NPS-FM-24-009

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BCA of Internet Connectivity for USS Abraham Lincoln (CVN-72)

December 2023

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Prepared for the Naval Postgraduate School, Monterey, CA 93943

The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

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ABSTRACT

Internet connectivity aboard U.S. Navy ships has been historically unreliable and slow, limiting both Quality of Work (QoW) and Quality of Life (QoL). USS Abraham Lincoln (ABE) is testing new advancements in internet technology (Starlink, 5G, and fiber) to close the bandwidth gap on ships. Our thesis aims to identify if having high-speed internet (HSI) aboard ABE, at sea and in-port, can provide a financial benefit to the Navy. We used peer-reviewed studies to determine the economic impact of HSI on the modern world, and the Net Present Value (NPV) method to calculate the value of having HSI for ABE over a 10-Year period. We concluded that HSI would provide a Net Benefit to ABE of $22,598,921 over a 10-Year period. This represents the monetary value of having improved QoW and QoL solely due to HSI. Even with all QoL benefits removed, HSI still provides a Net Benefit of $2,548,053. Our results point to the massive positive implications this could have for the Navy. We recommend further research be conducted into this field, and current policies be reviewed and modified for adoption of commercial HSI aboard U.S. Navy ships.

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ABOUT THE AUTHORS

LT Daniel Tsuji is a Submarine Warfare Officer. After attending Villanova University and graduating in the class of 2017 with a BS in Chemical Engineering, he commissioned through Officer Candidate School. Following completion of the Nuclear Power Training Pipeline he served as the Quality Assurance Officer and Assistant Engineer aboard the *USS West Virginia*, SSBN-736(B). After graduating from NPS, LT Tsuji will spend about three months TAD in Japan at CTF-74 qualifying as the Watch Officer for Theater Anti Submarine Warfare operations in the Pacific. From there, he will attend Submarine Officer Advanced Course in Groton, CT before his next tour at sea.

LT Marcus B. Padilla enlisted in the U.S. Navy in 2011 as a Nuclear Electrician's Mate. Following completion of the Enlisted Nuclear Power Training Pipeline he attended The Citadel in Charleston, SC through the STA-21 program, earning his BS in Civil Engineering. Following graduation, and the completion of the Officer's Nuclear Power Training Pipeline, he was stationed on the USS Ohio (Gold) SSGN-726 as the Reactor Control Assistant (RCA) and Assistant Operations Officer. Upon completion of his Junior Officer tour, LT Padilla was assigned to multiple Pre-Commission Units (PCU) in Groton, CT before attending the Naval Postgraduate School, where he earned his MBA in Financial Management. After graduating NPS, he will attend the Submarine Officer Advanced Course in Groton, CT before heading to his next submarine as a Department Head. LT Padilla is happily married to his wife of 12 years, and together they have four wonderful children.

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ACKNOWLEDGMENTS

We extend our sincere gratitude to our advisors, Dr. Nick Dew and Dr. Menichini, for their invaluable guidance and support throughout the thesis journey. Our deep appreciation goes to the dedicated team at NIWC Pacific, whose collaboration has been instrumental in enhancing Navy connectivity, and enabling a more efficient fleet. Special acknowledgment is due to CDR Kevin White for his leadership and passion in modernizing the USS Abraham Lincoln. His will and determination are directly improving the lives of sailors and their families aboard ABE. We want to highlight his crucial contributions and strategic insights that have significantly enhanced our research.

This endeavor has been a collective effort, and we acknowledge each individual and entity mentioned for their integral roles in advancing our mission to strengthen the Navy's capabilities, improve sailors' social well-being, and ultimately enhance the Navy's effectiveness as the most formidable fighting force on the planet.

LT Tsuji extends special thanks to his teammates for their diligence and expertise and his wife, LT Hannah Tsuji, for her undying patience and support.

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LIST OF ACRONYMS AND ABBREVIATIONS

5G	Fifth Generation
ABE	USS Abraham Lincoln (CVN-72)
ALT	Alternative
BCA	Business Case Analysis
BPI	Broadband Pricing Index
C2	Command and Control
CSO	Combat Systems Officer
CVN	Aircraft Carrier, Nuclear
DoD	Department of Defense
FWA	Fixed Wireless Access
GB	Gigabyte
Gbps	Gigabit per Second
IT	Information Technologies
LTE	Long-Term Evolution
MB	Megabyte
Mbps	Megabits per Second
NBER	National Bureau of Economic Research
NIPR	Non-Secure Internet Protocol Router
NIWC	Naval Information Warfare Center
NMCI	Navy-Marine Corps Intranet
NPV	Net Present Value
O&M	Operations and Maintenance
OFRP	Optimized Fleet Response Plan
OMB	Office of Management and Budget
PEO	Program Executive Office
QoL	Quality of Life
QoW	Quality of Work

RDT&E	Research, Development, Test, and Evaluation
SA	Sensitivity Analysis
SEA2	Sailor Edge Afloat and Ashore
SME	Small and Medium Enterprise
SWAA	Survey of Working Arrangements and Attitudes
U.S.	United States
VoIP	Voice Over Internet Protocol
VPN	Virtual Private Network
WTP	Willingness To Pay

EXECUTIVE SUMMARY

Internet connectivity aboard U.S. Navy ships has historically suffered from slow and unreliable systems, lagging significantly behind private sector standards. The advancements in fiber, cellular Fifth Generation (5G) internet and the emergence of commercial satellite systems, typified by Starlink, present a transformative opportunity for the Navy. Incorporating these new technologies not only facilitates the Navy's transition into a more modern paradigm, but also positions it as a seamlessly connected and formidable force, aligning with the technological progress inherent in today's digital landscape.

This thesis includes a Business Case Analysis (BCA) designed to analyze the financial implications of providing continuous, reliable high-speed internet access for the USS Abraham Lincoln (ABE, CVN-72) both in-port and at sea. The purpose is to determine whether supplying ABE with high-speed internet is financially viable for the Navy, and to quantify the benefits associated with having high-speed internet. Our analysis includes three business case alternatives, all of which provide ABE with continuous high-speed internet:

Alternative 1: Starlink at sea, Cox fiber in-port
Alternative 2: Starlink at sea, 5G/LTE cellular in-port
Alternative 3: Starlink only, both at sea and in-port

Our financial model employs Net Present Value (NPV) analysis to assess the net benefits associated with the business case alternatives, aiming to identify the scenario that delivers optimal value to the Navy. NPV—a financial metric discounting cash flows throughout a project's lifespan—serves as a pivotal tool for evaluating profitability. While traditionally applied to projects with measurable monetary gains, NPVs adaptability extends to scenarios featuring intangible benefits as well. To calculate NPV, primary costs of equipment and service plans for each alternative were identified and annualized, then contrasted with the expected monetized benefits due to an increase in Quality of Life (QoL) and Quality of Work (QoW). Our analysis examined the net benefit cash flows over a ten-year period, which was chosen to balance the need for a sufficiently long timeframe—to capture the effects of recurring costs—with the recognition of the advancements in telecommunications technology. The resulting NPV values facilitate a measurable comparison between alternatives, aiding in the selection of the most optimal business case for ABE.

QoL is the monetary benefit attributed to sailors and the Navy for having access to high-speed internet while underway; factors influencing QoL solely focus on the morale and welfare of the sailors. QoL benefits are primarily derived from an individual's willingness to pay (WTP) for internet service. In the absence of actual WTP survey data, we utilized peer-reviewed studies to estimate an individual's WTP for high-speed internet. Our research found six articles and reports that assigned a WTP to specific internet speeds and qualities. We formulated a comprehensive weighted average system to balance these articles, based on study size, scope, significance and age, to deliver a single monthly WTP value for an individual, based on internet speed. Table 1 summarizes these WTP values for four different internet speeds, 10, 25, 50 and 75 Mbps.

Table 1. Individual WTP for Internet at Varying Speeds

Speed (Mbps)	10	Weight	Speed (Mbps)	25	Weight
Bandwidth Price	$ 20.07	0.3	Bandwidth Price	$ 50.16	0.3
Baseline Price	$ 88.28	0.7	Baseline Price	$ 88.28	0.6
Added Speed	0		Added Speed	$ 22.02	0.1
Monthly Price	$ 67.82	1	Monthly Price	$ 70.22	1

Speed (Mbps)	50	Weight	Speed (Mbps)	75	Weight
Bandwidth Price	$ 100.33	0.3	Bandwidth Price	$ 150.49	0.3
Baseline Price	$ 88.28	0.5	Baseline Price	$ 88.28	0.4
Added Speed	$ 24.25	0.2	Added Speed	$ 21.13	0.3
Monthly Price	$ 79.09	1	Monthly Price	$ 86.80	1

QoW is the monetized benefit attributed to sailors and the Navy for having increased work productivity and efficiency, due to high-speed internet. Unlike QoL, the QoW benefit is applied both at sea and in-port, and is not affected by variations in internet speed – the research only highlighted the distinction between having high-speed internet or not. To quantify the monetary benefit of QoW, peer-reviewed studies were used to determine an average increase in productivity in the workplace, due to the use of high-speed internet. These values were then given different weightings based on age, scope, and size of the study. Once a final value was determined, it was used to determine the man-hour savings per month for those sailors that use internet for work. This value corresponds to the monetized QoW benefit the DoD receives for sailors completing certain jobs faster, solely due to high-speed internet. Our research concluded that high-speed internet would increase productivity by 14.01% leading to a monthly QoW benefit for ABE of $76,774 per month. Table 2 summarizes the annualized QoL and QoW benefits ABE would receive for having high-speed internet available.

Table 2. Annualized QoL and QoW Benefits

Internet Speed	**10 Mbps**	**25 Mbps**	**50 Mbps**	**75 Mbps**
QoL Benefit	$2,174,199	$2,251,252	$2,535,577	$2,782,818
QoW Benefit	$921,283	$921,283	$921,283	$921,283
ANNUAL BENEFITS	$3,095,482	$3,172,535	$3,456,860	$3,704,101

After all costs and benefits were determined, the NPV was calculated for each alternative, using a real discount rate of 1.5%. Alternative 2 (ALT2) with T-Mobile had the highest NPV but was excluded from the results because an actual quote could not be obtained. This led to ALT1 being the optimal choice for ABE, due to it having the highest NPV. Table 3 compares the NPV results for all alternatives and Table 4 summarizes the necessary expenses for ALT1.

Table 3. Summary of NPV Results

	ALT1	**ALT2 Verizon**	**ALT2 T-Mobile**	**ALT3**
NPV	***$22,598,921***	$22,481,108	$22,620,737	$18,541,160

Table 4. Summary of ALT1 Expenses

Expense	**Amount ($)**
Starlink Subscription (per month/per terminal)	30,000.00
Cox Subscription (per month)	2,000.00
Starlink Terminal Hardware (per unit)	6,140.00

The NPV for ALT1 of $22,598,921, represents the total benefit the Navy receives for implementing Starlink internet at sea, and Cox fiber in-port, over a ten-year period. This accounts for inflation and represents the monetary value for ALT1 in present day dollars, with all future cash flows discounted to June 2023 dollars. We conducted additional analysis of ALT1, excluding the QoL benefits entirely, to determine if ALT1 would still be viable with only QoW benefits. The outcome reveals a positive NPV of $2,548,053, highlighting the robust financial viability of this alternative, even without applying the QoL benefits.

These findings underscore the substantial positive implications that the recommended alternative (ALT1) could offer to the Navy. It is essential to emphasize the conservative nature of our results, indicating that the actual value of ALT1 is likely higher than our calculated NPV. Additionally, qualitative benefits, such as the redundant utility of Starlink for classified military applications, which would enhance wartime decision-making and lethality, were not considered in our analysis. Moreover, the potential impact on Navy retention rates, stemming from improved connectivity for sailors to stay in touch with their families while underway, was not factored into our calculations. In essence, our thesis illuminates the considerable financial advantages of providing continuous high-speed internet to the USS Abraham Lincoln, necessitating further research in this domain. We strongly recommend that additional research be undertaken, accompanied by a thorough review and potential modification of current policies to facilitate the adoption of commercial high-speed internet aboard U.S. Navy ships.

