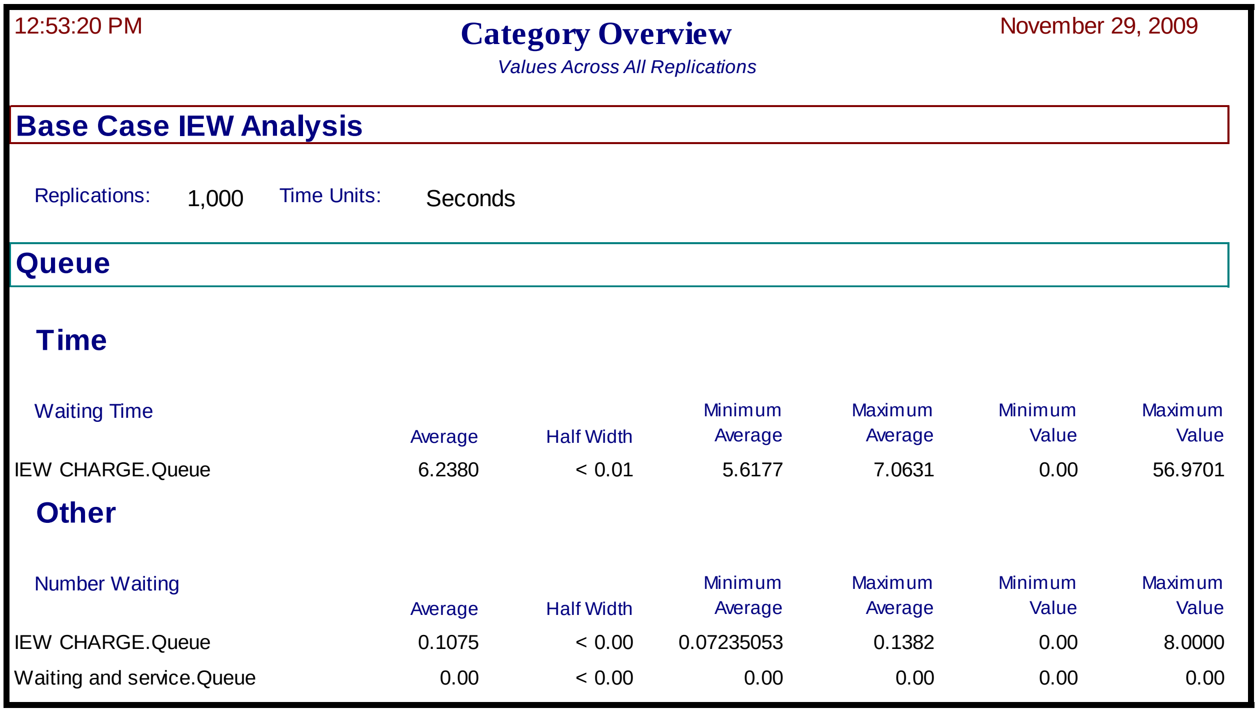
Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	3761.35	25.95	2532.27	4836.24

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	602.80	3.87	435.00	776.00
IEW Engagement	602.81	3.87	435.00	776.00
IEW Transition	602.81	3.87	435.00	776.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	602.81	3.87	435.00	776.00
IEW Engagement	602.81	3.87	435.00	776.00
IEW Transition	602.80	3.87	435.00	776.00



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Category Overview

Values Across All Replications

November 29, 2009

Base Case IEW Analysis

Replications: 1,000 Time Units: Seconds

Queue

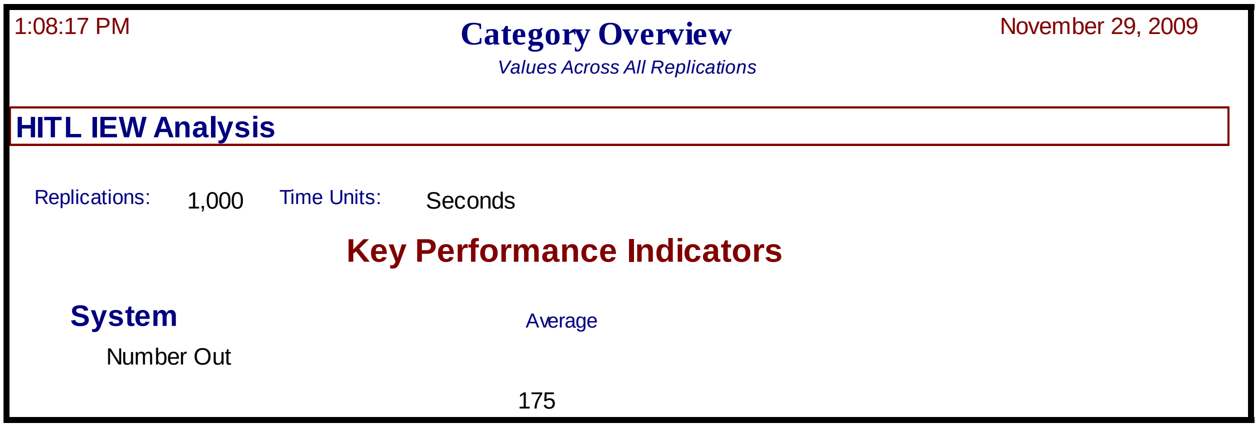
Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	6.2380	< 0.01	5.6177	7.0631	0.00	56.9701

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.1075	< 0.00	0.07235053	0.1382	0.00	8.0000
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

3. HITL 4 Second Response Light Time Results



1:08:17 PM

Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	175

1:08:17 PM

Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.2680	< 0.02	3.5824	5.2683	0.03056571	77.7357

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.1105	< 0.00	0.03795713	0.3393	0.00	22.4313

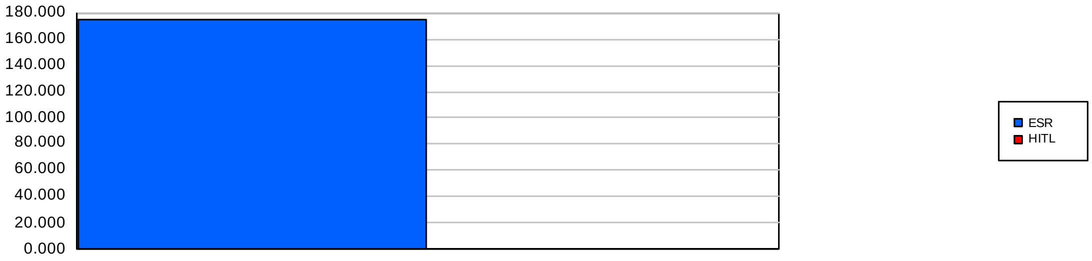
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	5.3278	< 0.01	4.7445	5.7775	2.0077	9.9840

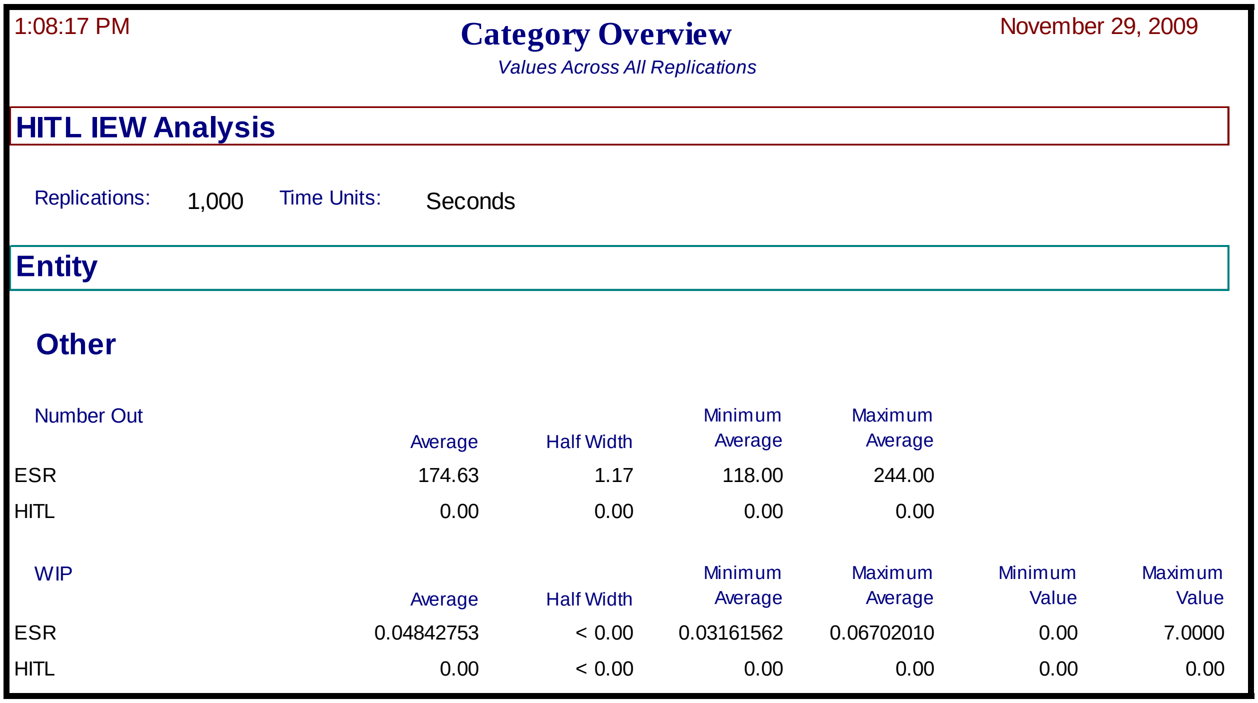
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	9.7063	< 0.02	8.8062	10.7687	2.6497	84.9507

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
ESR	174.62	1.17	118.00	244.00
HITL	0.00	0.00	0.00	0.00





1:08:17 PM

Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
ESR	174.63	1.17	118.00	244.00
HITL	0.00	0.00	0.00	0.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.04842753	< 0.00	0.03161562	0.06702010	0.00	7.0000
HITL	0.00	< 0.00	0.00	0.00	0.00	0.00

