MTR060202

MITRE TECHNICAL REPORT

The Economic Importance of Adequate Aeronautical Telemetry Spectrum

January 2007

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Sponsor:	TRMC	**Contract No.:**	WP15P7T-04-C-D199
Dept. No.:	W800	**Project No.:**	0705D100-AA

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Abstract

The flight test community faces a crisis in that insufficient spectrum is available to support telemetering requirements. The amount of spectrum available for aeronautical telemetry (ATM) is inadequate today, and demand is growing exponentially. Vital to flight testing of aeronautical vehicles for both commercial and military application, ATM is used to transmit real-time data during flight tests. The availability of such data is integral to the productivity and safety of live flight test programs. This paper estimates the economic impact of inadequate telemetry spectrum access. The analysis is derived from probable future scenarios at a test range complex over a twenty year period. While based on a US test range complex, spectrum encroachment is an international issue as a result of increased commercial interest. Economic considerations are important to the proposal currently before the International Telecommunication Union (ITU), as Agenda Item 1.5 of the 2007 World Radio Conference (WRC), which calls for the allocation of additional spectrum for wideband ATM in the 3-30 Gigahertz (GHz) band. This study was requested by Mr. Derrick Hinton, who represents the Director, Test Resource Management Center (TRMC).

KEYWORDS: Aeronautical Telemetry, ATM, Economic, Bandwidth, Bandwidth Demand Model, Economic Model, Range, Spectrum, Telemetering, Telemetry, Test, Wideband Telemetry, World Radio Conference, WRC

Executive Summary

The flight test community faces a crisis in that insufficient spectrum is available to support telemetering requirements. The amount of spectrum available for aeronautical telemetering is inadequate today, and demand is growing exponentially. Aeronautical telemetry is used to transmit real-time data during flight tests, and the availability of such data is integral to the productivity and safety of live flight test programs. Sufficient telemetry spectrum access is critical to maintaining rigorous system testing and meeting commercial and military flight test requirements. The Department of Defense is developing technological and regulatory solutions to help offset the spectrum shortfall. Technology research initiatives offer the prospect of increasing the bandwidth efficiency and, if they reach their intended capability, may partially offset telemetry spectrum demand until more spectrum access may be secured. A regulatory solution is currently proposed before the International Telecommunication Union as Agenda Item 1.5 of the 2007 World Radio Conference. This proposal calls for the allocation of additional spectrum for wideband aeronautical telemetry in the 3-30 Gigahertz band. There are economic implications associated with the potential outcomes of Agenda Item 1.5.

The MITRE Corporation defined probable future scenarios at a test range complex, projected demand and supply of telemetry spectrum, and modeled the economic impacts of spectrum shortfalls. Potential future scenarios vary from no spectrum allocation change to significantly increased allocation of telemetry spectrum to meet needs over the next twenty years. In each case, technology development plays an important role. MITRE defined six future scenarios of telemetry spectrum supply, the baseline being the 215 Megahertz of current available spectrum and five alternatives reflecting World Radio Conference decision outcomes ranging from 0 to 650 Megahertz of spectrum augmentation. The six scenarios used for analyzing economic impact also define additional influences including the use of additional and new test resources and test impacts due to spectrum shortfall. Forecasts of future telemetry demand are based on current usage, statistical analysis of historic test range data, projections of test demand associated with new complex aeronautical development programs, and recent and planned technology developments.

The study team built an economic model to estimate cost impacts of inadequate telemetry spectrum at a test range complex. Based on actual data from test ranges, expert interviews, and several previous reports, the model estimates component costs represented in each scenario. Programs incur significant costs – an estimated $60 million a year on a test range today – when tests must be delayed due to telemetry spectrum shortages. Test programs that are not able to obtain the spectrum access they need at their usual test facilities must find spectrum resources elsewhere. Lack of telemetry spectrum access may cause programs to reduce the number of test points collected during flight testing. This test point shedding may, in turn, lead to reduced quality of testing. At some point, failure to fully test results in catastrophes and fatalities. Inadequate testing is a major cost factor; based on a case example, inadequate testing may cost almost $1.6 billion per incident. Costs to programs, development contractors, and the national economy can be huge when one also considers loss of competitive advantage from delay in marketing and sales of new commercial aircraft, or reduced military effectiveness from unavailability of more advanced aeronautic systems.