I. INTRODUCTION

This thesis is a Business Case Analysis (BCA) examining the financial costs of maintaining continuous and reliable internet access for USS Abraham Lincoln (ABE, CVN-72) both in-port and at sea. The three main methods of connectivity analyzed were Cox pier side fiber internet, Fifth Generation or Long-Term Evolution (5G/LTE) cellular internet and Starlink commercial satellite internet. These financial costs were compared with the estimated monetized benefits of Sailors having improved Quality of Work (QoW) and Quality of Life (QoL) due to the availability of high-speed internet at sea, to calculate an overall Net Present Value (NPV). This thesis serves as financial proof of concept to encourage further research and analysis into this field, to enable a more productive, efficient and connected naval fleet.

A. PURPOSE

This BCA provides decision makers from Naval Information Warfare Center (NIWC) Pacific, Program Executive Office (PEO) Digital, and other Department of Defense (DoD) organizations with a spreadsheet model and the information necessary to make better informed decisions related to shipboard internet connectivity. The BCA is designed to quantify the costs and benefits of maintaining continuous internet connectivity aboard ABE to determine the network structure with the most residual benefits after costs, or highest net benefit. For the purposes of this study, Cox Fiber and 5G/LTE cellular internet are used in-port only, whereas Starlink satellite internet is used both at sea and in-port.

B. PROBLEM STATEMENT

Internet connectivity aboard U.S. Navy ships via traditional military satellite systems is historically unreliable and slow. These satellite systems are typically reserved for military purposes only (QoW) leaving very little room for sailors' personal or leisure access (QoL). A significant amount of sailors' work needs to be accomplished over the internet; therefore, the government computers on the ship are primarily used for work purposes only, and very rarely – if ever – used for leisure. Additionally, most U.S. Navy ships do not have Wi-Fi access aboard, for sailors' leisure. Sailors must bring with them all desired digital entertainment content before the ship leaves port.

Internet connectivity in-port is also well below standards for today's interconnected society. Most U.S. Navy ships have limited bandwidth and computer access, even when moored to the pier for a maintenance availability. Anecdotal evidence suggests computer access and low bandwidth may seriously hamper productivity in shipyard availabilities by making it difficult for sailors and shipyard workers to accomplish their work in a timely manner.

New advances in technology and connectivity have opened the door to potential solutions for the Navy; most notably, Starlink commercial satellite internet and 5G/LTE cellular internet. Our BCA aims to answer the following questions with respect to internet connectivity aboard CVN-72:

C. RESEARCH QUESTIONS

(1) Is there a net benefit to supplying high-speed internet to ABE continuously, both at sea and in-port?

(2) Which alternative, or combination of connectivity methods, attributes the highest net benefit to ABE?

(3) What primary findings from this study can be applied to further internet connectivity research for other U.S. Navy ship platforms?

D. BACKGROUND AND CONTEXT

1. Current Connectivity Aboard CVN-72

Current Non-secure Internet Protocol Router (NIPR) networks aboard CVN-72 do not meet the ship's unclassified traffic needs (K. White, email to authors, June 11, 2023). Complaints of insufficient bandwidth to serve both tasks associated with sailors' official duties (i.e., maintaining their service records) and maintain morale (i.e., communicating with family ashore) without increased latency and further degraded network performance are common. In response to this problem, CVN-72 has begun aggressive testing of its own data usage rates and the value thereof.

In December 2022, CVN-72 completed at-sea Wi-Fi testing using Starlink satellite internet terminals. The ship created a secure, standalone Wi-Fi network and data traffic control system to provide commercial internet access to the crew. This network provided sailors access to social media and entertainment services including Facebook and Netflix, while also enabling the possibility of future use for military applications. Certain unclassified tasks that require internet connectivity were able to be accomplished on the Wi-Fi network, much faster than using the traditional military NIPR network. In one instance, the ship uploaded dental files for use in fabricating a custom crown for a servicemember: completing the task 500% faster than using the traditional NIPR network. With good initial results, the ship demonstrated that the use of commercial internet using Starlink may have potential benefits that need to be explored further.

2. Fifth Generation Wireless

5G is the cutting edge in communications technology, providing benefits to bandwidth, signal speed, device capacity, and connection quality. 5G infrastructure maintains the flexibility and versatility of a wireless network while providing speed enhancements of 100 times that of 4G LTE, crucial to workplace efficiency (Intel Corp, n.d.). Latency, the time data takes to travel from emitter to receiver and make the return trip, drops to less than 5 milliseconds with this technology (Intel Corp, n.d.). With such speeds, human processing time becomes the slowest component of a remote-control device. In addition to these improvements, 5G can support more than 1000 times the number of devices on a single network than LTE (Intel Corp, n.d.). This superior capacity provides 5G connected devices the network speeds they need to operate as fast as possible. The final benefit 5G offers its users is bandwidth; a 5G network can process more total data per second than older technology (Intel Corp, n.d.). A commercial 5G/LTE signal received aboard the ship through an antenna known as a “Cradlepoint” is a wireless option to provide internet connectivity in port.

3. Starlink

Starlink is a constellation of low orbit satellites produced by the company SpaceX to provide internet access to underserved parts of world. The project began in 2015 and launched its first set of satellites in 2018 (Duan et al., 2021). Aiming for a total of 12,000 satellites, the project is intended to provide space-based internet with global coverage. SpaceX boasts up to 5TB of data per month with latency under 99ms and speeds up to 220 Megabits per second (Mbps) (downloads) and 25Mbps (uploads) (Starlink, n.d.). These parameters feasibly support network taxing user activities such as streaming and video calls. This technology provides another possible method of connectivity for a ship, both in port and at sea.

E. PROJECT INITIATIVE

The current state of wireless services aboard CVN-72 is untenable for a crew living in 2023. The rise in demand for services, both for unofficial and official purposes, has outpaced ship's capacity in terms of both bandwidth and latency. The widespread use of personal applications such as video calls and video streaming have driven demand for connectivity to ease the rigor of deployments far from the continental U.S. In addition, government furnished websites that serve sailors' official records and require them to have internet access to fulfill their duties in both medical and administrative capacities have only increased in scope and number.

To fulfill this increased demand and serve the needs of the Navy, ship's company have implemented a guest wireless network. This network uses Cox fiber, 5G/LTE Cradlepoints furnished by the NIWC–Pacific, and Starlink connections while in port and connects to Starlink satellites at sea to provide internet access to its in-hull networks. Figure 1 displays the current infrastructure and signal flow paths for ABE's standalone network. ABE conducted a test, called "Sailor Edge Afloat and Ashore (SEA2)," that demonstrated the feasibility, reliability, and applications of this unclassified network both in-port and at sea using all three connection types. Data collected from this test informs the command of what uses the crew finds for this network, network security, and statistics concerning capacity, bandwidth, connection quality, and latency. Following this test, the ship has maintained the network aboard for multiple months in port. With other carriers copying CVN-72's network infrastructure, the Navy sees the potential to transition this technology from a single CVN's innovation to a standardized system aboard ships of multiple hull types across the fleet.

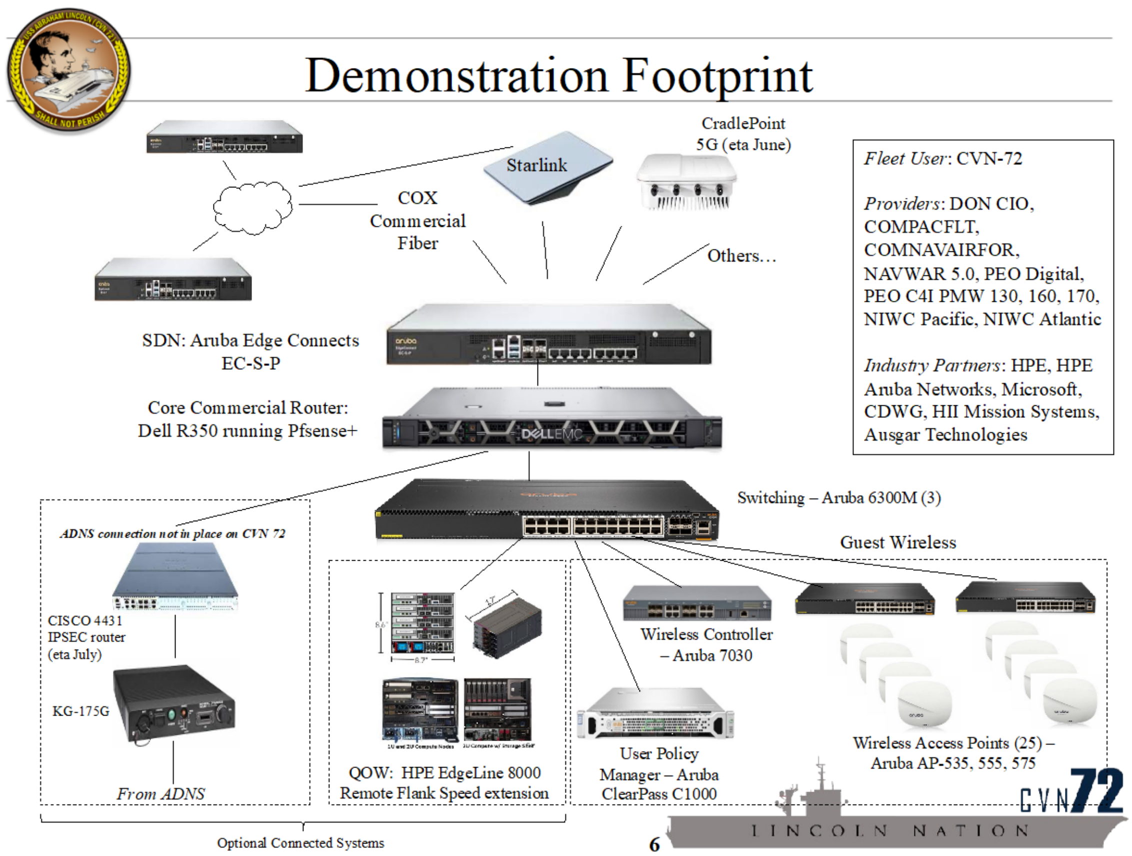

Figure 1. CVN-72 Private Wi-Fi Network Infrastructure. Source: K. White (email to authors, June 11, 2023).

This report intends to provide decision makers with an analysis of the costs and benefits of the network aboard CVN-72 to justify its costs. A comparison of the particular costs and benefits associated with connections using Cox fiber, 5G Cradlepoint, and Starlink is intended to identify which technologies the Navy should consider implementing. An analysis of the benefits to both QoW and QoL is intended to determine the potential value of the network, to be compared with its costs.

One stakeholder of this study is NIWC-Pacific. NIWC-Pacific is a research facility located in San Diego dedicated to the development of Information Technologies (IT) that enable the warfighter to efficiently accomplish their operational tasks. Their work involves cybersecurity, Command and Control systems, wireless connectivity solutions, satellite and space technologies, and naval applications of quantum technology.

Program Executive Office for Digital and Enterprise Services (PEO Digital) is the ultimate stakeholder for this research. Described as "the Department of the Navy's enterprise-wide information technology acquisition agent," PEO Digital works to enhance the IT services sailors and marines use to accomplish their missions (PEO Digital, n.d.). Balancing delivery speed, metric-driven performance, and conscientious use of tax-payer funds, they manage eight Digital Portfolios delivering the following services: End User, Digital Workplace, Platform Application, Public Safety, Infrastructure, Cybersecurity and Operational, and Special IT Services (PEO Digital, n.d.).

F. ORGANIZATION OF STUDY

The five chapters of this thesis are organized as follows. Chapter II provides the background assembled through a review of previous research. The constraints, assumptions, and method of analysis are all discussed in Chapter III. Chapter IV examines the alternatives, their estimated life cycle costs, and the net present value results. Chapter V provides our ultimate conclusions, recommended policy and technology options, and areas left for future studies along with our closing remarks.

II. LITERATURE REVIEW

This chapter briefly discusses previous research from six studies concerning the willingness to pay (WTP) for internet services, six studies concerning the potential work efficiency benefits to CVN-72's crew with internet access, and one paper examining the share of benefits a supplier retains from a business innovation. This literature supports the initiative to provide internet access to sailors by providing the evidence necessary to monetize the benefits thereof. The final paper included in this chapter provides some economic theory with which to evaluate the reasonableness of the results we discuss in Chapter IV. Overall, these findings provide substantial encouragement to analyze the costs and potential benefits of internet services aboard CVN-72.