1:08:17 PM

Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.6245	< 0.00	0.4535	0.8358	0.00000343	11.3603
IEW Engagement	2.0820	< 0.00	1.8524	2.3909	0.00	6.8495
IEW Transition	1.5614	< 0.01	0.9864	2.3256	0.00000000	75.4940

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.1105	< 0.00	0.03795713	0.3393	0.00	22.4313

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.7350	< 0.00	0.5203	1.0052	0.00000343	22.5159
IEW Engagement	2.0820	< 0.00	1.8524	2.3909	0.00	6.8495
IEW Transition	1.5614	< 0.01	0.9864	2.3256	0.00000000	75.4940

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	109.08	0.94	60.7714	172.17
IEW Engagement	363.60	2.56	237.99	525.20
IEW Transition	272.61	2.97	148.37	468.51

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Category Overview

Values Across All Replications

November 29, 2009

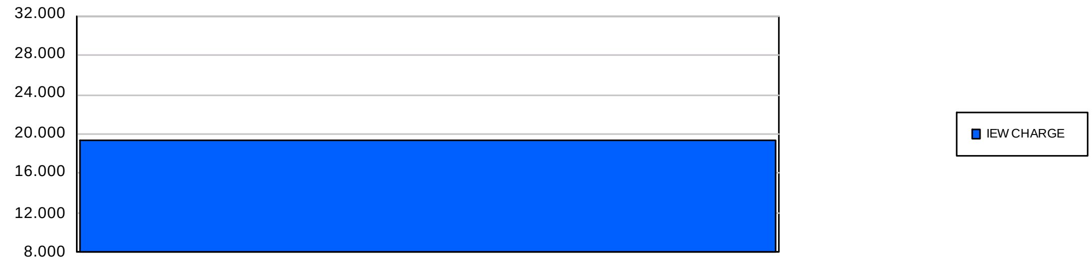
HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

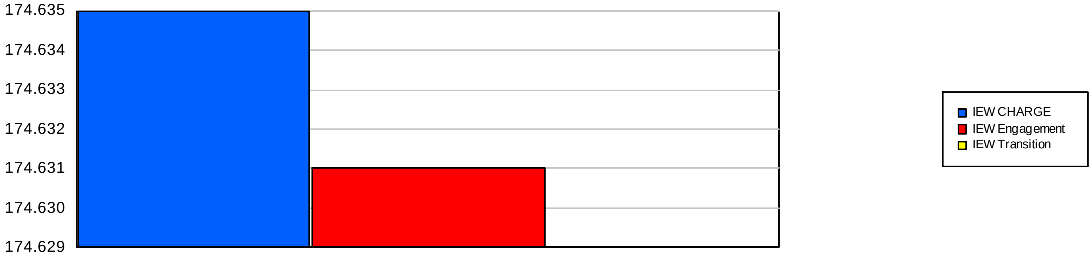
Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	19.3793	0.47	5.4658	61.0779

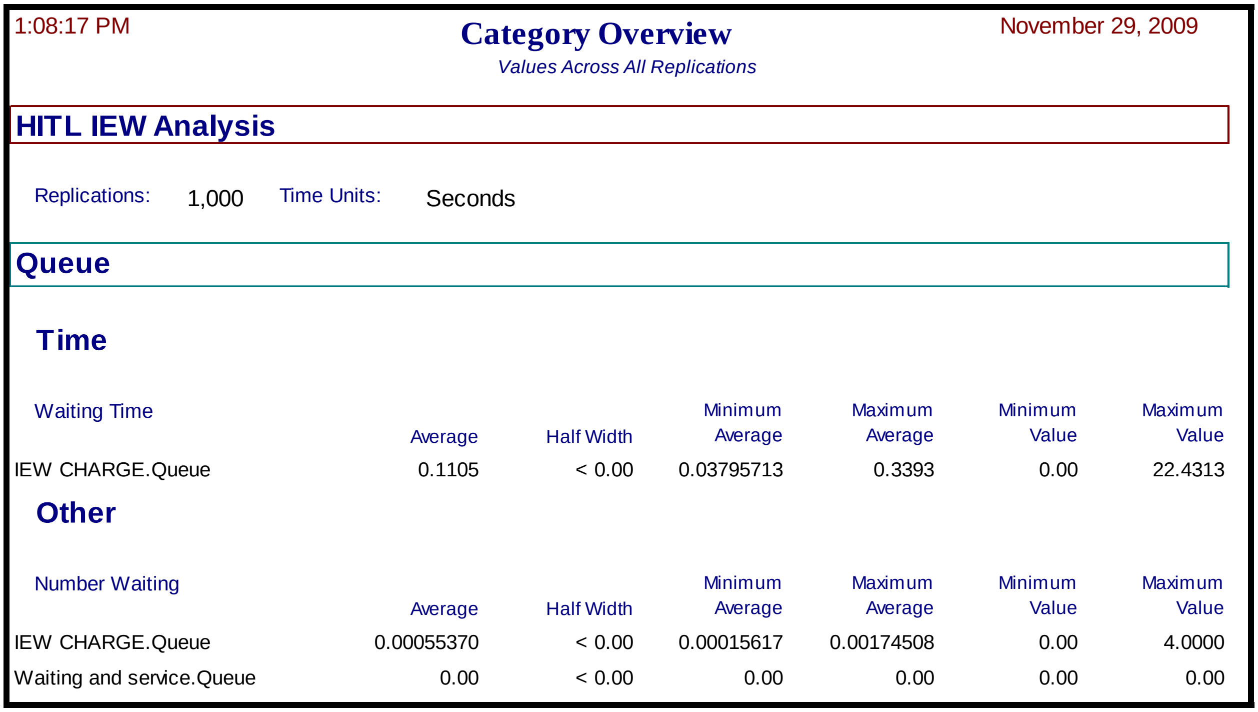


Other

Number In	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	174.64	1.17	118.00	244.00
IEW Engagement	174.63	1.17	118.00	244.00
IEW Transition	174.63	1.17	118.00	244.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	174.63	1.17	118.00	244.00
IEW Engagement	174.63	1.17	118.00	244.00
IEW Transition	174.63	1.17	118.00	244.00



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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Queue

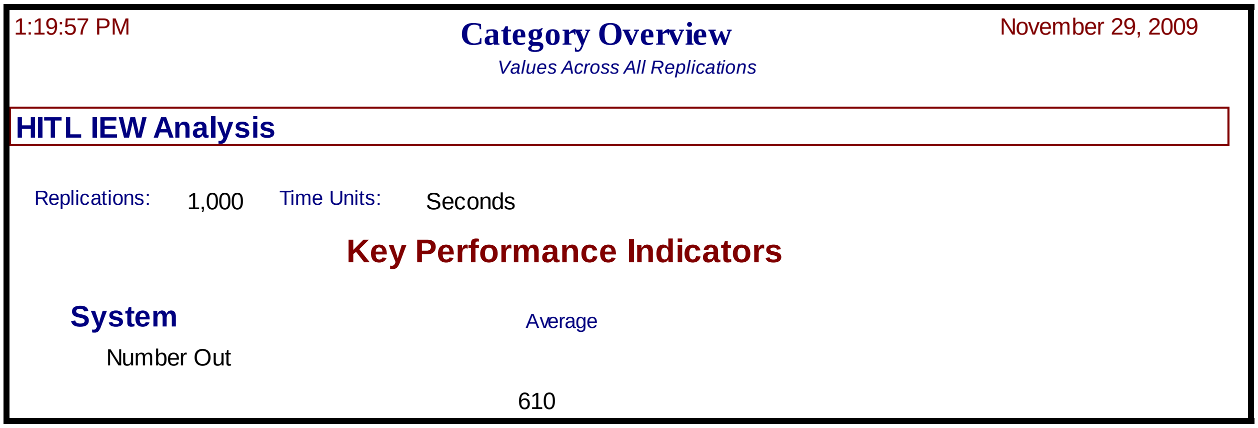
Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.1105	< 0.00	0.03795713	0.3393	0.00	22.4313

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.00055370	< 0.00	0.00015617	0.00174508	0.00	4.0000
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

4. HITL 4 Second Response Heavy Time Results



1:19:57 PM

Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	610

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.2656	< 0.01	3.7717	4.8987	0.00	77.7357

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	1.4707	< 0.01	1.0530	1.9975	0.00	32.9534

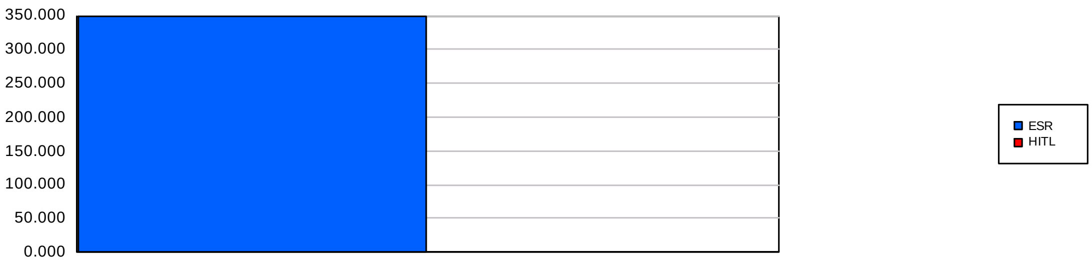
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	5.3294	< 0.01	5.0491	5.6526	2.0077	9.9930

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	11.0658	< 0.02	10.2990	12.0169	2.5266	88.6217

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
ESR	348.34	2.33	240.00	496.00
HITL	0.00	0.00	0.00	0.00



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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
ESR	348.42	2.33	240.00	499.00
HITL	0.00	0.00	0.00	0.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.1101	< 0.00	0.07527058	0.1532	0.00	15.0000
HITL	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	0.6241	< 0.00	0.4984	0.7784	0.00000064	11.3603
IEW Engagement	2.0791	< 0.00	1.9187	2.2876	0.00	6.6394
IEW Transition	1.5627	< 0.01	1.1771	2.1332	0.00	75.4940

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	1.4708	< 0.01	1.0530	1.9975	0.00	32.9534