Inadequate telemetry spectrum access also amplifies the need for investment in technology research and development. This offers the prospect of new methods to increase the efficiency of bandwidth utilization so real-time data can be transmitted as efficiently as possible. However, there is technical risk for technologies not yet proven, and research initiatives that do not reach their intended capability will not improve bandwidth utilization. The Integrated Network Enhanced Telemetry (iNET) project offers the prospect of a wireless network to supplement point-to-point telemetry capabilities. In addition to technology research and development, investment in test infrastructure may be required to utilize additional or new test resources. Use of additional test resources is only possible if there are alternative ranges available far enough away from existing ranges to allow for spectrum reuse. New test ranges are only possible at a huge expense, and thus are not realistic in the present environment due to the significant geographic, legal, environmental, political, and upfront investment hurdles.

The economic model aggregates the cost impacts of inadequate telemetry spectrum at a test range complex over a twenty year period, from 2005 to 2025. For the defined scenarios, this cost varies from almost $23 billion in the worst case to over $1 billion in the best case. Projections of other scenarios fall within this range. In the year 2025, the worst case shows an annual cost of almost $3 billion and a spectrum shortfall of 977 Megahertz, whereas the best case shows an annual cost of under $58 million and a zero spectrum shortfall. The best case is the only scenario in which requirements for telemetry spectrum are met over the next twenty years.

This study and its resulting economic model point to substantial cost impacts associated with telemetry spectrum shortfall. Operational and scheduling setbacks for flight testers seen daily at test ranges result in millions of dollars of added cost to the development or modification of aeronautical systems. The increasing complexity of these systems – driving the need for more extensive testing and integration with more test assets, advanced testing techniques requiring greater utilization of real-time video and high data rates, and shorter development cycles – are conclusively leading to an exponential growth in the demand for telemetry. While technology advances may mitigate some of the bandwidth shortfall, it is clear that spectrum augmentation is critical to closing the gap and reducing the costs identified in this study. It is important that the telemetry user and provider community protect and defend spectrum to ensure its future availability for aeronautical telemetering. The future use of spectrum must be carefully planned so it can adequately support commercial and government flight test missions. The World Radio Conference decision on telemetry spectrum augmentation is critical and will determine the nature of flight testing and impacts to this community far into the future.

Acknowledgments

The authors would like to acknowledge and thank the other individuals who contributed to this study. First and foremost, we would like to extend our sincere appreciation to those who shared their experiences, wisdom, and time with us. In particular, thanks to Tim Chalfant, Jim Zimmerman, Jeffrey Acurso, Michelle Caldera, Steve Cronk, Pat Feeley, Ed Garza, Paul Hashfield, Bob Jefferies, Paul Jonas, Charles Jones, Sid Jones, John Kellas, Steven Kuipers, Dan Laird, J. J. Littlefield, Dennis Madl, Steve O'Neal, Saul Ortigoza, Randy Scott, Bob Selbrede, Ronald Streich, George C. Tolis, Doug Warren, Gary D. Welty, and Vicky Yoshida. These individuals helped make this study possible. Further thanks to Craig Ernst, Jean-Claude Ghnassia, Bill Horne, and Mikel Ryan for their contributions. The authors would like to thank David Crawford, Frank Dello Russo, Ray Faulstich, Robert Giallombardo, Edward Gonzalez, Charles Lehan, Joe McMorrow, Barbara Moran, Andrew Wisdom, and Beverly Woodward for their insights and helpful reviews. Thanks to Janice Ballo for the materials and information contributed through her search efforts. Also, thank you to Rosemarie Mauriello for assistance in producing this document.

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1.0 Introduction

A communications revolution began in the late 1980s as the telecommunications industry made far-reaching strategic plans to make wireless data communications an inexpensive consumer commodity. These plans led to the auctioning of radio spectrum that was formerly used for high technology research and development. But the same developments in information technology that are driving the consumer telecommunications market are also driving the growth in technical capabilities in the aerospace research and development community, a community that lost spectrum to the commercial services.

Research, development, fielding, and upgrades of aeronautical products – including engines, avionics, and aircraft – rely heavily on aeronautical telemetry (ATM)[1] spectrum for the testing of these products. New and existing aircraft programs conduct flight tests to evaluate the performance of a new prototype aircraft or a new piece of avionics equipment on an existing aircraft. These flight tests rely on ATM spectrum to transmit real-time data from test vehicles to ground stations. Displaying and analyzing data in real-time allows testers to conduct safe, effective, and efficient tests. Telemetry also expedites testing by enabling real-time decisions and results that shorten the time required to complete testing and qualify new products. This results in new, safer, more efficient products reaching the market faster. In turn, old systems can be retired faster, operation and maintenance costs can be reduced, and aerospace companies reap higher profits.

ATM cannot exist without Radio Frequency (RF) spectrum, and the amount of spectrum now available for ATM is not sufficient to meet today's needs and requirements. This problem only worsens with the sharp rise in demand of ATM spectrum expected in the future. ATM spectrum is vital to both commercial and military flight testing activities.