A. MONETIZING QUALITY OF LIFE BENEFITS THROUGH WILLINGNESS TO PAY

Several sources provide estimates of consumers' WTP for internet services in units of dollar per Mbps download speed. A statewide survey of 1,423 people conducted in Spring 2017 provided a selection of hypothetical internet service packages differing across factors such as speed and price to respondents in order to extrapolate WTP (Lai et al., 2020). This survey found WTP was between $0.06 and $0.10 per Mbps (Lai et al., 2020). USTELECOM's 2022 Broadband Pricing Index used data from required reports by broadband service providers with almost 10,400 plan observations "statistically constructed to represent an accurate profile of a mix of U.S. broadband prices" (Menko, 2022). The index found that 90% of consumers purchase 98 Mbps at a monthly price of $45.97, with the fastest plan providing 259 Mbps at a monthly price of $73.55 (Menko, 2022). The use of these plans is discussed further in Chapter III. Another paper provides conclusions from two national surveys conducted on multiple metrics including bandwidth (both upload and download speeds), price, and data caps, with one survey including latency (Liu et al., 2018). These survey results indicate the mean speed/price pair is 149.56 Mbps for $64.84 per month (Liu et al., 2018). Another source states an average internet monthly price of $44 (Carare et al., 2015). The use of this number is explained in Chapter III. A paper reporting findings from a survey of more than 4700 households from southern Ontario, Canada, found the mean WTP values per MBPS of rural and urban respondents were $20.85 Canadian and $5.58 Canadian, respectively (Worden and Hambly, 2022). The use of these numbers and conversion to U.S. currency are discussed in Chapter III.

Liu, Prince, and Wallsten's work mentioned above, and one additional article provide further WTP data than just a per Mbps basis. Liu, Prince, and Wallsten list several price rates in $/ Mbps increase between two threshold speeds; for example, they find that consumers exhibit a WTP of between $2.34 and $2.83 per Mbps increase to improve their speed within the range of four and 10 Mbps (Liu et al., 2017). Authors Rabbani, Bogulski, Eswaran, and Hayes published results of a conjoint analysis using data from a survey of 5,200 respondents across several U.S. states: $1.13 per Mbps of speed improvement and $45.52 per month for improved connection quality (Rabbani et al., 2023). These numbers are also useful in estimating the WTP for internet access aboard CVN-72.

Sources such as these provide context for such estimations, which in turn enable the monetization of QoL benefits from internet access afloat. By estimating the WTP of a sailor for such access, we will estimate the equivalent monetary benefit of the uses that sailor finds for it, such as communicating with family members using Facetime or Facebook, streaming video through Netflix, or surfing the internet. The process used in this paper to provide such estimates is thoroughly discussed in Chapter III.

Despite the fact that none of these studies examine the WTP of sailors deployed on CVN's (indeed, we are unaware that any such study has been published), we expect to use these published figures as conservative estimates for the WTP of CVN-72's crew. This expectation arises in part from the isolation sailors experience at sea; cut off from family, friends, and the world in a way that civilians are not, we expect that sailors would likely exhibit higher WTP than the literature suggests. In addition, many of CVN-72's sailors are younger and have grown up with internet technology, which means they have a higher dependency on high-speed, high-quality internet than the populations of these studies. Again, this difference would suggest a higher WTP for these sailors. Ideally, our research would use WTP figures directly from the sailors, but in the absence of such direct measures we will use these data as indicators.

B. MONETIZING QUALITY OF WORK BENEFITS THROUGH EFFICIENCY GAINS

Another type of benefit provided to the Navy and its sailors from internet access takes the form of efficiency improvements in the workplace. These gains are estimated in the literature in a variety of ways. One paper provides an analysis of the authors' Survey of Working Arrangements and Attitudes (SWAA). The SWAA, a monthly survey running from May 2020 through the time of publication, gives data from 43,000 Americans of working age making at least $20,000 in 2019 on working arrangements, internet access quality, productivity, and other aspects of working from home (Barrero et al., 2021). The paper concludes that high-quality, reliable internet access at home would provide an estimated 1.1% rise in productivity (Barrero et al., 2021). A second paper provides an estimate of productivity gains from improved internet connectivity at 10% from the results of a micro-study of New Zealand firms (Grimes et al., 2009). A third analyzes 799 firms over the period from 1998 to 2004 representative of small and medium enterprises in Italy and finds that efficiency gains of 20.40% may be expected (Colombo et al., 2013). Such gains are useful when estimating the benefit to work aboard CVN-72.

Additional studies provide further evidence. One discusses 20% wage growth from 1995 to 2000 across 2,743 firms that implemented internet services (Forman et al., 2012). Another examines micro and small firms in Peru using data from 2011, 2012, and 2013 surveys of such businesses in eight Peruvian municipalities and concludes that "internet adoption leads to firm-level productivity increases of 25% on average" (Viollaz, 2018). Finally, Berschek and Niebel in their paper use a data set of 2,143 German firms in the year 2014 to conclude that for every one percent increase in the employee share of mobile internet access, the average firm will enjoy 0.2% higher labor productivity (Bertschek and Niebel, 2016). A detailed discussion of the use of these metrics is provided in Chapter III.

Again, the issue arises that none of these values are directly measured from sailors on a CVN and thus only indirectly apply to our project. This difficulty is overcome in a similar way as described for WTP; without direct evidence, we are using these figures as indicators of the working benefits sailors will likely enjoy with internet access. Just as their younger age and greater familiarity and dependence on internet technology leads us to expect higher WTP values for sailors compared with the populations examined in the literature, we will use the metrics for QOL benefits as conservative estimates when applied to sailors aboard CVN-72.

C. SCHUMPETERIAN PROFITS IN THE AMERICAN ECONOMY: THEORY AND MEASUREMENT

In his paper, "Schumpeterian Profits in the American Economy: Theory and Measurement," Dr. William D. Nordhaus examines the relationship between innovation and Schumpeterian profits. Schumpeterian profits are defined as "those profits that arise when firms are able to appropriate returns from innovative activity" (Nordhaus, 2004). Essentially, when a firm produces an innovation that reduces the cost of generating an output, some of the reduction in cost is captured by the innovating firm as new profits; the new price of the output that the consumer pays does not drop as much as the cost reduction provided by the innovation. A producer cannot charge the same price for a cheaper product, but they do enjoy additional profits following an innovation for a limited time. Schumpeterian profits are the difference between the new price and the new cost of production. These profits tend to decline over time in general because additional competition for the inciting innovation arises in various ways, such as patent expiration, competing innovations, new competing goods or services that serve the same need, and loss of first mover advantages (Nordhaus, 2004). Furthermore, Schumpeterian profits tend to be a low ratio of the value of an innovation because some of that value is non-capturable; for example, the introduction of faster printers to an office result in time savings that cannot be easily translated into additional profits for the printer manufacturer.

Nordhaus concludes that Schumpeterian profits are "about 2.2 percent of the total surplus from innovation" (Nordhaus, 2004). This small ratio results from two primary factors: the initial ability of an innovator to capture the value of their work in profits is low (about 7 percent), and it depreciates quickly (Nordhaus estimates a rate of 20 percent each year) (Nordhaus, 2004). While he admits that the rate seems low in the face of the pace of American innovation, he points out that profits remained in line with the cost of capital for the latter half of the 20th century (Nordhaus, 2004). This relationship suggests that profits are difficult to generate in the hyper-competitive landscape of the American economy, which would also support his findings on the meager nature of Schumpeterian profits.

This relationship is key to our research because it suggests that the value generated by the innovations in information technology are almost all retained by the consumer, who in our case is the CVN-72 sailor. Using the internet access provided by innovations like 5G and Starlink technology, the user would experience most of the value, while the companies providing such access in exchange for Navy funding would see a relatively small share in the value converted to profits. Ultimately, Nordhaus' work provides a solid foundation to assume the benefits of providing internet access to sailors probably far outweigh the costs.

D. SUMMARY

The literature discussed in this chapter provides the data necessary to perform our BCA and provided useful expectations for its results. By estimating the WTP for internet services for sailors aboard CVN-72, the broad range of qualitative benefits those sailors enjoy including communications with family, and entertainment may be monetized in a relatively simple manner. The estimates of work productivity gains offer another source of potential benefits to the Navy from the implementation of internet access for these sailors. Finally, the examination of Schumpeterian innovation theory provides a convenient way to examine the validity of the BCA's results: we expect the benefits to outweigh the costs of internet access, especially in the case of Starlink, given the typical amount of value captured by an innovative service's price. However, the literature varies in the details of how these estimates were calculated and occurred across many different demographics in terms of time and geography, with none directly examining sailors aboard a USN Aircraft Carrier. This report provides an analysis tailored to the situation aboard CVN-72 that compares the costs and benefits of internet access aboard the ship.

III. METHODOLOGY AND APPROACH

This chapter discusses the financial methods, data sources, and assumptions used to compute the 10-year Net Present Value (NPV) for three different alternatives, all of which provide ABE with continuous internet connectivity at sea and in-port.

A. BUSINESS CASE ANALYSIS OVERVIEW

This BCA incorporated a financial model using Microsoft Excel that can be used for ABE and other U.S. Navy surface ships to estimate the costs and benefits of different internet connectivity methods. We modeled the costs associated with all three methods using carrier provided data, as well as an estimate of the monetized benefits associated with having high-speed internet available to sailors at sea and in-port. Additionally, we did not include the costs of creating a standalone Wi-Fi network for ABE, since it was already in place, and therefore a sunk cost. The three alternatives listed below are considered in this analysis.

Alternative 1: Starlink at sea, Cox fiber in-port
Alternative 2: Starlink at sea, 5G/LTE cellular in-port
Alternative 3: Starlink only, both at sea and in-port

While compiling cost estimates is straightforward and mostly objective, monetizing the benefits the Navy realizes for sailors having access to high-speed internet is not; it can be very subjective. The following section discusses our method for identifying these benefits and assigning a dollar value to their worth, as well as our process for quantifying the net benefit utilizing the NPV method.

B. ANALYSIS METHODOLOGY

Our financial model used the basic principles of NPV analysis to compare the net benefits of each of the three business case alternatives, to determine a best-case scenario that provides the most value to the Navy. NPV is a financial metric that discounts cash flows over the lifespan of a project, to evaluate its profitability (Brealey et al., 2020). In the comparison of multiple projects or alternatives, the one with the highest NPV is deemed the optimal choice. It is essential to clarify that our NPV analysis doesn't directly signify a monetary gain for the Navy; rather, it serves as a metric to quantify the overall benefit. While conventionally applied to projects with measurable monetary gains, NPV's adaptability extends to scenarios featuring more intangible benefits as well. In such instances, NPV helps to evaluate the overall value proposition, by considering factors beyond explicit cash inflows. This process allows for a measurable comparison between alternatives, to select the most optimal business case for ABE.

To calculate NPV, we first identified the primary costs of the equipment and service plans associated with each alternative. Our process for acquiring this data is discussed further in the Data Collection section. Non-recurring, upfront costs were placed in year zero, and the monthly costs were annualized to a single value for each of the 10 years in the analysis. Next, we applied the expected monetized benefits – this process is explained in detail in the assumptions section – to compare with the expected costs each year. The quantitative benefits were separated into two categories: QoL and QoW. QoL is the monetary benefit attributed to sailors and the Navy for having access to the internet while underway; factors influencing QoL solely focus on the morale and welfare of the sailors. QoL is attributed to things such as media streaming, news, social media, and the ability to make video calls back home to family members. All these factors directly impact a sailor's mental and spiritual well-being. QoL is primarily derived from an individual's WTP for the service. WTP provides an aggregate measure of what someone is willing to forego, to obtain a given benefit (Office of Management and Budget [OMB], 1992) In general, the higher the WTP for a service, the more valuable it is to that individual. The most accurate means of determining WTP are to conduct a focused survey on the target group. Due to administrative hurdles and associated time constraints, it was not possible for us to conduct a survey for our BCA, so we utilized peer-reviewed studies dating back to the late 1990s, to compute our own estimate of an individual's WTP for high-speed internet. WTP values from the studies were given a weighting, based on the size, scope and age of the study; we then used the weighted average of these WTP numbers to determine a reasonable value that would be used for the NPV analysis.