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE	2.0949	< 0.01	1.6104	2.6628	0.00000064	34.0714
IEW Engagement	2.0791	< 0.00	1.9187	2.2876	0.00	6.6394
IEW Transition	1.5627	< 0.01	1.1771	2.1332	0.00	75.4940

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	217.35	1.64	146.87	304.59
IEW Engagement	724.31	4.94	491.18	1015.35
IEW Transition	544.42	4.96	320.82	886.56

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications:	1,000	Time Units:	Seconds

Process

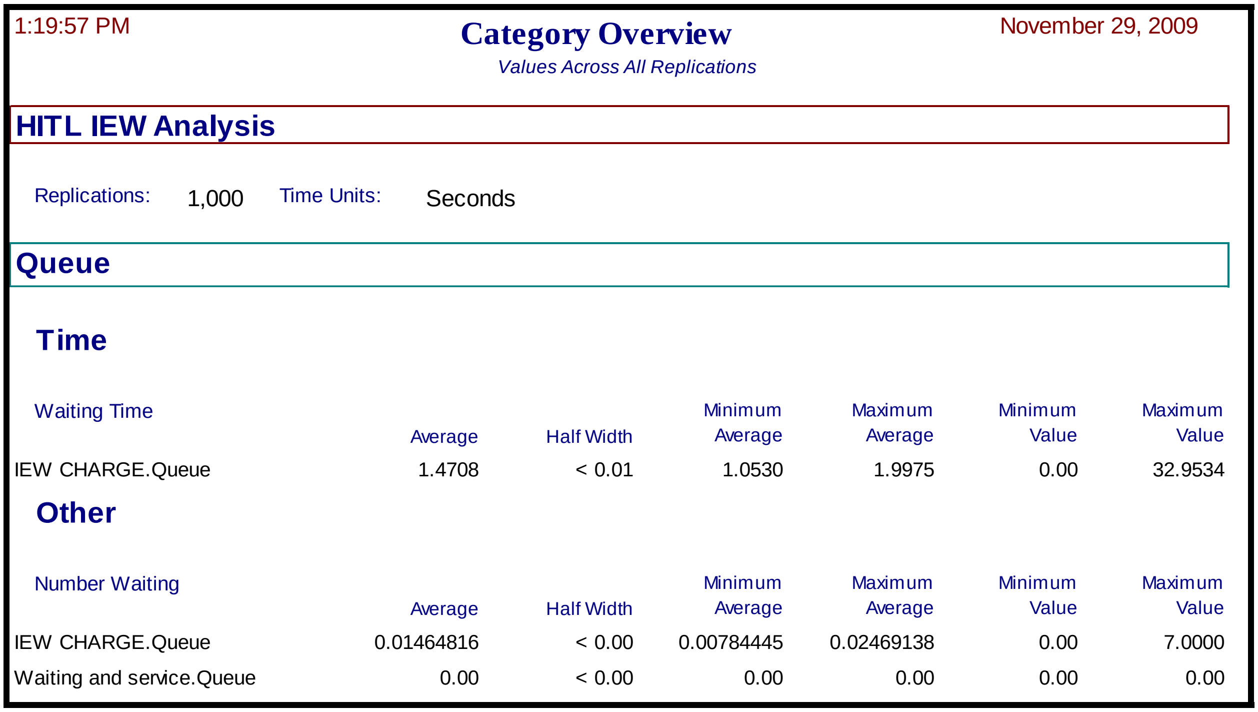
Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	512.72	4.81	274.56	864.20

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	348.34	2.33	240.00	497.00
IEW Engagement	348.37	2.33	240.00	498.00
IEW Transition	348.38	2.33	240.00	498.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	348.37	2.33	240.00	498.00
IEW Engagement	348.38	2.33	240.00	498.00
IEW Transition	348.39	2.33	240.00	499.00



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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	1.4708	< 0.01	1.0530	1.9975	0.00	32.9534

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.01464816	< 0.00	0.00784445	0.02469138	0.00	7.0000
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

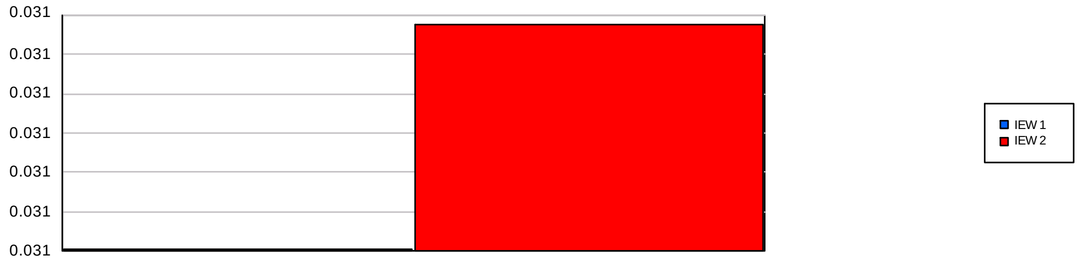
Usage

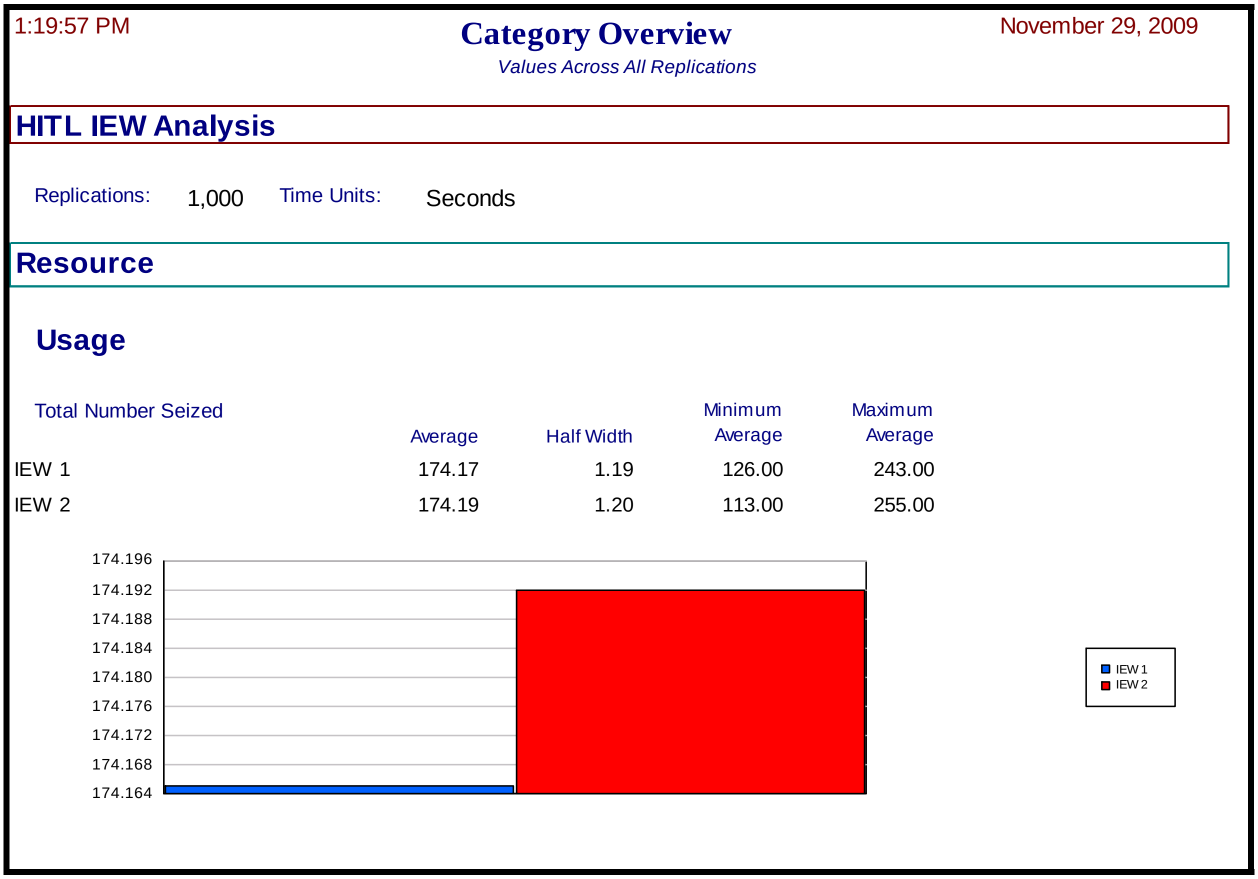
Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.02122115	< 0.00	0.01376296	0.03068669	0.00	1.0000
IEW 2	0.02123676	< 0.00	0.01385430	0.03088972	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.02122115	< 0.00	0.01376296	0.03068669	0.00	1.0000
IEW 2	0.02123676	< 0.00	0.01385430	0.03088972	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.6908	< 0.00	0.6852	0.6946	0.00	1.0000
IEW 2	0.6908	< 0.00	0.6859	0.6943	0.00	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
IEW 1	0.03072418	0.00	0.01981493	0.04478641
IEW 2	0.03074702	0.00	0.01995501	0.04503830





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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

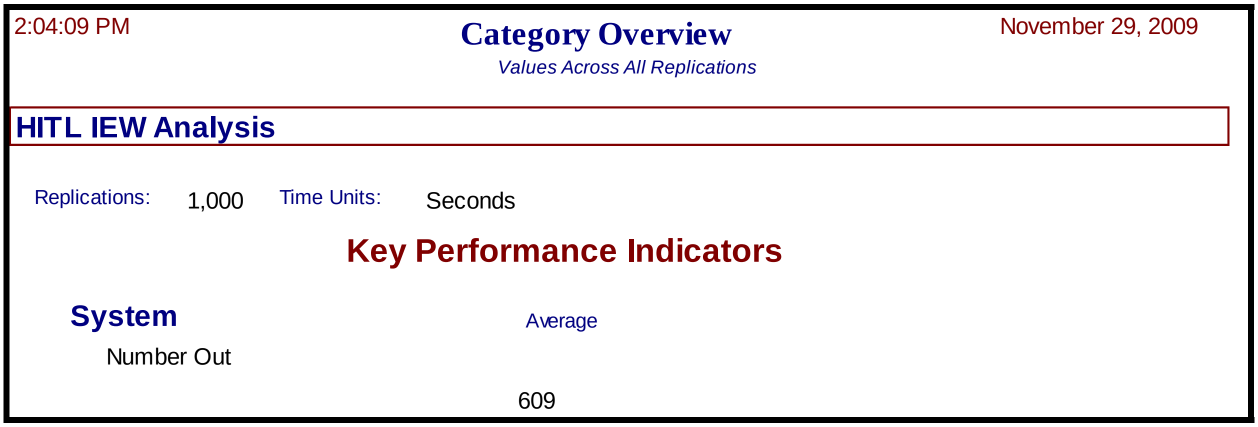
Replications: 1,000 Time Units: Seconds

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
IEW 1	174.17	1.19	126.00	243.00
IEW 2	174.19	1.20	113.00	255.00