The next category of quantitative benefits used in our NPV analysis was QoW. QoW is the monetized benefit attributed to sailors and the Navy for having increased work productivity and efficiency, due to high-speed internet. ABE has already seen success in this arena. Starlink has been used at sea to quickly transfer medical diagnoses information, mechanical schematics, and logistics information; all of which were accomplished in a fraction of the amount of time compared to traditional methods. ABE also has access to Cox fiber internet in-port, which can be used to quickly accomplish certain unclassified tasks. To quantify the monetary benefit of QoW we used a similar process to the QoL method – discussed in detail in the assumptions section. Peer-reviewed studies were used to determine an average increase in productivity in the workplace, due to the use of high-speed internet. These values were then given different weightings based on age, scope, and size of the study. Once a final value was determined, it was used to determine the man-hour savings per month for those sailors that use internet for work. This value corresponds to the monetized QoW benefit the DoD receives for sailors completing certain jobs faster, solely due to high-speed internet.

Finally, after all costs and benefits were calculated, they were combined to determine the overall net benefit per year. To evaluate the financial viability of various alternatives, we applied the NPV method, which aligns with the standard practices outlined in Circular A-94 (1992) by the Office of Management and Budget (OMB). NPV serves as the primary tool for financial comparison. Circular A-94 provides a framework for conducting economic analysis of proposed investments or projects, of which our analysis adheres to. Figure 2 provides a simple visual breakdown of the NPV method.

Net Present Value (NPV) Analysis *(numbers in dollars)*				
Year	**0**	**1**	**2**	**3**
COSTS				
Cost 1				
Cost 2				
TOTAL COSTS	$0	$0	$0	$0
BENEFITS				
Benefit 1				
Benefit 2				
TOTAL BENEFITS	$0	$0	$0	$0
NET BENEFIT	$0	$0	$0	$0
PRESENT VALUE	$0	$0	$0	$0
NET PRESENT VALUE (NPV)	**$0**			

Figure 2. Net Present Value Financial Model Outline.

Our analysis examined the net benefit cash flows associated with the project within a ten-year period, which was chosen to balance the need for a sufficiently long timeframe—to capture the effects of recurring costs—with the recognition of the advancements in telecommunications technology, necessitating potential modernization in the future. The initiation of the project is denoted as Year 0; all non-recurring upfront costs (e.g., Starlink hardware) were allocated to this initial year, while recurring costs were spread across subsequent years. NPV, as defined by OMB, represents "the discounted monetized value of expected net benefits (i.e., benefits minus costs)" (OMB, 1992). It is computed by applying a discount rate to the projected cash flow associated with a proposed project. The discounting process facilitates the conversion of future-period cash flows into a common unit of measurement, for comparison purposes. This approach empowers decision-makers to determine which course of action is the most financially advantageous over a specified time horizon.

To compute the NPV for each proposed alternative, we selected an appropriate discount rate, which plays a key role in the analysis. Given that many of the project costs are incurred in future periods, the choice of discount rate is of utmost significance. Following the guidance provided by OMB we used the real interest rate on treasury notes and bonds with 10-year maturities, which was set at 1.5% (Young, 2023). This real interest rate effectively captures the time value of money and aligns with the current financial landscape. The real rate of 1.5% also accounts for inflation, and any future cost increases as a result. Applying the chosen discount rate to each annual cash flow projection yields a series of discounted cash flows. The final NPV for each alternative is then computed by summing up these discounted cash flows. This value represents the estimated net present value of the financial aspects of each alternative, allowing for a meaningful comparison of their financial viability. In general, if the NPV's are negative (net cost) the project with the lowest value (closest to zero) would be the best alternative. If the alternative NPV's are all positive (net benefit) then the project with the highest NPV would be the best pick.

C. DATA COLLECTION

To generate an effective financial analysis, we gathered a significant amount of benefit and cost data. All cost data pertaining to Starlink (hardware costs, and service plans) was obtained directly from ABE and Starlink. All costs related to 5G/LTE cellular plan options and equipment were obtained from NIWC Pacific, or directly from cellular carriers (Verizon, AT&T, T-Mobile). Benefit values—discussed in the literature review, and assumptions section—were obtained from public, open-source databases, primarily the Naval Postgraduate School library, Elsevier and Google.

D. ASSUMPTIONS

In this section, we will explain key assumptions underpinning the derivation of the cost and benefit values used in our NPV analysis. It is important to acknowledge that these assumptions bear a degree of subjectivity and wield a substantial influence on the outcome. Consequently, we exercised prudence in selecting our assumptions, prioritizing conservatism to ensure the presentation of a more realistic, if not potentially understated, set of values. To enhance the depth of our analysis, we supplemented our approach with a sensitivity analysis, as detailed in Chapter IV, to show how variations in these assumptions and weightings impact the resulting data. These assumptions are summarized in Table 1.

Table 1. Summary of Assumptions

Assumption	Value
Months at sea each year	7
Months in-port each year	5
Sailors onboard without air wing (CVN-72 Crew)	2,900
Sailors onboard with air wing	5,000
Percentage of time air wing onboard	80%
Weighted average of sailors on board, at sea	4,580
Required total bandwidth at sea	900 Mbps
Required amount of Starlink terminals	3
Required Cradlepoint antennas in-port	3 – 9 (Varies)
Replacement period Cradlepoint/Starlink Antennae	Every 4 years

1. Internet Usage and Operational Schedule

To determine the costs and benefits associated with ABE's internet usage over a 10-year period, it was required to establish a foundational assumption regarding the vessel's operational status, specifically, the duration it spends at sea versus in-port. This assumption plays a pivotal role in shaping the cost dynamics related to Starlink connectivity at sea and 5G/LTE or fiber while in-port. The choice between ABE being at sea for 10 months annually or in port for the same duration can significantly influence the NPV analysis. With a 10-year analytical timeframe, we gain a more nuanced perspective on the frequency of ABE's at sea deployments by segmenting this period into yearly assumptions. Through deliberations with the CVN-72 Combat Systems Officer (CSO), it was determined that, on average, ABE is projected to spend approximately seven months at sea each year over the course of a decade. It's essential to highlight that all cost estimates were predicated on the assumption that the contract with the internet provider would permit the temporary suspension or cancellation of services when not required. However, this condition may be subject to alteration and might not necessarily be a standard feature in an official contract.

To ascertain bandwidth usage, it was necessary to estimate the number of internet users on board ABE during various times of the year, a figure subject to fluctuations. ABE's personnel composition varies depending on its operational status. When ABE is underway without a carrier air wing, the skeleton crew consists of roughly 2,900 sailors. However, with the air wing embarked, this number swells to approximately 5,000. Given this dynamic, we needed to make an assumption regarding how frequently the air wing is attached to ABE. After consultations with the CSO, it was determined that, on average, the air wing was affiliated with the ship approximately 80% of the time, during its underway periods. Employing a straightforward weighted average calculation, we established that, on average, ABE accommodated approximately 4,580 sailors when in an underway status.

During at-sea testing, ABE achieved maximum download speeds of approximately 300 Mbps per Starlink terminal. With three terminals deployed on board, even during peak usage, sailors consistently experienced download speeds of 10 Mbps. This testing led us to conclude that a minimum of three Starlink terminals would be necessary for ABE to maintain a baseline internet quality of 10 Mbps for end users. Additionally, the Starlink antennae are constantly exposed to harsh conditions at sea, so we assumed that the hardware terminals would need to be replaced every four years.

The quality and speed of the internet connection are crucial factors in determining the monetized benefits. In our financial model, we examined four different internet speeds: 10, 25, 50, and 75 Mbps. We selected these values for several reasons: First, the baseline speed of 10 Mbps corresponds to the expected end-user experience during periods of maximum traffic. Second, during less congested times, it is likely that sailors will enjoy speeds higher than 10 Mbps. Finally, our research on WTP for QoL benefits indicated that the speed increments of 10, 25, 50, and 75 Mbps were commonly used values in relevant studies.

In our analysis, we assumed that the financial model would not consider QoL benefits, related to high-speed internet availability, when ABE was in-port. This assumption was driven by the fact that sailors already have access to high-speed internet through personal cell phones and home connections while in-port. While our analysis did not incorporate the quantification of QoL benefits related to in-port internet access, we did consider QoW advantages. This can be attributed to the availability of high-speed internet for in-port use, facilitating unclassified work tasks such as updating Navy personnel records and accessing supply chain systems, among others.

With respect to in-port cost assumptions, for Alternative 1, no assumptions were needed, as it involved ABE continuing its regular operations with Cox pier-side fiber when in-port. For Alternative 2, we assessed the costs associated with the three major cellular providers in the region, namely T-Mobile, Verizon, and AT&T. Our objective was to match the internet speed and quality provided by the current Cox fiber infrastructure using these cellular providers. Based upon shipboard testing, we estimated that T-Mobile would require three Cradlepoint antennas, AT&T four, and Verizon nine. Like the Starlink antennas, we also assumed the Cradlepoint antennae would be replaced every four years. In the case of Alternative 3, ABE would solely rely on Starlink and maintain the same setup used at sea even while in-port.

2. Quality of Life Benefits

As elaborated in Section B, an individual's willingness to pay (WTP) serves as the primary determinant for assessing the financial QoL benefits associated with having high-speed internet at sea. During our research, we identified six articles and reports that explicitly assigned a WTP or monetary value to specific internet speeds or qualities; these articles and their intended purposes are discussed in Chapter II—Literature Review. This section, however, exclusively focuses on the relevant values derived from these studies, which were synthesized and categorized into three distinct groups: 1) Monthly WTP for bandwidth ($/Mbps), 2) Monthly WTP for increased bandwidth ($/Mbps), and 3) Monthly WTP for supplementary features or quality improvements, unrelated to bandwidth specifically ($). These values were then given a relative weighting based on size, scope, significance, and age of the study, which were then used to compute an average monthly value for WTP.

(1) Monthly WTP for Bandwidth

The first article of significance, “Eliciting Consumer Willingness to Pay for Home Internet Service: Closing the Digital Divide in the State of Indiana” referred to hereafter as *Indiana*, found that the “mean WTP for residents is between $0.06/Mbps and $0.10/ Mbps per month for broadband” (Lai et al., 2020, p. 263). This makes the average WTP, adjusted for inflation, approximately $0.10 Mbps. This 2017 study was relatively small, only having 855 respondents, and was very localized to a rural part of Indiana that were not as dependent on internet access as most of the modern world. For these reasons, we assigned a weighting to this study of only 5%.

The next article of significance was the 2022 Broadband Pricing Index (BPI). This report found that the average monthly payment for the Nation’s most popular internet speeds (“Consumer Choice” at 98 Mbps) was $45.97 per month, and the fastest internet speeds (“Speed” at 259 Mbps) was $73.55 per month. These values correspond to a WTP for Consumer Choice of $0.47/Mbps and Speed of $0.28/Mbps. The BPI states that 90% of the U.S. have the “Consumer Choice” internet plan; this leads to a weighted average, adjusted for inflation, of $0.46/Mbps. Due to the recency of this report, the vast sample size, and the wide array of demographics it covers, we assigned a weighting to this report of 50%.

The next article, *“*Distinguishing Bandwidth and Latency in Households’ Willingness- to-Pay for Broadband Internet Speed*”* referred to hereafter as *Bandwidth and Latency*, measured households’ WTP for changes in “key home broadband Internet features using data from two nationally administered, discrete choice surveys” (Liu et al., 2017). This report found that of the approximately 1,400 respondents, the average monthly price for home internet plans was $64.84 per month, and the average download speed was 149.56 Mbps, leading to an inflation adjusted $0.54/Mbps. The survey was comprehensive in scope and matched the demographics of the U.S., but was relatively small, having only 1,411 respondents. For these reasons, we assigned a weighting to this article of 20%.

The next article, "The Willingness to Pay for Broadband of Non-Adopters in the U.S.: Estimates from A Multi-State Survey" referred to hereafter as *Non-Adopters*, stated that the average price of broadband internet in March of 2011 was $44/month. According to the FCC, the average broadband internet speed in March of 2011 was 10 Mbps, which corresponds with a price rate of $6.00/Mbps when adjusted for inflation. The survey had a large sample size—approximately 15,000 respondents—but was targeted at households that had not adopted broadband internet. The survey is also severely outdated, as the price of broadband internet, with respect to speed, has drastically decreased since 2011. For those reasons, we weighted this study at only 5%.

The final article that incorporated WTP for bandwidth was "Willingness to Pay and Pricing for Broadband Access Across the Rural/Urban Divide in Canada" referred to hereafter as *Canada*. This 2020 study found that rural internet users had a WTP of $20.85/Mbps whereas urban users had a WTP of $5.58/Mbps. However, they note that "our sample is 54 percent rural in comparison with the actual 13.8 percent of rural households for all of Ontario" (Worden et al., 2021). This led to a weighted average calculation—adjusted for currency and inflation—of $6.81/Mbps. This study had a modest sample size of roughly 4,700 individuals, across all demographics, in the greater Ontario area. Due to the recency, demographic spread, and scope of the survey, we assigned a weighting to this study of 20%.

By amalgamating the mean WTP values derived from these five articles and incorporating the relevant weightings we have assigned, we computed a monthly weighted average WTP for bandwidth, amounting to $2.01 per Mbps. Table 2 provides an overview of these five articles, delineating the essential factors used to establish a fair and reasonable weighting scheme. In broad terms, studies with more recent data, larger sample sizes, and broader demographic representation were accorded higher weightings in our analysis.

Table 2. Summary of Article Weightings

Article	**Sample Size**	**Year**	**Demographics (LO/MED/HI)**	**WTP ($/Mbps)**	**Weighting**
Indiana (Lai et al., 2020)	855	2017	LOW	0.10	5%
BPI (Menko, A. 2022)	~10,400	2022	HIGH	0.46	50%
Bandwidth and Latency (Liu et al., 2018)	1,411	2017	HIGH	0.54	20%
Non-Adopters (Carare et al., 2015)	15,082	2011	MED	6.00	5%
Canada (Worden et al., 2022)	4,742	2020	MED	6.81	20%

(2) Monthly WTP for Increased Bandwidth (Added Speed)

This section focuses on an individual's WTP for an increase in bandwidth, above a baseline value. As previously discussed, our financial model examined four different internet speeds: 10 Mbps, 25 Mbps, 50 Mbps, and 75 Mbps; 10 Mbps being the baseline case during maximum internet traffic. Our research found two articles that directly associated WTP for increasing bandwidth in $ per Mbps. The first article of significance was a 2023 study titled "Willingness to Pay for Internet Services" referred to hereon as *Internet Services*. This study found that individuals "are willing to pay an extra $1.13 per month for 1Mbps faster speed" (Rabbani et al., 2023). The surveys were conducted in 2022, therefore the inflation adjusted WTP for an increase in 1 Mbps is $1.14.

The next article *Bandwidth and Latency* found that "In particular, households on average value increasing bandwidth from 4 Mbps to 10 Mbps at about $14 ($2.34/Mbps), 10 to 25 Mbps at $24 ($1.57/Mbps), 25 to 50 Mbps at $14 ($0.57/Mbps), 50 to 75 Mbps at $8 ($0.32/Mbps), and 75 to 100 Mbps at $4 ($0.16/Mbps). Households were willing to pay only an additional $19 ($0.02/Mbps) for bandwidth increased from 100 Mbps to 1Gbps" (Liu et al., 2017).

Table 3. Bandwidth Brackets. Source: Liu et al. (2017).

Speed Increase	2017 Values ($/Mbps)	Inflation Adjusted ($/Mbps)
4 → 10 Mbps	2.34	2.91
10 → 25 Mbps	1.57	1.96
25 → 50 Mbps	0.57	0.71
50 → 75 Mbps	0.32	0.40
75 → 100 Mbps	0.16	0.20
100 → 1000 Mbps	0.02	0.02

Using these two articles, we calculated an individual's monthly WTP to increase bandwidth from a baseline value, to a higher one. For weighting purposes, we assigned *Internet Services* a slightly higher weighting of 60%, compared to *Bandwidth and Latency*'s 40%. This is because the *Internet Services* study was very recent (2023) and had over 5,200 respondents, whereas the *Bandwidth and Latency* study was from 2017, and only had 1,411 respondents.

(3) Monthly WTP for Increased Quality

This section contained a single article, *Internet Services*, which offered valuable quantitative insights for our analysis. The study in question revealed that individuals using a low-quality internet connection were willing to invest an additional $85.71 ($88.28 adjusted for inflation) per month to upgrade their internet quality to a medium level (Rabbani et al., 2023). Medium internet quality was defined as "the internet slows down only a few times a month. The internet disconnects for several hours a few times a year. Sometimes video calls are unstable, or voices break up" (Rabbani et al., 2023). To apply this information to our analysis, we made an assumption: if an average citizen is willing to pay $85.71 per month to transition from low-quality internet to medium-quality internet, how much more would a sailor on deployment be willing to pay to upgrade from having no internet at all to enjoying medium-quality internet? This assumption served as a cornerstone for establishing the baseline QoL WTP for a 10 Mbps internet speed.

(4) Combining all Three Factors

Next, we combined these three categories to derive a singular monthly WTP value for the examined internet speeds of 10, 25, 50, and 75 Mbps. In our analysis, we designated 10 Mbps as the fundamental benchmark, representing a medium-quality internet speed. This serves as the initial baseline for a sailor's internet experience, and thus, our calculation incorporated WTP for Quality and Bandwidth only, and did not include WTP for additional speed. In this baseline scenario—where a sailor transitions from having no internet access, to attaining a low tier medium-quality internet—we primarily based our calculation on the WTP for quality values, drawn from the *Internet Services* article. We applied a 70% weight to the quality upgrade ($88.28) aspect and a 30% weight to the bandwidth price ($2.01/Mbps) component in this assessment, leading to a monthly WTP of $67.82. The equation below illustrates how the bandwidth price for 10 Mbps was calculated.

$$Bandwidth\ Price = price\ per\ Mbps * speed\ (Mbps)$$

$$Bandwidth\ Price\ (10\ Mbps) = \frac{\$2.01}{Mbps} *\ 10 Mbps = \$20.07$$

For the next three bandwidth cases, we maintained the bandwidth price weighting at 30% and adjusted the other two. As the internet speed increased, we reduced the emphasis on the baseline price (quality upgrade value) and shifted it towards the WTP for increased bandwidth (additional speed). Table 4 provides a detailed breakdown of these weightings and their respective effects on the monthly price, or WTP, for all speed scenarios.

Table 4. Weighted Average Monthly WTP for Various Internet Speeds

Speed (Mbps)	10	Weight	Speed (Mbps)	25	Weight
Bandwidth Price	$ 20.07	0.3	Bandwidth Price	$ 50.16	0.3
Baseline Price	$ 88.28	0.7	Baseline Price	$ 88.28	0.6
Added Speed	0		Added Speed	$ 22.02	0.1
Monthly Price	$ 67.82	1	Monthly Price	$ 70.22	1

Speed (Mbps)	50	Weight	Speed (Mbps)	75	Weight
Bandwidth Price	$ 100.33	0.3	Bandwidth Price	$ 150.49	0.3
Baseline Price	$ 88.28	0.5	Baseline Price	$ 88.28	0.4
Added Speed	$ 24.25	0.2	Added Speed	$ 21.13	0.3
Monthly Price	$ 79.09	1	Monthly Price	$ 86.80	1

The WTP for increased bandwidth (added speed) came from the weighted average of the WTP values in sub section (ii) multiplied by the change in bandwidth speed in Mbps. The following equation shows how the added speed WTP was calculated for 25 Mbps, using the values from Table 3.

$$Added\ Speed\ Price = Weighted\ Avg.Speed\ Increase * Increase\ in\ Speed$$

$$Added\ Speed\ Price\ (10 \rightarrow 25\ Mbps) =$$

$$\{(\$1.14 * 0.6) + (\$1.96 * 0.4)\} * (25\ Mbps - 10\ Mbps) = \$22.02$$

In summary, the QoL benefits—which only apply when ABE is at sea—were derived from three WTP categories: 1) Monthly WTP for bandwidth ($/Mbps), 2) Monthly WTP for increased bandwidth ($/Mbps), and 3) Monthly WTP for quality improvements ($). These values were all derived from the six articles mentioned in this section, using weighted averages to balance the importance, relevance, and recency of the studies. The three categories were then balanced together using another weighted average to arrive to a singular WTP value per month. This value represents a sailor's willingness to pay for a specific internet speed and quality while underway. The individual value was then multiplied by the average number of sailors at sea (4,580) to compute a total monthly QoL benefit for the entire ship. While these values are subjective and dependent on the weighting system explained in this section, we believe they are understated, and the actual WTP for a sailor would be notably higher than this.

3. Quality of Work Benefits

This section will focus on the quantitative QoW benefits ABE receives for having continuous high-speed internet available to sailors for work purposes. While the QoL benefit only applies while ABE is at sea, the QoW benefit applies both at sea and in-port. This is primarily because high-speed internet enhances the efficiency of sailors work on a continuous basis, and traditional military pier side internet connections are notoriously slow and unreliable. To determine the monetary value of having high-speed internet, we have drawn from studies examining the impact of high-speed internet on productivity. We used these studies to calculate an estimated average increase in productivity for a sailor using high-speed internet. This value was then multiplied by the weighted average of sailors' salaries across the ship, to determine a cost savings to the DoD. The underlying assumption here is that when sailors complete their online tasks quicker, they will have additional time to devote to other duties, resulting in a net benefit to the ship and the Navy.

We utilized six studies in our research to quantify a productivity increase due to high-speed internet. The first article, "Internet Access and its Implications for Productivity, Inequality, and Resilience" by the National Bureau of Economic Research (NBER) found that, for individual's working from home one day per week, if they had access to high quality home internet it "would raise earnings-weighted labor productivity by an estimated 1.1% in the coming years" (Barrero et al., 2021). The next article, "The Need for Speed: Impacts of Internet Connectivity on Firm Productivity" from Motu, compared firms that utilized broadband internet with those that did not, and noted "[w]e find a (levels) productivity effect of broadband relative to no broadband of approximately 10% across all firms" (Grimes et al., 2009).

The next article "ICT Services and Small Businesses' Productivity Gains: An Analysis of the Adoption of Broadband Internet Technology" found that small and medium enterprises (SMEs) that adopted at least two advanced communications applications (VPN, VoIP, video conference, etc.) and implemented organizational structure changes to promote these applications, were drastically more efficient than those that did not. "The average productivity increase obtained by a service SME that adopts broadband applications included in this group varies from +20.4% to +68.3% as the number of applications adopted increases from 2 to 5" (Colombo et al., 2013). In a move towards conservatism, we opted to utilize the lower bounds of this range, specifically 20.4%, in our analysis. The next article "The Internet and Local Wages: A Puzzle" looked at how wage growth in U.S. Counties was affected by the adoption of the internet and advanced internet applications. "[w]ell-off counties averaged 28 percent wage growth from 1995 to 2000 (unweighted by population), while all counties averaged just 20 percent wage growth over this period" (Forman et al., 2012). While it's important to recognize that wage growth and increased productivity are not identical concepts, one can contend that the value placed on wage growth is closely aligned with the idea of heightened productivity. Therefore, we included the 20% wage growth in our analysis, but assigned it a lower weighting.

The next article, "Information and Communication Technology Adoption in Micro and Small Firms: Can Internet Access Improve Labour Productivity?*"* examined the impact of internet adoption on labor productivity and the mechanisms shaping the relationship in Peruvian micro and small manufacturing firms from 2011–2013. This study found that "internet adoption leads to firm-level productivity increases of 25% on average" (Viollaz, 2018). The final article used in our research was "Mobile and More Productive? Firm-level Evidence on the Productivity Effects of Mobile Internet Use." This study analyzed 2,143 German firms in 2014 and concluded that for every one percent increase in the employee share of mobile internet access, the average firm will enjoy 0.2% higher labor productivity (Bertschek and Niebel, 2016). While this study primarily centered around mobile internet access, it remains closely aligned with our overarching hypothesis: the availability of high-speed internet is likely to enhance productivity compared to users lacking such access. Consequently, we incorporated this study into our research, assuming a 100% utilization rate, resulting in a 20% boost in productivity. However, it received a relatively lower weighting due to its comparative relevance when juxtaposed with the other studies.