5. HITL 6 Second Response Heavy Time Results



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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	609

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.2190	< 0.01	3.7988	4.7253	0.00	135.92

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	4.1552	< 0.01	3.4461	4.8604	0.00	59.4301

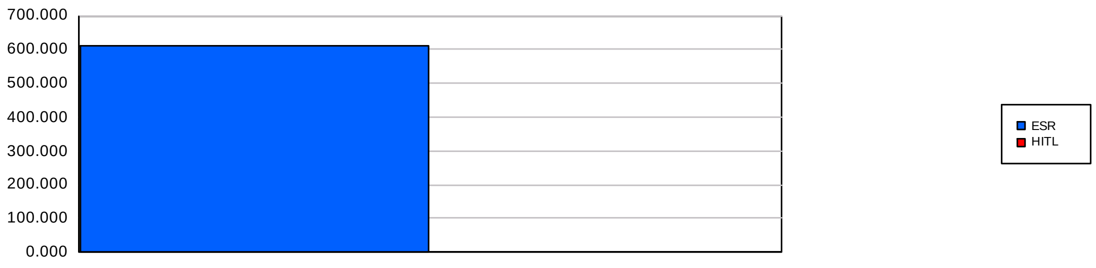
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	6.6710	< 0.01	6.3709	6.9176	2.0092	11.9936

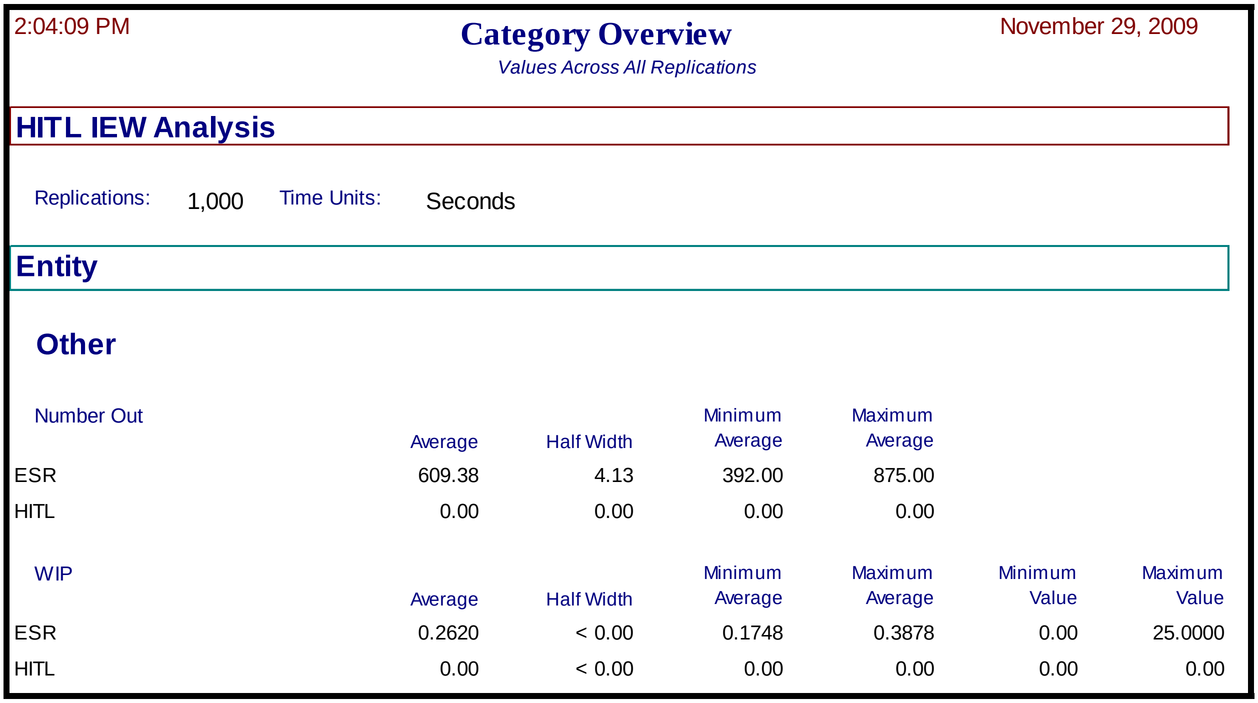
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	15.0452	< 0.02	14.0789	16.3370	2.6607	144.04

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
ESR	609.42	4.14	392.00	875.00
HITL	0.00	0.00	0.00	0.00





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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
ESR	609.38	4.13	392.00	875.00
HITL	0.00	0.00	0.00	0.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ESR	0.2620	< 0.00	0.1748	0.3878	0.00	25.0000
HITL	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity			Minimum	Maximum	Minimum	Maximum
	Average	Half Width	Average	Average	Value	Value
IEW CHARGE	0.6213	< 0.00	0.5318	0.7118	0.00000367	12.2331
IEW Engagement	2.0788	< 0.00	1.9701	2.2390	0.00	6.9541
IEW Transition	1.5622	< 0.01	1.2221	2.0357	0.00000000	130.14

Wait Time Per Entity			Minimum	Maximum	Minimum	Maximum
	Average	Half Width	Average	Average	Value	Value
IEW CHARGE	4.1986	< 0.01	3.4841	4.9514	0.00	59.4301

Total Time Per Entity			Minimum	Maximum	Minimum	Maximum
	Average	Half Width	Average	Average	Value	Value
IEW CHARGE	4.8199	< 0.02	4.0730	5.5791	0.00000787	60.8307
IEW Engagement	2.0788	< 0.00	1.9701	2.2390	0.00	6.9541
IEW Transition	1.5622	< 0.01	1.2221	2.0357	0.00000000	130.14

Accumulated Time

Accum VA Time			Minimum	Maximum
	Average	Half Width	Average	Average
IEW CHARGE	374.86	2.81	221.36	564.78
IEW Engagement	1253.83	8.60	831.89	1821.90
IEW Transition	942.46	7.92	572.21	1456.13

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

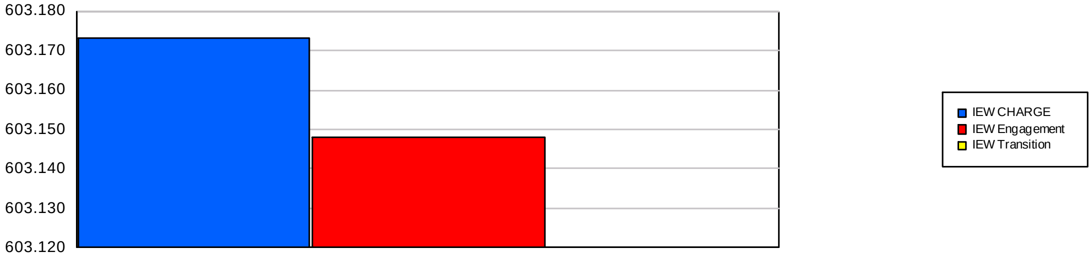
Process

Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	2534.51	20.24	1578.31	3890.01

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	603.17	4.07	382.00	864.00
IEW Engagement	603.15	4.06	382.00	864.00
IEW Transition	603.12	4.06	382.00	864.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
IEW CHARGE	603.15	4.06	382.00	864.00
IEW Engagement	603.12	4.06	382.00	864.00
IEW Transition	603.12	4.06	382.00	864.00

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	4.1986	< 0.01	3.4782	4.9514	0.00	59.4301

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW CHARGE.Queue	0.07241624	< 0.00	0.04511672	0.1111	0.00	8.0000
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 29, 2009

HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

Usage

Instantaneous Utilization

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.03672345	< 0.00	0.02419161	0.05457049	0.00	1.0000
IEW 2	0.03673911	< 0.00	0.02422065	0.05522418	0.00	1.0000

Number Busy

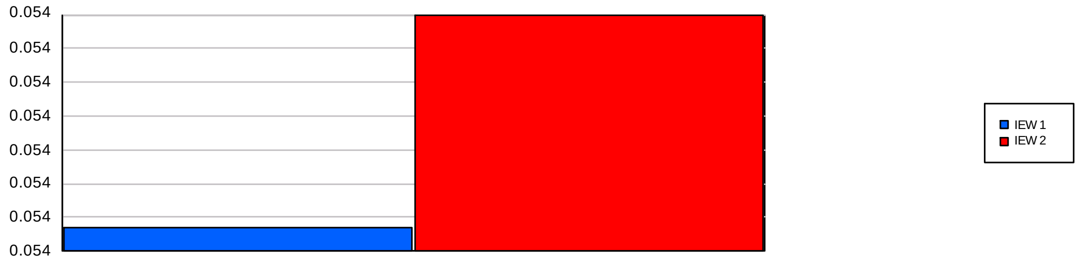
	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.03672345	< 0.00	0.02419161	0.05457049	0.00	1.0000
IEW 2	0.03673911	< 0.00	0.02422065	0.05522418	0.00	1.0000

Number Scheduled

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IEW 1	0.6847	< 0.00	0.6769	0.6902	0.00	1.0000
IEW 2	0.6847	< 0.00	0.6767	0.6902	0.00	1.0000

Scheduled Utilization

	Average	Half Width	Minimum Average	Maximum Average
IEW 1	0.05365073	0.00	0.03504852	0.08062007
IEW 2	0.05367589	0.00	0.03509118	0.08161174