Table 5 provides a concise summary of the six key articles utilized in our analysis, along with the pertinent details that guided the formulation of our weighting scale. The criteria for assigning weightings closely mirrored those employed in the QoL section. We analyzed the size and scope of the study, how relevant the results were to our analysis, as well as the age and demographic spread of the study. In general, more recent studies with large sample sizes and demographic spreads, that compared productivity with and without broadband, received higher weightings than those that did not.

Table 5. Summary of Articles with Efficiencies and Weightings

Article	Sample Size	Year	Demographics (LO/MED/HI)	Efficiency Improvement	Weighting
NBER (Barrero et al., 2021)	43,000	2021	HIGH	1.1%	20%
Motu (Grimes et al., 2009)	6,000	2009	HIGH	10.0%	30%
ICT SMEs (Colombo et al., 2013)	799	'98 – '04	LOW	20.4%	10%
Puzzle (Forman et al., 2012)	2,743	'95 – '00	HIGH	20.0%	15%
Peru (Viollaz, 2018)	1,893	'11 – '13	LOW	25.0%	15%
Germany (Bertschek and Niebel, 2016)	2,143	2014	LOW	20.0%	10%

Utilizing the values and weightings delineated in Table 5, we derived an average productivity increase for sailors, attributable to high-speed internet, of 14.01%. Next, we incorporated a series of assumptions to delineate the work-related internet usage patterns aboard the ship. Our initial assumption revolved around the percentage of sailors aboard ABE who would employ the internet for work purposes. Based on conversations with ABE's CSO, we estimated that approximately 30% of the sailors on board would use internet for work, at least once per week. Following this, we considered the extent of work that these sailors would accomplish via the internet. Given that most job responsibilities on the ship do not necessitate internet access, we assumed that these sailors would allocate approximately one hour per day, equivalent to five hours per week, for internet work tasks. Assuming a 40-hour work week, this equates to approximately 12.5% of their total work being conducted online.

Subsequently, we applied this value by multiplying it with the rank-weighted average of sailors present on the ship. Using data from ABE and public pay charts, we factored in the rank distribution and multiplied it by the average monthly salary, corresponding to each position. This calculation allowed us to determine the average monthly salary for the entire ship, which was approximately $14.6 million per month. Utilizing this average monthly salary as a benchmark, we then integrated the efficiency gains and internet utilization rates to arrive at an average QoW efficiency benefit of $76,774 per month, for the entire ship. This number represents the monetary benefit the Navy receives each month for having high-speed internet available to sailors to complete work tasks.

E. SCOPE OF ANALYSIS

This study primarily examined the direct costs and benefits associated with procuring specific internet plans for ABE over a 10-year timeframe. It is important to note that we did not factor in expenses associated with establishing an independent private network to deliver Wi-Fi services to the ship. This is a substantial and essential cost component that demands a case-by-case assessment for each vessel. In the context of our financial analysis concerning ABE, these were considered sunk costs since the network was already constructed and operational. However, if ABE's network were to be replicated on another CVN or large surface ship, the initial outlay, including labor and materials, would likely exceed $125,000 (D. Chock, email to authors, October 26, 2023).

Regarding our QoW assumptions, we operated under the premise that the stand-alone network would exclusively support unclassified work. Presently, there exists no established policy permitting the use of classified work on commercial internet platforms. However, it's worth noting that there is a path forward for such integration, which would yield significant advantages for the Navy. Additionally, our QoW assumptions were based solely on base pay; we did not include additional components such as bonuses, medical benefits, retirement plans, or other special pay considerations in the calculation of the average monthly salary.

IV. ANALYSIS OF RESULTS

This chapter provides an in-depth analysis of the three alternative technology options considered for ABE. For each alternative we discuss the overall benefits and drawbacks, specific costs, related benefits, the NPV results, and a sensitivity and break-even analysis to provide greater perspective and deeper understanding of the results. The aim is to select the alternative with the highest NPV, as this provides the greatest benefit to ABE. For all three alternatives, we used the baseline values and assumptions, detailed in Table 1 in Chapter III. Unless otherwise stated, all NPV calculations assume a conservative internet speed of 10 Mbps.

A. ALTERNATIVE 1: STARLINK AT SEA, COX FIBER IN-PORT

1. Overview

Alternative one (ALT1) uses Starlink at sea and Cox fiber internet in-port; this alternative most closely represents ABE's current configuration. ABE currently has one Starlink terminal supplying internet to the Ship. Figure 3 displays this terminal, which is mounted on the Port Quarter of the ship. These connectivity methods supply ABE's standalone private Wi-Fi network, but do not provide connectivity to integrated ship's systems. Both Cox and Starlink provide unlimited monthly data usage with no caps (K. White, email to authors, November 13, 2023). As with alternatives two and three, ALT1 enables continuous internet access both at sea and in-port. ALT1 provides the same monetary benefit as alternatives two and three, but has the lowest cost and therefore, the highest NPV, making it the most appealing option for ABE.

Figure 3. Starlink Terminal Mounted on Port Quarter

2. Costs

As discussed in Chapter III, we used real prices denominated in June 2023 dollars to anticipate future expenditures. This highlights the need to incorporate real interest rates in NPV calculations—a widely accepted practice for discounting future cash flows (Brealey et al., 2020, p. 257). Utilizing real interest rates not only accounts for inflation but also mitigates uncertainty in forecasting cash flows linked to service price increases. Furthermore, this method enhances simplicity in determining future cash flows by retaining the current real price instead of relying on estimates for future costs.

Recurring costs associated with Cox fiber internet and Starlink data plans were sourced directly from CVN-72, as well as Starlink hardware costs. Subscription costs for Starlink and Cox were tailored to ABE and are not bound by long-term contracts, making them susceptible to adjustments. Table 6 provides an overview of all expenditures essential for ALT1 over the duration of a 10-year period.

Table 6. Summary of ALT1 Expenses

Expense	Amount ($)
Starlink Subscription (per month/per terminal)	30,000.00
Cox Subscription (per month)	2,000.00
Starlink Terminal Hardware (per unit)	6,140.00

Since ABE already possesses one Starlink terminal but requires three to meet bandwidth demands, the initial outlay for ALT1 encompassed the purchase of two additional Starlink terminals at $6,140 each (K. White, email to authors, November 27, 2023). All other costs associated with setting up Cox and the private Wi-Fi network were sunk costs, since they were already purchased. The two additional Starlink terminals purchased in Year 0 amount to $12,280, whereas the replacement costs in Years 4 and 8 are $18,420. The vast majority of the recurring monthly expenses come from the Starlink subscription at sea, while only a minority are attributed to Cox in-port. Assuming ABE is underway seven months out of the year, the total cost for Starlink would be $630,000 per year.

$$Annual\ Starlink\ Price = (Terminal\ Cost) * (\#\ Terminals) * (\#\ Months\ at\ Sea)$$

= ($30,000.00) * (3 Terminals) * (7 months) = $630,000.00 per year

When ABE is in-port, the cost for Cox fiber is $2,000 per month (K. White, email to authors, November 13, 2023) which leads to an annual cost of $10,000 per year. Table 7 summarizes the total costs for ALT1 over the course of ten years.

Table 7. Total Costs for ALT1 10-Year Period

Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
Cox Fiber Data Plan		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL COSTS	$12,280	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000

3. Benefits

As previously discussed, all three alternatives yield identical monetary benefits over the 10-year period. These benefits are classified as either Quality of Life (QoL) or

Quality of Work (QoW). We assumed QoL benefits are exclusively accrued while ABE is at sea; hence, the longer ABE remains at sea, the more substantial the actualized QoL benefit becomes. Moreover, QoL is directly correlated to internet speed and quality. As sailors experience consistently higher speed and quality, the benefit increases. To uphold conservative estimations and avoid exaggerating the realized benefit of having internet at sea, we have based our calculations on the worst-case bandwidth scenario of 10 Mbps, aligning with the lowest conceivable QoL monetary benefit. While the QoL benefit is only applied at sea, QoW applies year-round, both in-port and at sea (see Chapter III). Table 8 shows the annual monetized benefits for different internet speeds. Of note, the QoW benefit is unaffected by different internet speeds, whereas QoL is. While it makes logical sense that as internet speed increases productivity would increase as well, our research only pointed to the productivity difference between having high-speed internet and not having it.

Table 8. QoL and QoW Annual Benefits at Varying Internet Speeds

Internet Speed	10 Mbps	25 Mbps	50 Mbps	75 Mbps
QoL Benefit	$2,174,199	$2,251,252	$2,535,577	$2,782,818
QoW Benefit	$921,283	$921,283	$921,283	$921,283
ANNUAL BENEFITS	$3,095,482	$3,172,535	$3,456,860	$3,704,101

4. Net Present Value Results

Using the real discount rate of 1.5% over a 10-year period, we calculated the NPV for ALT1 to be $22,598,921. This number accounts for inflation and represents the monetary value for ALT1 in present day dollars, with all future cash flows discounted to June 2023 dollars. Appendix A summarizes the total costs, benefits, present values and NPV for the ten-year business case.

5. Sensitivity Analysis

Sensitivity analysis (SA) is a tool used in financial modeling, particularly in NPV and cash flow forecasting, to assess how changes in key variables impact the outcomes of a financial model (Brealey et al., 2020, p. 258). It involves determining the most significant variables that affect the outcome of the NPV analysis and varying them based on pessimistic or optimistic assumptions. The analysis involves changing only one variable at a time, then annotating the corresponding NPV result. For our analysis we identified six factors that had a significant impact on the NPV results: Baseline Internet WTP ($/month per sailor), the monthly cost of Starlink service ($/month per terminal), number of months at sea in a given year, QoW efficiency increase (%), internet speed (Mbps) and the real discount rate (%). For baseline internet WTP, months at sea, and QoW efficiency, we used the assumptions from Chapter III as a starting point, then added a pessimistic and optimistic value. Base internet WTP and QoW efficiency were varied by 20% to capture a high and low value, whereas number of months at sea was varied by three months. For the remaining three variables (Starlink cost, internet speed and real discount rate) we already included the pessimistic values in our assumptions, therefore, the SA displays only more pessimistic values. This ensures that our NPV results are conservative, not overinflated, and in-line with realistic expectations. Table 9 shows the SA for ALT1. Values in blue text are baseline assumed values used in the nominal NPV calculations. The most influential variable in our SA is the number of months ABE spends at sea. This is due to the QoL benefit being directly attributed to sailor's improved welfare at sea when high-speed internet is available for leisure. For a ten-month deployment, ALT1 yields a high NPV of $28,757,494. Comparatively, if ABE only spends four months at sea, the NPV is lower, at $16,440,348.

Table 9. ALT1 Sensitivity Analysis Results

ALT 1	Internet WTP ($/mo)	Starlink Cost ($/mo)	Months at Sea	QoW Efficiency (%)	Internet Speed (Mbps)	Real Discount Rate (%)
NPV	$26,253,641	$20,662,262	$28,757,494	$24,296,956	$25,931,611	$21,446,449
HIGH	105.94	40,000	10	16.81	50	2.5
NPV	*$22,598,921*	$21,630,592	*$22,598,921*	*$22,598,921*	$23,309,513	$22,011,557
MED	*88.28*	35,000	*7*	*14.01*	25	2.0
NPV	$18,943,663	*$22,598,921*	$16,440,348	$20,900,886	*$22,598,921*	*$22,598,921*
LOW	70.62	*30,000*	4	11.21	*10*	*1.5*

6. Break-Even Analysis

Break-even analysis is an important process that entails identifying the most unfavorable expenses or conditions capable of causing the project's NPV to turn negative (Brealey et al., 2020, p. 262). Among the three alternatives considered, the monthly service cost for Starlink stands out as the most substantial expense. In our break-even analysis, we adjusted the monthly Starlink price to pinpoint the threshold just before the NPV turns negative, rounding the figure to the nearest whole dollar. This adjustment reflects the maximum monthly price the Navy would be willing to pay for Starlink usage while still maintaining a net benefit, albeit at a level extremely close to zero. For ALT1 the break-even analysis resulted in a Starlink monthly price of $146,690 per terminal, which yielded a NPV of $50. Table 10 displays the break-even point as Starlink monthly price increases.

Table 10. ALT1 Break-Even Analysis

ALT 1 Break-Even Analysis								
Starlink Price	$146,687	$146,688	$146,689	$146,690	$146,691	$146,692	$146,693	$146,694
NPV	$631	$437	$244	$50	($144)	($337)	($531)	($725)

B. ALTERNATIVE 2: STARLINK AT SEA, 5G/LTE IN-PORT

1. Overview

Alternative two (ALT2) leverages Starlink for maritime connectivity and relies on 5G/LTE cellular internet while in port. We assessed cellular internet options from the prominent service providers in the region, namely AT&T, T-Mobile, and Verizon. Among these carriers, only Verizon provided a monthly data plan quote; T-Mobile did not respond within the specified timeframe, and AT&T could not meet ABE's service requirements. In shipboard testing, T-Mobile exhibited notably superior performance compared to Verizon, achieving an average download speed of 150 Mbps for a single SIM card, whereas Verizon's LTE service in the harbor peaked at 80 Mbps (K. White, email to authors, October 5, 2023). To calculate the NPV for Verizon in ALT2, we utilized their provided quote. However, for T-Mobile, an assumption was made for the pricing since an actual quote was not received. Verizon's quote was centered on maintaining internet speeds and quality akin to the existing Cox fiber infrastructure. However, unlike Cox, Verizon's data plans do not include unlimited data usage, which must be considered when comparing alternatives.

2. Costs

While ALT1 provides pier side internet service to ABE without the need for additional hardware, ALT2 requires an external antenna to receive the 5G/LTE signals. ABE currently employs one Cradlepoint W2005 cellular antenna, shown in Figure 4, to capture 5G/LTE signals and transfer them via ethernet to the ship's private network. Each W2005 antenna has the capacity to support two cellular SIM cards, therefore, the more SIM cards required, the more Cradlepoint antennas that are required. To attain performance levels comparable to Cox, Verizon necessitates 17 SIM cards, each with a 300 GB per month data cap, resulting in a cumulative data cap of 5.1 terabytes (TB's). This requirement mandates the addition of eight more W2005 antennas, considering ABE already possesses one. With each Cradlepoint W2005 antenna priced at $3,490 (D. Chock, email to authors, October 2, 2023). The initial investment for the hardware essential for the Verizon data plan amounts to $27,920. Subsequently, the replacement costs in Years 4 and 8 for all nine Cradlepoint antennas would be $31,410. Finally, the monthly service plan for all 17 Verizon SIM cards equals $2,703 per month (C. Pineda, email to authors, October 18, 2023). Therefore, for a nominal five months in port, the total cost per year for Verizon LTE service would be $13,515.

Figure 4. Cradlepoint W2005 Antenna Mounted on Port Quarter

While a direct quote from T-Mobile could not be obtained, we deemed it essential to factor in the potential of their services, given their superior coverage. Reverse-engineering Verizon's pricing led us to an estimated monthly cost of $160 per SIM card. Recognizing that T-Mobile's rates are likely different, we proceeded with the assumption that they matched Verizon's pricing for analytical purposes. Drawing on T-Mobile's bandwidth tests on ABE, we determined that six SIM cards would be necessary to attain comparable internet speed and quality to Cox. This configuration requires three Cradlepoint antennas, resulting in an initial investment of two extra units in Year 0 and the replacement of all three units in Years 4 and 8. The service cost for six SIM cards amounts to $960 per month, or $4,800 per year for a given five months in-port. Table 11 outlines the key expenses necessary for ALT2.

Table 11. Summary of ALT2 Expenses

Expense	Amount ($)
Starlink Subscription (per month/per terminal)	30,000.00
Starlink Terminal Hardware (per unit)	6,140.00
Cradlepoint W2005 Antenna (per unit)	3,490.00
Verizon Data Plan 17 SIMs (per month)	2,703.00
Assumed T-Mobile Data Plan 6 SIMS (per month)	960.00

All costs related to Starlink in ALT2, were identical to ALT1, leading to an annual service price of $630,000 for seven months at sea in a given year. Table 12 summarizes the total costs for Verizon's LTE alternative, whereas Table 13 displays the assumed total costs for T-Mobile's 5G plan.

Table 12. Total Costs for ALT2 (Verizon) 10-Year Period

Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
Verizon Monthly Plan		$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515
Cradlepoint Antenna	$27,920				$31,410				$31,410		
TOTAL COSTS	$40,200	$643,515	$643,515	$643,515	$693,345	$643,515	$643,515	$643,515	$693,345	$643,515	$643,515

Table 13. Assumed Total Costs for ALT2 (T-Mobile) 10-Year Period

Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
T-Mobile Monthly Plan		$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800
Cradlepoint Antenna	$6,980				$10,470				$10,470		
TOTAL COSTS	$19,260	$634,800	$634,800	$634,800	$663,690	$634,800	$634,800	$634,800	$663,690	$634,800	$634,800

3. Benefits

ALT2 presents identical quantitative benefits as ALT1 and ALT3, as outlined in Table 8. Nevertheless, there are nuanced qualitative distinctions between ALT1 and ALT2, notably the imposition of a data cap on 5G/LTE usage during ABE's in-port periods. Although ABE's CSO projects that 5 terabytes per month should meet the ship's needs, it is not a guarantee. An unfortunate scenario could unfold during data-intensive periods, potentially leading to an abrupt cessation of the ship's data access for the remainder of the month. This contingency demands thoughtful consideration in the decision-making process. Furthermore, the reliability of internet quality is contingent on wireless conditions and overall traffic in the surrounding area. As a result, a consistent level of quality cannot always be assured, adding another layer of consideration in the evaluation of alternatives.

4. Net Present Value Results

Applying a real discount rate of 1.5% over the span of 10 years, we computed the NPV for ALT2, resulting in $22,481,108 for Verizon and $22,620,737 for T-Mobile. It's crucial to note that the NPV for T-Mobile was not factored into the comparison of alternatives, due to the reliance on an assumed price. These NPV figures account for inflation, and signify the present-day monetary value of ALT2, with all forthcoming cash flows discounted to June 2023 dollars. Appendix A summarizes the total costs, benefits, present values and NPV for the ten-year business case.

5. Sensitivity Analysis

Alternative two used the exact same variables and corresponding pessimistic and optimistic values as ALT1. While T-Mobile's data cannot be used for decision making purposes, we included the SA results anyway, to show what the NPV results could be if T-Mobile's pricing was in line with Verizon's. The SA results show that the number of months ABE is at sea is still the driving factor for overall NPV. Table 14 displays the overall SA results for ALT2 with Verizon, and Table 15 shows the assumed SA results for T-Mobile.

Table 14. Sensitivity Analysis ALT2 (Verizon)

ALT 2 (Verizon)	Internet WTP ($/mo)	Starlink Cost ($/mo)	Months at Sea	QoW Efficiency (%)	Internet Speed (Mbps)	Real Discount Rate (%)
NPV	$26,135,828	$20,544,449	$28,659,130	$24,179,143	$25,813,798	$21,333,530
HIGH	105.94	40,000	10	16.81	50	2.5
NPV	$22,481,108	$21,512,779	$22,481,108	$22,481,108	$23,191,700	$21,896,237
MED	88.28	35,000	7	14.01	25	2.0
NPV	$18,825,850	$22,481,108	$16,303,086	$20,783,073	$22,481,108	$22,481,108
LOW	70.62	30,000	4	11.21	10	1.5

Table 15. Assumed Sensitivity Analysis ALT2 (T-Mobile)

ALT 2 (T-Mobile)	Internet WTP ($/mo)	Starlink Cost ($/mo)	Months at Sea	QoW Efficiency (%)	Internet Speed (Mbps)	Real Discount Rate (%)
NPV	$26,275,457	$20,684,079	$28,750,537	$24,318,722	$25,953,427	$21,466,901
HIGH	105.94	40,000	10	16.81	50	2.5
NPV	*$22,620,737*	$21,652,408	*$22,620,737*	*$22,620,737*	$23,331,330	$22,032,678
MED	*88.28*	35,000	*7*	*14.01*	25	2.0
NPV	$18,965,479	*$22,620,737*	$16,490,938	$20,922,703	*$22,620,737*	*$22,620,737*
LOW	70.62	*30,000*	4	11.21	*10*	*1.5*

6. Break-Even Analysis

As discussed in section A.6 of this chapter, break-even analysis represents the value of an expense at which point the NPV of the project turns negative. For ALT2 with Verizon, the break-even analysis, shown in Table 16, resulted in a Starlink monthly price of $146,081 per terminal, which yielded a NPV of $180. Table 17 displays T-Mobile's results, assuming they could match Verizon's pricing, which yielded a Starlink price of $146,802 and an NPV of $176.

Table 16. ALT2 (Verizon) Break-Even Analysis

ALT 2 (Verizon) Break-Even Analysis								
Starlink Price	$146,078	$146,079	$146,080	$146,081	$146,082	$146,083	$146,084	$146,085
NPV	$761	$567	$373	$180	($14)	($208)	($401)	($595)

Table 17. ALT2 (T-Mobile) Assumed Break-Even Analysis

ALT 2 (T-Mobile) Break-Even Analysis								
Starlink Price	$146,799	$146,800	$146,801	$146,802	$146,803	$146,804	$146,805	$146,806
NPV	$757	$563	$369	$176	($18)	($212)	($405)	($599)

C. ALTERNATIVE 3: STARLINK ONLY

1. Overview

Alternative three (ALT3) exclusively depends on Starlink for both maritime and in-port connectivity, eschewing the use of Cox fiber internet or 5G/LTE services while in-port. Similar assumptions regarding the quantity of Starlink terminals and the corresponding data plans apply to ALT3 as in alternatives one and two. While ALT3 may be the least cost-effective option, it does present certain advantages that warrant its inclusion in our research.

2. Costs

All costs associated with Starlink usage were identical to ALT1, the only difference is the assumed usage period for Starlink. While alternatives one and two only used Starlink seven months out of the year, ALT3 uses Starlink the entire year, which increases the cost. Table 18 summarizes the total costs for ALT3 over the 10-Year period of analysis.

Table 18. Total Costs for ALT3 10-Year Period

Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000
TOTAL COSTS	$12,280	$1,080,000	$1,080,000	$1,080,000	$1,098,420	$1,080,000	$1,080,000	$1,080,000	$1,098,420	$1,080,000	$1,080,000

3. Benefits

While alternative three is the most expensive option, it has one potential benefit over ALT1 and ALT2. This is the ability to have un-interrupted connectivity when pulling in and out of port. There is no need to obtain a fiber cable, and route it to the ship to obtain connectivity—ABE is always connected. Additionally, there are no "dead zones" as the ship pulls in or out, which is common for cellular service.

4. Net Present Value Results

Applying a real discount rate of 1.5% over the span of 10 years, we computed the NPV for ALT3, resulting in $18,541,160. This value accounts for inflation and signifies the present-day monetary value of ALT3, with all forthcoming cash flows discounted to June 2023 dollars. Appendix A summarizes the total costs, benefits, present values and NPV for the ten-year business case.

5. Sensitivity Analysis

Alternative three used the same variables and corresponding pessimistic and optimistic values as ALT1. As with the other two alternatives, sea time was the largest variable affecting NPV. For a lower than average four months at sea, the NPV amounts to

$9,947,931, whereas the high estimate of ten months at sea equals $27,134,389. Table 19 summarizes the SA for ALT3.