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Category Overview

Values Across All Replications

November 29, 2009

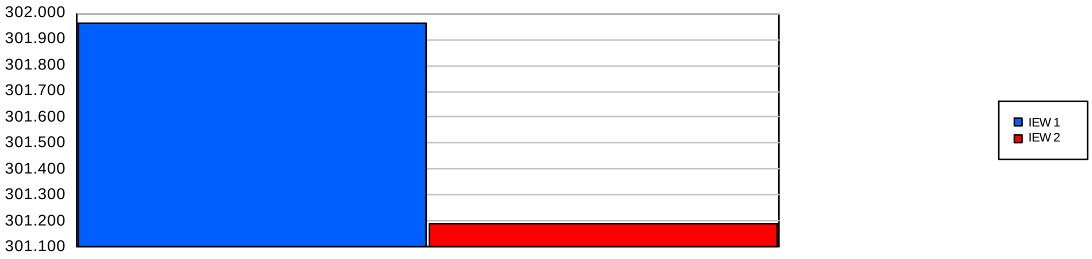
HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
IEW 1	301.96	2.07	192.00	418.00
IEW 2	301.19	2.08	190.00	446.00



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Category Overview

Values Across All Replications

November 29, 2009

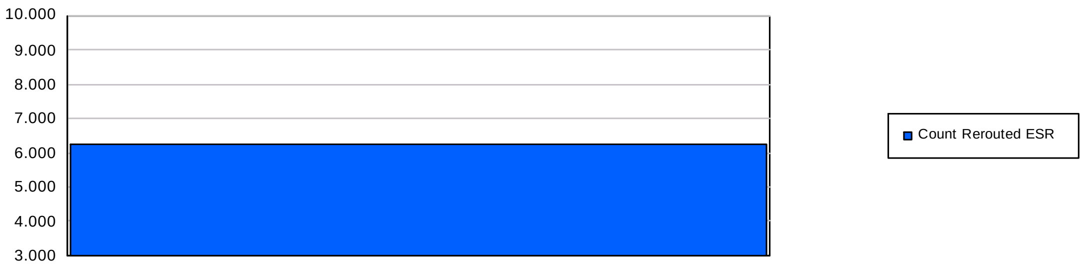
HITL IEW Analysis

Replications: 1,000 Time Units: Seconds

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Count Rerouted ESR	6.2600	< 0.30	0.00	27.0000



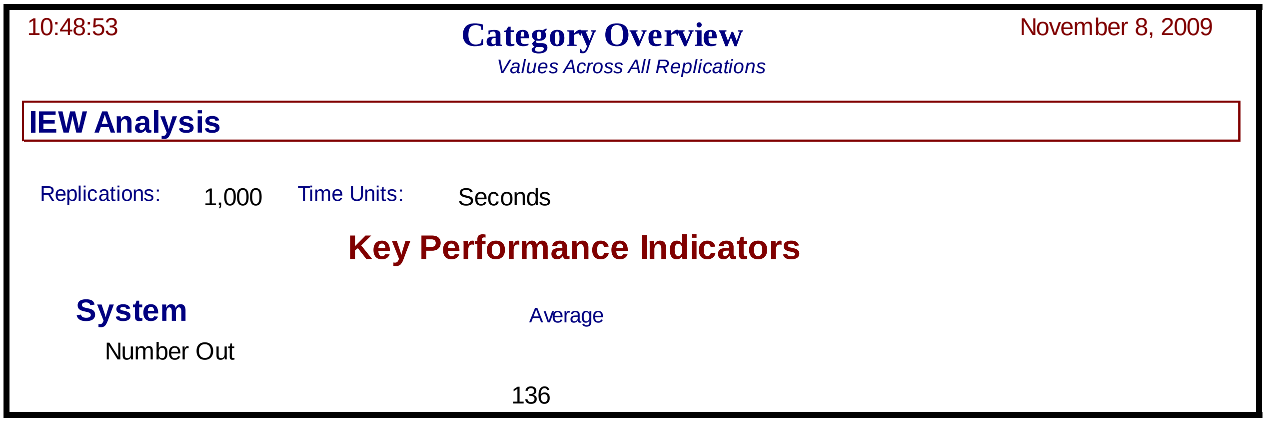
Time Persistent

Time Persistent	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HITL Ave Delay	0.00	< 0.00	0.00	0.00	0.00	0.00
HITL ESR Tot time	4.1117	< 0.02	3.0056	5.3490	0.00	18.2616
HITL ESRs in Sys	0.2620	< 0.00	0.1748	0.3878	0.00	25.0000

Output

Output	Average	Half Width	Minimum Average	Maximum Average
HITL Pct Balk Out	0.01016053	0.00	0.00	0.04192547

6. Integrated HITL 0 second Delay Case IEW



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	
	136

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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	46.3704	< 0.32	32.1369	66.0550	0.00	751.97

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	46.3704	< 0.32	32.1369	66.0550	0.00	751.97

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
FSR	149.33	1.26	83.0000	215.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
FSR	149.47	1.26	83.0000	216.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.2177	< 0.00	0.1193	0.3181	0.00	12.0000

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	45.1863	< 0.36	26.3236	71.5458	0.00062110	513.93
HITL Delay	0.00	< 0.00	0.00	0.00	0.00	0.00
HK Assess	6.0039	< 0.02	5.0365	7.2212	2.0002	9.9999
HK Engage	59.8786	< 0.52	34.7856	91.0537	0.00376410	742.82

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	45.1863	< 0.36	26.3236	71.5458	0.00062110	513.93
HITL Delay	0.00	< 0.00	0.00	0.00	0.00	0.00
HK Assess	6.0039	< 0.02	5.0365	7.2212	2.0002	9.9999
HK Engage	59.8786	< 0.52	34.7856	91.0537	0.00376410	742.82

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
EW Engage	2898.64	41.14	1029.08	4958.67
HITL Delay	0.00	0.00	0.00	0.00
HK Assess	304.63	1.07	230.55	378.78
HK Engage	3036.94	26.72	1739.28	4552.69

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
EW Engage	64.2740	0.78	22.0000	108.00
HITL Delay	50.5350	0.08	42.0000	57.0000
HK Assess	50.7220	0.07	42.0000	57.0000
HK Engage	50.5350	0.08	42.0000	57.0000

Number Out	Average	Half Width	Minimum Average	Maximum Average
EW Engage	64.2140	0.78	22.0000	108.00
HITL Delay	50.5350	0.08	42.0000	57.0000
HK Assess	50.7380	0.07	42.0000	57.0000
HK Engage	50.7220	0.07	42.0000	57.0000

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

10:48:53

Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
HK System 2	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
System 1	0.7778	< 0.00	0.7778	0.7778	0.00	1.0000
System 2	0.7000	< 0.00	0.7000	0.7000	0.00	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Count EW Balk	20.8160	< 0.54	1.0000	50.0000
Count EW Engagement	64.2140	< 0.78	22.0000	108.00
Count EW FSR	85.0900	< 1.24	24.0000	150.00
Count HK Hit	35.6410	< 0.21	24.0000	46.0000
Count HK Miss	15.0970	< 0.20	6.0000	27.0000

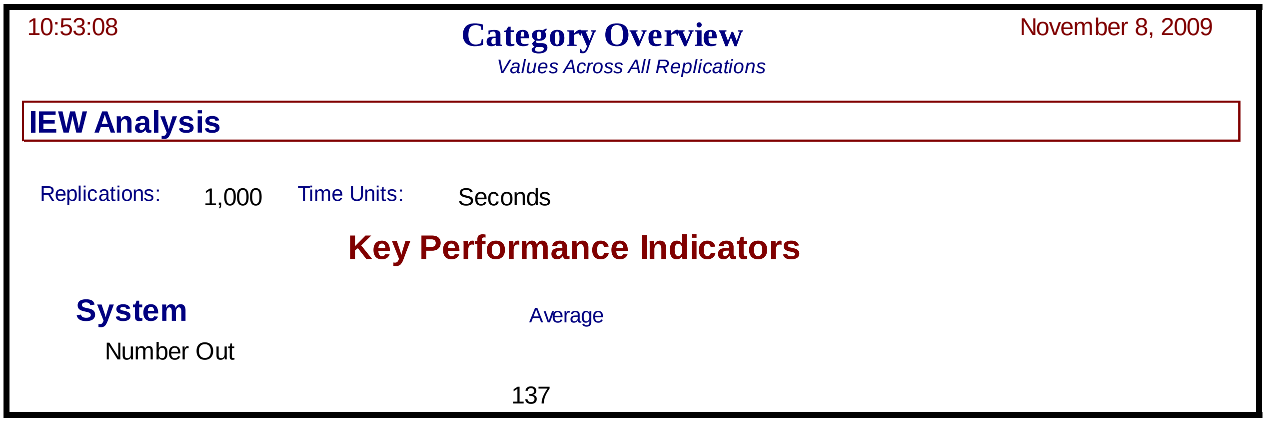
Time Persistent

Time Persistent	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Base FSR in System	0.2177	< 0.00	0.1193	0.3181	0.00	12.0000
Base FSR Wait time	0.00	< 0.00	0.00	0.00	0.00	0.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Base Pct Balk	0.6179	0.00	0.3380	0.7463
Base Pct Hit	0.7381	0.00	0.6220	0.8812

7. Integrated HITL 4 second Delay Case IEW



10:53:08

Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	137

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	47.8286	< 0.32	35.0027	68.0944	0.00	704.94

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	47.8286	< 0.32	35.0027	68.0944	0.00	704.94

Other

Number In

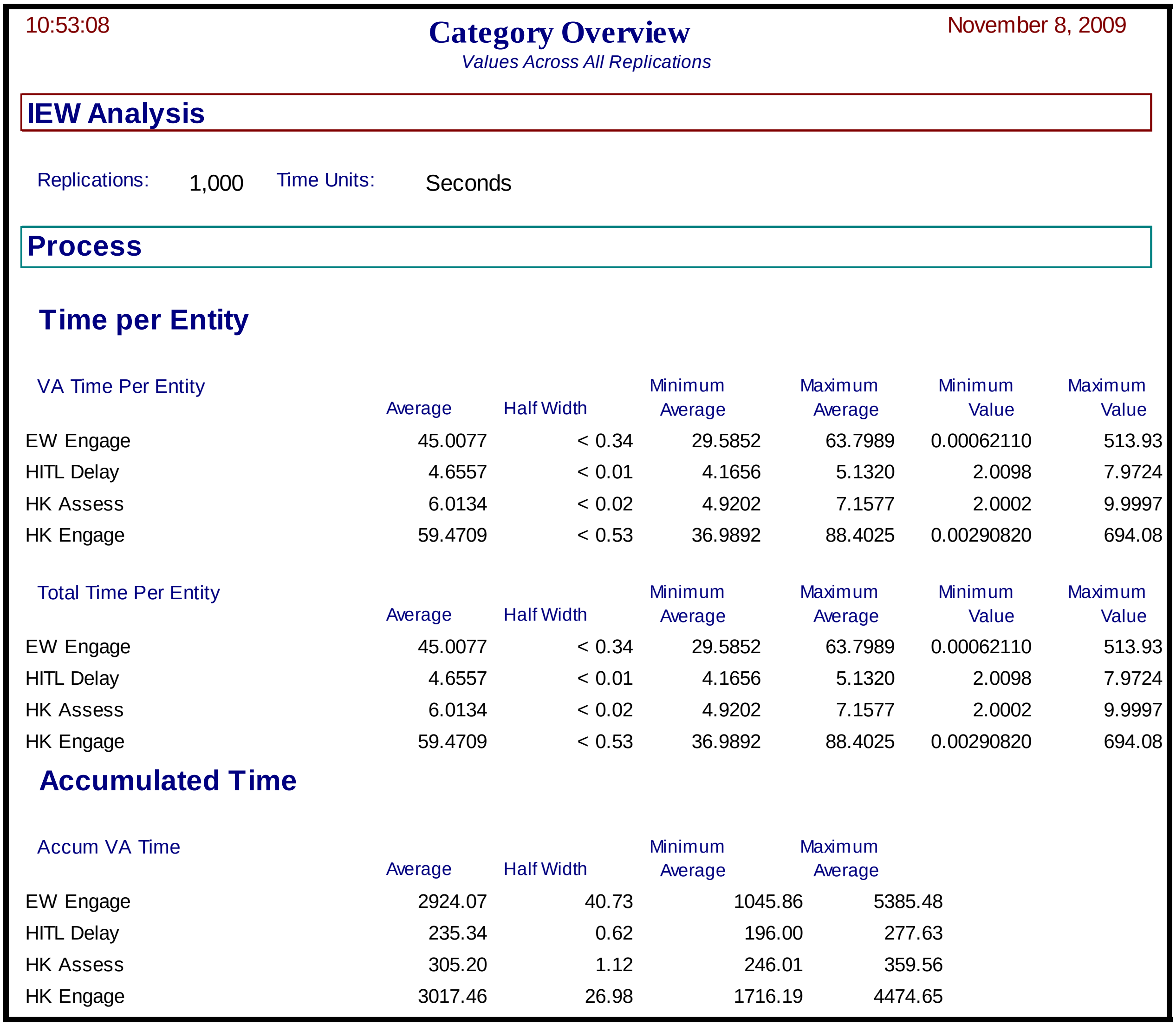
	Average	Half Width	Minimum Average	Maximum Average
FSR	150.19	1.26	93.0000	224.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
FSR	150.35	1.26	93.0000	224.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.2261	< 0.00	0.1343	0.3399	0.00	12.0000



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	45.0077	< 0.34	29.5852	63.7989	0.00062110	513.93
HITL Delay	4.6557	< 0.01	4.1656	5.1320	2.0098	7.9724
HK Assess	6.0134	< 0.02	4.9202	7.1577	2.0002	9.9997
HK Engage	59.4709	< 0.53	36.9892	88.4025	0.00290820	694.08

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	45.0077	< 0.34	29.5852	63.7989	0.00062110	513.93
HITL Delay	4.6557	< 0.01	4.1656	5.1320	2.0098	7.9724
HK Assess	6.0134	< 0.02	4.9202	7.1577	2.0002	9.9997
HK Engage	59.4709	< 0.53	36.9892	88.4025	0.00290820	694.08

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
EW Engage	2924.07	40.73	1045.86	5385.48
HITL Delay	235.34	0.62	196.00	277.63
HK Assess	305.20	1.12	246.01	359.56
HK Engage	3017.46	26.98	1716.19	4474.65

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
EW Engage	65.0490	0.78	28.0000	102.00
HITL Delay	50.5470	0.07	42.0000	57.0000
HK Assess	50.7340	0.07	41.0000	57.0000
HK Engage	50.5520	0.07	42.0000	57.0000

Number Out

	Average	Half Width	Minimum Average	Maximum Average
EW Engage	65.0040	0.78	27.0000	103.00
HITL Delay	50.5520	0.07	42.0000	57.0000
HK Assess	50.7540	0.07	41.0000	57.0000
HK Engage	50.7340	0.07	41.0000	57.0000

Queue

Other

Number Waiting

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

Usage

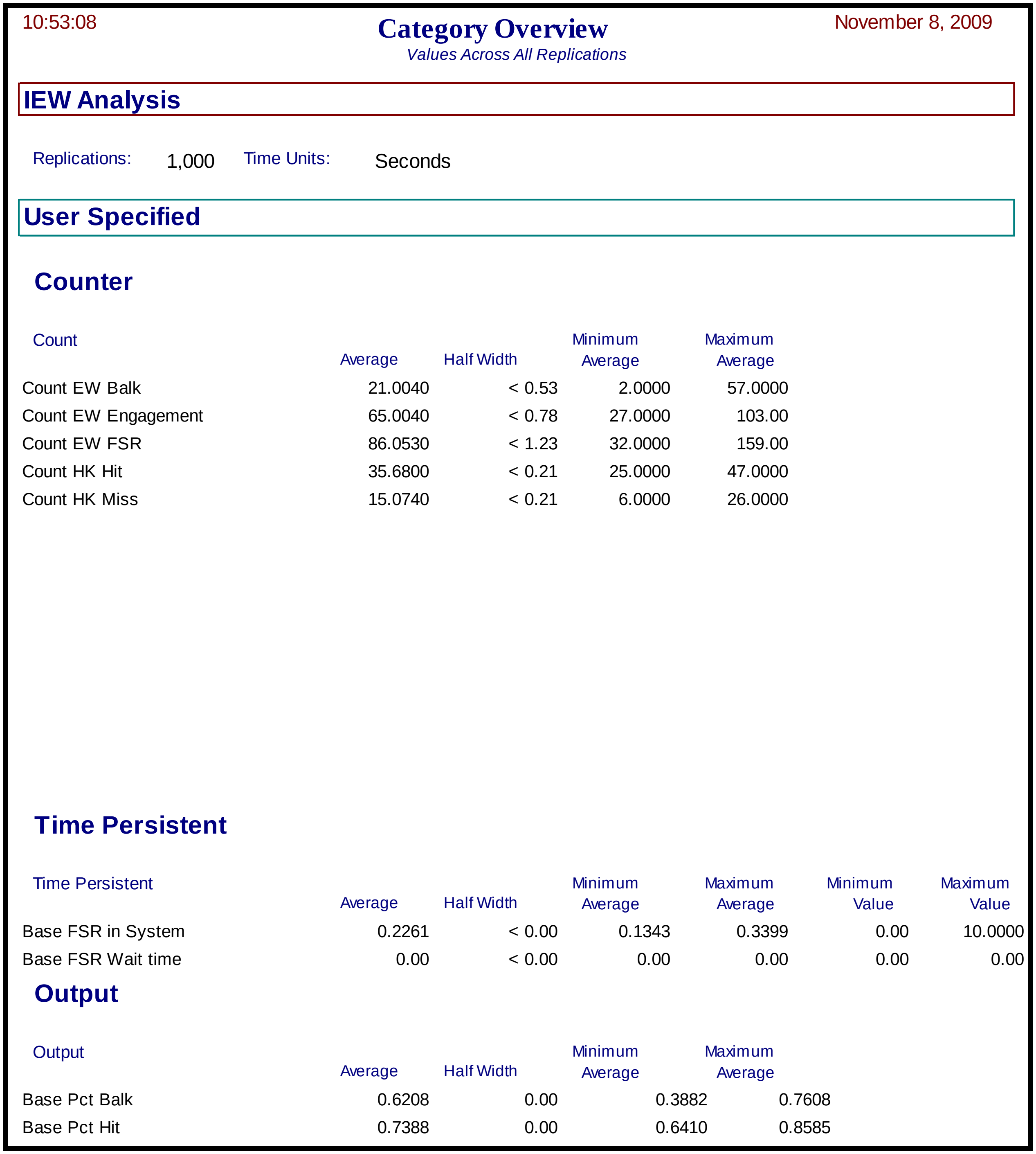
Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
HK System 2	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
System 1	0.7778	< 0.00	0.7778	0.7778	0.00	1.0000
System 2	0.7000	< 0.00	0.7000	0.7000	0.00	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Count EW Balk	21.0040	< 0.53	2.0000	57.0000
Count EW Engagement	65.0040	< 0.78	27.0000	103.00
Count EW FSR	86.0530	< 1.23	32.0000	159.00
Count HK Hit	35.6800	< 0.21	25.0000	47.0000
Count HK Miss	15.0740	< 0.21	6.0000	26.0000