Table 19. Sensitivity Analysis ALT3

ALT 3	Internet WTP ($/mo)	Starlink Cost ($/mo)	Months at Sea	QoW Efficiency (%)	Internet Speed (Mbps)	Real Discount Rate (%)
NPV	$22,195,880	$15,221,173	$27,134,389	$20,239,194	$21,873,850	$17,595,541
HIGH	105.94	40,000	10	16.81	50	2.5
NPV	$18,541,160	$16,881,167	$18,541,160	$18,541,160	$19,251,752	$18,059,219
MED	88.28	35,000	7	14.01	25	2.0
NPV	$14,885,902	$18,541,160	$9,947,931	$16,843,125	$18,541,160	$18,541,160
LOW	70.62	30,000	4	11.21	10	1.5

6. Break-Even Analysis

As discussed in section A.6 of this chapter, break-even analysis represents the value of an expense at which point the NPV of the project turns negative. Table 20 displays the break-even analysis for ALT3 which resulted in a Starlink monthly price of $85,847 per terminal, and yielded a NPV of $32.

Table 20. ALT3 Break-Even Analysis

ALT 3 Break-Even Analysis								
Starlink Price	$85,844	$85,845	$85,846	$85,847	$85,848	$85,849	$85,850	$85,851
NPV	$1,028	$696	$364	$32	($300)	($632)	($964)	($1,296)

D. RESULTS

1. Selecting the Best Alternative

The primary purpose of conducting NPV analysis is to derive a singular, monetary value for a prospective long-term project. This valuation is crucial for comparative assessments, aiding in the selection of the optimal alternative. In the context of evaluating business case alternatives, preference is placed on the project with the highest NPV, as it provides the most value to the organization. In our BCA, we assessed three distinct alternatives, each proposing a unique method of delivering internet connectivity to ABE. Our analysis revealed that ALT2, featuring T-Mobile, exhibited the highest NPV at $22,620,737, closely followed by ALT1 at $22,598,921. However, it's imperative to note that the higher NPV associated with T-Mobile is contingent upon the assumption that their monthly price per data plan aligns with that of Verizon's. This assumption, though, is not conclusively substantiated, and uncertainties remain regarding T-Mobile's capacity to fulfill ABE's service requirements. Additionally, Verizon—and likely T-Mobile as well—was unable to provide unlimited monthly data, which is a notably large constraint. In light of these considerations, despite the initially apparent NPV advantage of ALT2 with T-Mobile, it is deemed an unviable option. Consequently, ALT1 is the more prudent choice, having the highest NPV and avoiding the speculative assumptions associated with T-Mobile's pricing and service capabilities. Table 21 provides a summary of the NPVs for the three alternatives we considered in our BCA.

Table 21. Summary of Alternatives and Associated NPVs

	ALT1	ALT2 Verizon	ALT2 T-Mobile	ALT3
NPV	$22,598,921	$22,481,108	$22,620,737	$18,541,160

2. Analysis Based on QoW Benefits Only

Our research has demonstrated that adopting an alternative one—utilizing Starlink at sea and Cox fiber internet in-port—offers the most substantial monetary benefit to ABE and her crew. To showcase a more conservative option, we conducted additional analysis of ALT1, excluding the QoL benefits entirely. For this NPV analysis, we maintained all initial assumptions, while setting the monthly QoL WTP benefit to zero, eliminating any QoL benefits over the entire ten-year period. In this scenario, the only monetary benefits considered for ALT1, were the efficiency improvements in QoW resulting from the availability of high-speed internet for work-related purposes exclusively. The outcome—detailed in Appendix B—reveals a positive NPV of $2,548,053, underscoring the robust financial viability of this alternative, even without applying the dominant QoL benefits.

V. CONCLUSION AND RECOMMENDATIONS

The purpose of this BCA is to provide decision makers from Naval Information Warfare Center (NIWC) Pacific, PEO Digital, and other DoD organizations with a financial model and the information necessary to make better informed decisions related to shipboard internet connectivity. To accomplish this, we conducted thorough research into the field of broadband connectivity and consumers' WTP to determine realistic monetary values for QoW and QoL benefits. These values were compared with the costs associated with sustaining internet access aboard ABE continuously, at sea and in-port.

A. RECOMMENDED ALTERNATIVE

Our recommended alternative, Alternative 1: Cox Fiber in-port with Starlink connectivity at sea, presents the highest NPV of $22,598,921. Both QoL and QoW benefits contribute to this value. QoL describes all those benefits arising from sailors' personal internet use, including entertainment purposes, communications with family and friends ashore, news media, and more. QoW describes benefits related to official duties, such as time savings for administrative tasks and official correspondence when compared to traditional unclassified networks. We expect substantial value from QoL benefits for two main reasons. First, the modern world is more connected than ever, meaning sailors, especially younger recruits, are more dependent upon internet services than ever to remain connected to the society they serve. Second, our benefits were estimated using WTP data from across civilian populations, whereas sailors at sea are much more isolated than most communities and therefore stand to benefit more from virtual connections.

While our work estimates QoL benefits are substantial, QoW benefits alone justify this alternative, providing a positive NPV of $2,548,053 assuming QoL benefits of $0. It is also possible that QoW benefits are much higher than estimated in this paper since this alternative provides a redundant unclassified network to ABE on deployment, with potential warfighting benefits outside the scope of this paper.

B. FLEET APPLICATIONS

This analysis concerned only ABE, but the Navy maintains ten additional CVN's in the fleet, with over 150 more surface ships of various classes as well. The QoL and QoW benefits examined in this paper could apply in analogous fashion to the sailors aboard these other ships, with costs and benefits varying based on the size of the crew, a given platform's nominal deployment schedule, and the size of the interior spaces. A simple multiplication of the NPV for Alternative 1 to reflect implementation across all 11 CVN's provides a total NPV of almost $249 Million, demonstrating substantial potential benefits from continuous internet access.

The spreadsheet we developed to perform this analysis could most easily be applied to other CVN's, but it provides the framework necessary to examine the costs and benefits of providing continuous internet access to all surface platforms.

C. FUTURE STUDIES

In this section, we offer areas we found beyond the scope of our project that should be considered for future research.

1. Sailor WTP Surveys

The biggest limitation of our research was the discrepancy between the survey populations from which we drew our WTP figures and ABE's crew. While we discussed how we mitigated these differences in Chapter III, an obvious area for future study would be to conduct surveys of actual sailors on U.S. Navy ships to determine much more accurate WTP estimates. This work would significantly improve the accuracy of QoL estimates and thus the NPV for each alternative.

2. Sailor QoW Efficiency Gain Studies

Another area of imprecision in our research was the approximation of efficiency gains observed in civilian firms to the crew of a CVN. Studies measuring the real gains to efficiency ABE experiences following implementation of one of the alternatives examined in our paper would refine the QoW benefits other ships could expect. In turn, these more precise benefits would provide more accurate NPV estimates for implementing internet access in like manner on additional surface ships.

3. Security of Starlink for Potential Military Applications

One way to substantially raise the benefits provided by internet access at sea using Starlink's constellation is to broaden this use to military applications beyond the personal and administrative uses we examined in our research. Continuous, high-quality connections to classified information networks and military systems could greatly improve the lethality of the surface fleet but requires rigorous security testing and research.

D. FINAL THOUGHTS

This paper should be understood as a preliminary estimate of the costs and benefits associated with continuous, quality internet access for sailors at sea. The estimates conducted as part of our research may be refined through studies like the ones suggested above, and the costs used in our analysis should be updated as they change with the marketplace. We developed a spreadsheet model which may be easily modified to reflect these updates and maintain the accuracy of its estimates.

This paper provides research-based evidence in support of improving the sailor's workplace at sea. Ultimately, implementing any of the alternatives discussed in this paper would serve the needs of the sailors aboard ABE as they maintain morale on deployment and seek ways to work more efficiently.

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APPENDIX A. NPV RESULTS FOR ALL ALTERNATIVES

Alternative 1: Starlink at Sea, COX Fiber in Port (numbers in dollars)											
Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
COX Fiber Unlimited Data Plan		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL COSTS	$12,280	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000
BENEFITS											
QoL 10 Mbps		$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199
QoW		$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
TOTAL BENEFITS	$0	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482
NET BENEFIT	($12,280)	$2,455,482	$2,455,482	$2,455,482	$2,437,062	$2,455,482	$2,455,482	$2,455,482	$2,437,062	$2,455,482	$2,455,482
PRESENT VALUE	($12,280)	$2,419,194	$2,383,442	$2,348,219	$2,296,161	$2,279,326	$2,245,642	$2,212,455	$2,163,407	$2,147,545	$2,115,808

NET PRESENT VALUE (NPV)	$22,598,921

Alternative 2: Starlink at Sea, 5G/LTE in Port (numbers in dollars)											
	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
Verizon Monthly Plan		$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515	$13,515
Cradlepoint Antenna	$27,920				$31,410				$31,410		
TOTAL COSTS	$40,200	$643,515	$643,515	$643,515	$693,345	$643,515	$643,515	$643,515	$693,345	$643,515	$643,515
BENEFITS											
QoL 10 Mbps		$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199
QoW		$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
TOTAL BENEFITS	$0	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482
NET BENEFIT	($40,200)	$2,451,967	$2,451,967	$2,451,967	$2,402,137	$2,451,967	$2,451,967	$2,451,967	$2,402,137	$2,451,967	$2,451,967
PRESENT VALUE	($40,200)	$2,415,731	$2,380,031	$2,344,858	$2,263,256	$2,276,064	$2,242,427	$2,209,288	$2,132,404	$2,144,471	$2,112,780

NET PRESENT VALUE (NPV)	$22,481,108

Alternative 2: Starlink at Sea, 5G/LTE in Port *(numbers in dollars)*											
	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
T-Mobile Monthly Plan		$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800
Cradlepoint Antenna	$6,980				$10,470				$10,470		
TOTAL COSTS	$19,260	$634,800	$634,800	$634,800	$663,690	$634,800	$634,800	$634,800	$663,690	$634,800	$634,800
BENEFITS											
QoL 10 Mbps		$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199
QoW		$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
TOTAL BENEFITS	$0	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482
NET BENEFIT	($19,260)	$2,460,682	$2,460,682	$2,460,682	$2,431,792	$2,460,682	$2,460,682	$2,460,682	$2,431,792	$2,460,682	$2,460,682
PRESENT VALUE	($19,260)	$2,424,317	$2,388,490	$2,353,192	$2,291,196	$2,284,153	$2,250,397	$2,217,140	$2,158,729	$2,152,093	$2,120,289

NET PRESENT VALUE (NPV)	**$22,620,737**

Alternative 3: Starlink at Sea and In-Port *(numbers in dollars)*											
	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000	$1,080,000
TOTAL COSTS	$12,280	$1,080,000	$1,080,000	$1,080,000	$1,098,420	$1,080,000	$1,080,000	$1,080,000	$1,098,420	$1,080,000	$1,080,000
BENEFITS											
QoL 10 Mbps		$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199	$2,174,199
QoW		$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
TOTAL BENEFITS	$0	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482	$3,095,482
NET BENEFIT	($12,280)	$2,015,482	$2,015,482	$2,015,482	$1,997,062	$2,015,482	$2,015,482	$2,015,482	$1,997,062	$2,015,482	$2,015,482
PRESENT VALUE	($12,280)	$1,985,697	$1,956,351	$1,927,440	$1,881,600	$1,870,892	$1,843,243	$1,816,003	$1,772,814	$1,762,725	$1,736,675

NET PRESENT VALUE (NPV)	**$18,541,160**

APPENDIX B. ALT1 NPV RESULTS WITHOUT QOL BENEFITS

Alternative 1: Starlink at Sea, COX Fiber in Port (numbers in dollars)											
Year	0	1	2	3	4	5	6	7	8	9	10
COSTS											
Starlink Hardware	$12,280				$18,420				$18,420		
Starlink Data Rate Plan		$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000	$630,000
COX Fiber Unlimited Data Plan		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL COSTS	$12,280	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000	$640,000	$658,420	$640,000	$640,000
BENEFITS											
QoL 10 Mbps		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
QoW		$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
TOTAL BENEFITS	$0	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283	$921,283
NET BENEFIT	($12,280)	$281,283	$281,283	$281,283	$262,863	$281,283	$281,283	$281,283	$262,863	$281,283	$281,283
PRESENT VALUE	($12,280)	$277,126	$273,030	$268,995	$247,665	$261,103	$257,245	$253,443	$233,346	$246,008	$242,372

NET PRESENT VALUE (NPV)	$2,548,053

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