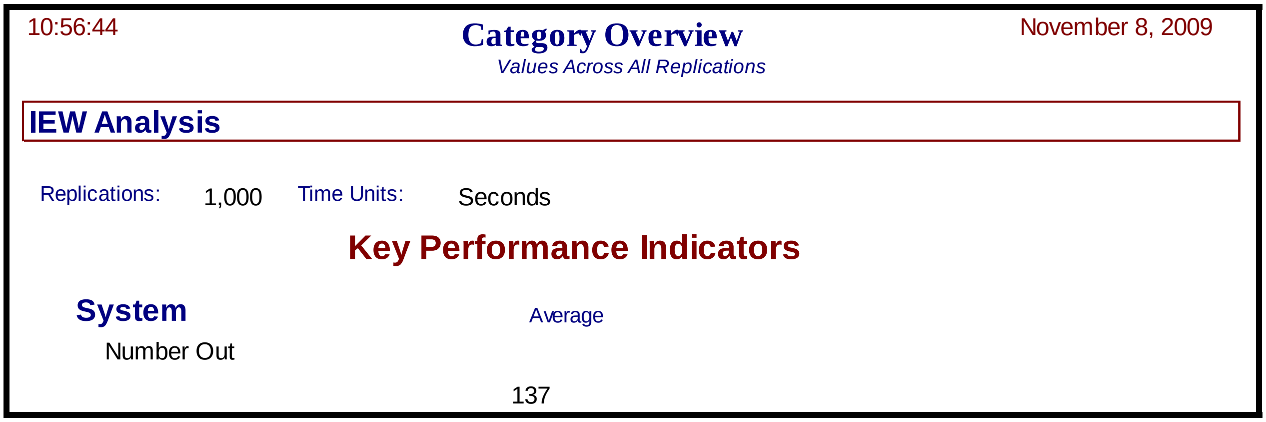
Time Persistent

Time Persistent	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Base FSR in System	0.2261	< 0.00	0.1343	0.3399	0.00	10.0000
Base FSR Wait time	0.00	< 0.00	0.00	0.00	0.00	0.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Base Pct Balk	0.6208	0.00	0.3882	0.7608
Base Pct Hit	0.7388	0.00	0.6410	0.8585

8. Integrated HITL 6 second Delay Case IEW



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Key Performance Indicators

System	Average
Number Out	
	137

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Category Overview

Values Across All Replications

IEW Analysis

Replications: 1,000 Time Units: Seconds

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	48.6843	< 0.32	33.3521	68.8363	0.00	758.03

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.00	< 0.00	0.00	0.00	0.00	0.00

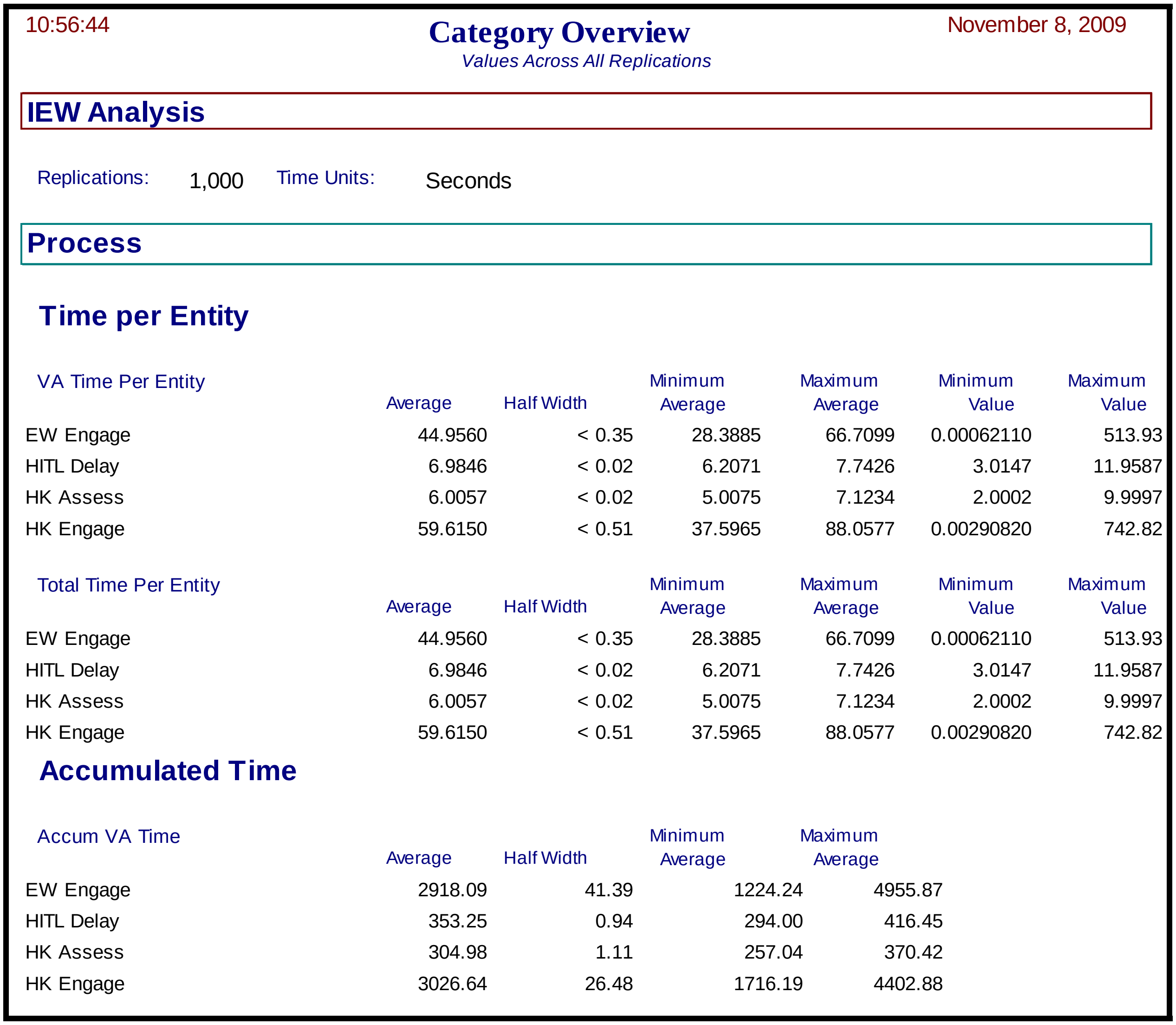
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	48.6843	< 0.32	33.3521	68.8363	0.00	758.03

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
FSR	150.33	1.27	93.0000	226.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
FSR	150.49	1.27	93.0000	226.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
FSR	0.2303	< 0.00	0.1378	0.3357	0.00	11.0000



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

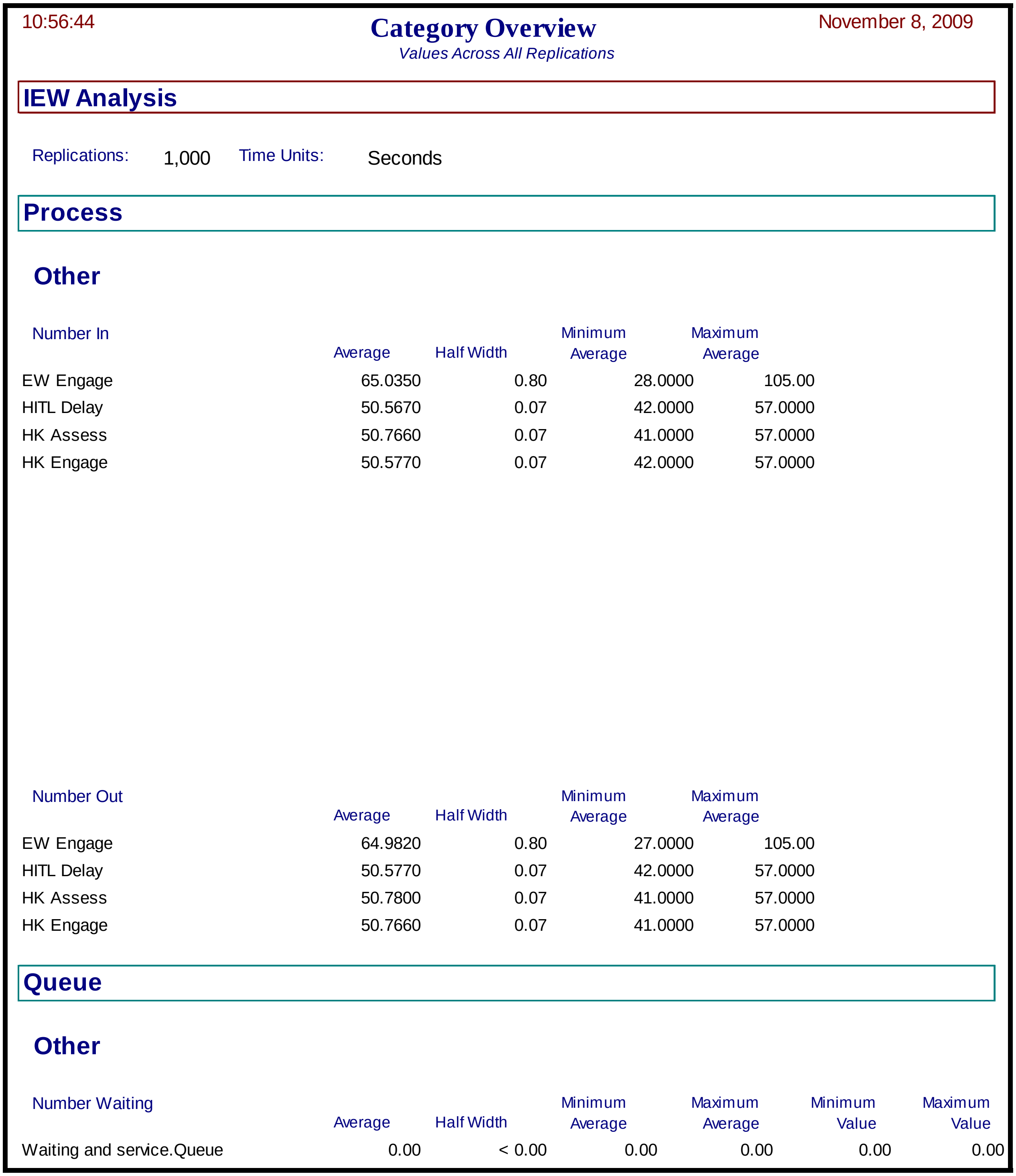
Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	44.9560	< 0.35	28.3885	66.7099	0.00062110	513.93
HITL Delay	6.9846	< 0.02	6.2071	7.7426	3.0147	11.9587
HK Assess	6.0057	< 0.02	5.0075	7.1234	2.0002	9.9997
HK Engage	59.6150	< 0.51	37.5965	88.0577	0.00290820	742.82

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
EW Engage	44.9560	< 0.35	28.3885	66.7099	0.00062110	513.93
HITL Delay	6.9846	< 0.02	6.2071	7.7426	3.0147	11.9587
HK Assess	6.0057	< 0.02	5.0075	7.1234	2.0002	9.9997
HK Engage	59.6150	< 0.51	37.5965	88.0577	0.00290820	742.82

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
EW Engage	2918.09	41.39	1224.24	4955.87
HITL Delay	353.25	0.94	294.00	416.45
HK Assess	304.98	1.11	257.04	370.42
HK Engage	3026.64	26.48	1716.19	4402.88



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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Process

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
EW Engage	65.0350	0.80	28.0000	105.00
HITL Delay	50.5670	0.07	42.0000	57.0000
HK Assess	50.7660	0.07	41.0000	57.0000
HK Engage	50.5770	0.07	42.0000	57.0000

Number Out

	Average	Half Width	Minimum Average	Maximum Average
EW Engage	64.9820	0.80	27.0000	105.00
HITL Delay	50.5770	0.07	42.0000	57.0000
HK Assess	50.7800	0.07	41.0000	57.0000
HK Engage	50.7660	0.07	41.0000	57.0000

Queue

Other

Number Waiting

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Waiting and service.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
HK System 2	0.00	< 0.00	0.00	0.00	0.00	0.00
System 1	0.00	< 0.00	0.00	0.00	0.00	0.00
System 2	0.00	< 0.00	0.00	0.00	0.00	0.00

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HK System 1	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
HK System 2	1.0000	< 0.00	1.0000	1.0000	1.0000	1.0000
System 1	0.7778	< 0.00	0.7778	0.7778	0.00	1.0000
System 2	0.7000	< 0.00	0.7000	0.7000	0.00	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
HK System 1	0.00	0.00	0.00	0.00
HK System 2	0.00	0.00	0.00	0.00
System 1	0.00	0.00	0.00	0.00
System 2	0.00	0.00	0.00	0.00

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Category Overview

Values Across All Replications

November 8, 2009

IEW Analysis

Replications: 1,000 Time Units: Seconds

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Count EW Balk	21.1820	< 0.53	2.0000	53.0000
Count EW Engagement	64.9820	< 0.80	27.0000	105.00
Count EW FSR	86.2170	< 1.25	33.0000	158.00
Count HK Hit	35.6670	< 0.21	27.0000	48.0000
Count HK Miss	15.1130	< 0.21	4.0000	25.0000

Time Persistent

Time Persistent	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Base FSR in System	0.2303	< 0.00	0.1378	0.3357	0.00	10.0000
Base FSR Wait time	0.00	< 0.00	0.00	0.00	0.00	0.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Base Pct Balk	0.6210	0.00	0.3882	0.7453
Base Pct Hit	0.7375	0.00	0.6346	0.8585

Appendix E – Team Introduction and Composition

The team is comprised of six students from the Naval Postgraduate School Masters of Science in Systems Engineering Cohort 311. The team consists of Mr. Matthew P. Artelt, Mr. Gerardo "Jerry" Gamboa and Mrs. Sarah E. Hentges from the Naval Air Warfare Center, Weapons Division, China Lake (NAWCWD-CL), Lieutenant Commander (LCDR) Nicholas E. Andrews from Carrier Strike Group (CSG) 12, Mr. Roscoe A. "Rocky" Smith from the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) and Mr. Dereck D. Wright from the Naval Surface Warfare Center, Corona Division (NSWCCD).

Mr. Artelt is an electronics engineer with the Weapons Electromagnetic Environmental Effects (E3) Branch at NAWCWD-CL. He is the E3 Integrated Product Team (IPT) lead for several major Naval weapons programs. For this project, he was the deputy program manager (PM), assistant scheduler, the assistant program manager for logistics (APML), a risk board member, and a researcher.

Mr. Gamboa is an electrical engineer with the Weapon Systems Analysis Branch at NAWCWD-CL. He is involved in infrared (IR) performance M&S for AIM-9X Sidewinder and Joint Air-to-Ground Missile (JAGM). For this project, he was the lead modeler, configuration manager, and a risk board member.

Mrs. Hentges is a computer scientist at NAWCWD-CL. At the start of this project she was a member of the flight software IPT for Tomahawk missile systems; however, she has recently transitioned to a branch head position within the Software Integration Modeling and Simulation (SIMS) Branch. For this project, she was the PM, a risk board member, and a researcher.

LCDR Andrews is an Information Professional Officer and P-3 Orion pilot in the United States Navy (USN). He is currently assigned as the communications officer (COMMO) for Carrier Strike Group 12 stationed at Norfolk Virginia. For this project, he was the principal for safety, a modeler, a risk board member, and a researcher, as well as being the primary interface to the stakeholders.

Mr. Smith is a systems engineer supporting Program Manager – Air (PMA) 280 and the Tomahawk Weapon System (TWS). He is a 23-year USN veteran and has 12 years of experience with Tomahawk. For this project, he was the risk manager, a risk board member, and a researcher.

Mr. Wright is a computer engineer and analyst with the shipboard reliability and maintenance group at NSWCCD, focusing on the AN/SPY-1 radar and MK99 Fire Control System (FCS). For this project he was the editor, scheduler, a risk board member, and a researcher.

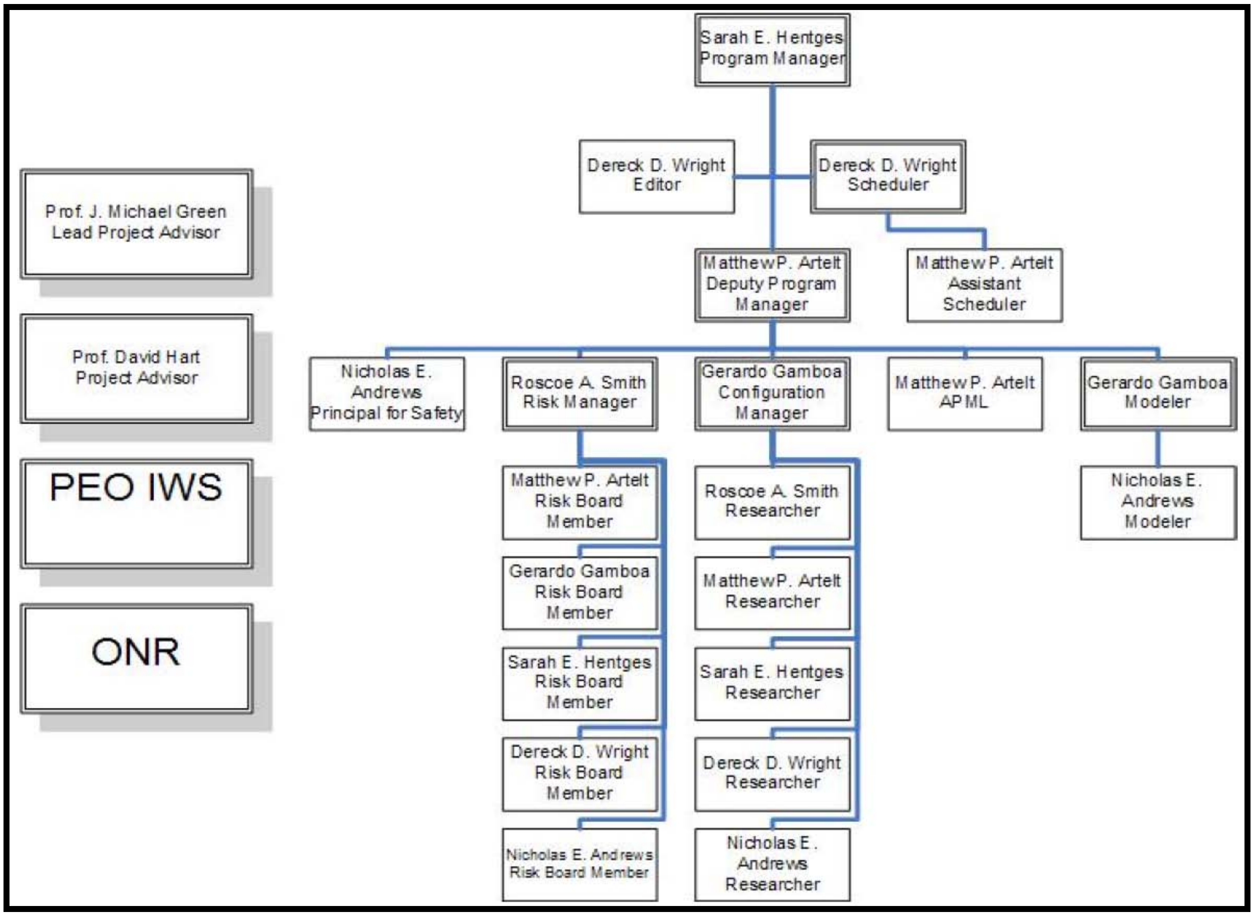

Figure 23: Team Hierarchy
This figure shows the hierarchy and task breakdown of the team.

Initial Distribution List

1. Dudley Knox Library, Code 52
Naval Post Graduate School
Monterey, California

2. Research Office, Code 09
Naval Post Graduate School
Monterey, California

3. John M. Green
Senior Lecturer
Naval Post Graduate School
Monterey, California

4. David A. Hart
Professor of Practice
Naval Post Graduate School
Monterey, California

5. CDR Susan Cerovsky
United States Navy
Naval Network Warfare Command
Norfolk, Virginia

6. Matthew Artelt
Naval Air Warfare Center
China Lake, California

7. Gerardo Gamboa
Naval Air Warfare Center
China Lake, California

8. Sarah Hentges
Naval Air Warfare Center
China Lake, California

9. Nicholas Andrews
United States Navy
Carrier Strike Group TWELVE
Norfolk, Virginia

10. Roscoe Smith
PMA - 280
Norfolk, Virginia

11. Dereck Wright
Naval Surface Warfare Center
Corona, California