1.1 Objective

The purpose of this paper is to assess and evaluate the economic importance of having adequate accessibility to ATM spectrum. Economic considerations are important to the proposal currently before the International Telecommunication Union (ITU), as Agenda Item 1.5 of the 2007 World Radio Conference (WRC), which calls for the allocation of additional spectrum for wideband ATM in the 3-30 Gigahertz (GHz) band. Spectrum allocation for telemetry has both national and international economic implications. The economic considerations addressed in this study, in the context of impacts to a US test range complex over a twenty year period, impact the development and testing of aeronautical systems for both commercial and military programs. The

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[1] Telemetry is the process of measuring at a distance. Aeronautical telemetry is the process of making measurements on an aeronautical vehicle and sending those measurements to a distant location for analysis.

sponsor for this task is the Director, Test Resource Management Center (TRMC), whose predecessor components were formerly under the Director, Operational Test and Evaluation (DOT&E). Under the Office of the Undersecretary of Defense for Acquisition, Technology & Logistics (ATL), TRMC is responsible for US test range infrastructure. This report documents an analysis and economic model developed to quantify a likely range of costs resulting from possible outcomes of WRC Agenda Item 1.5.

1.2 Background

A 2003 MITRE study by Darrell Ernst and Carolyn Kahn, entitled "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," investigated general economic factors associated with telemetry spectrum. Its findings serve as a starting point for this subsequent paper. The 2003 study researched and documented the importance and value of telemetry to the US economy. The 215 Megahertz (MHz) of currently available telemetry spectrum, all below 3 GHz, all unrestricted and accessible across the US, is valued at approximately $105 billion.[2]

The aerospace industry contributes greatly to the US economy. The aerospace industry generates 15% of the US gross domestic product (GDP) and over 11 million jobs. Aerospace products account for the largest positive balance of payments contribution of any sector of the nation's economy. Over 40% of the industry's products are exported. The largest US exporter is an aerospace company. The US relies on air travel to move passengers and products rapidly across the nation and around the world. Each year, US airlines move over 600 million passengers and many times that number of pieces of cargo. The country depends on satellites for inexpensive and instantaneous global communications and navigation. The US also depends on the aerospace industry to arm the military with superior weapons, particularly the advanced airborne systems needed for the command, control, communications, and surveillance that are the foundation of our national and international security. A strong aerospace industry also enables scientific discovery.[3] A high priority should be placed on enhancing the health of the aerospace industry, considering its

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[2] The Office of Management and Budget (OMB) values 1 MHz of spectrum at about $500 million. In addition to the 215 MHz of spectrum, there are bits and pieces of telemetry spectrum allocated in other bands. However, these additional bits and pieces of spectrum have not been included in the $105 billion; its high degree of fragmentation and large number of caveats makes it difficult to quantify or to use.

[3] Walker, Robert S. "US Aerospace Commission Letter to President Bush," Commission on the Future of the US Aerospace Industry, 20 March 2002. Further information on the US aerospace and aviation industry can be found in Appendix I.

importance to the US economy. Nations with strong aerospace industries typically also have strong government support and R&D.[4]

The aerospace industry depends heavily on aeronautical telemetry for flight testing. Wideband aeronautical telemetry is used to transmit real-time data from the test vehicle.[5] It provides data from the aerospace vehicle to the ground, video of cockpit or test article, and monitoring of flight research and test parameters. By displaying and analyzing data in real-time, flight testers can conduct safe, effective, and efficient missions. This is vital to both commercial and military flight testing. Aerospace companies benefit from the use of telemetry, reducing cost and risks of flight testing while enabling them to develop and deliver increasingly sophisticated aeronautical systems. Telemetry spectrum is an enabler to the aerospace industry and must be defended and augmented to meet future requirements.

There are serious consequences when aerospace programs do not have access to sufficient telemetry spectrum. Flight test missions are sometimes delayed or cancelled. This, subsequently, results in schedule delays, additional test flights, increased program costs, and greater risks. Development of Department of Defense (DoD) systems, already strained by limited budgets, suffer further schedule delays and cost increases. Companies contracted to develop aeronautical systems incur increased costs and delays that erode their competitive position in the international marketplace. Consequently, aerospace companies would likely sell fewer exports.

The 2003 MITRE study documents specific economic impacts to aerospace organizations resulting from limited ATM spectrum. For example, if telemetry spectrum allocation were reduced by half, the number of flight tests may increase two- to four-fold.[6] If telemetry spectrum were not available at all, many flight tests could not be conducted. For the remaining flight tests, the testing period may extend over 5-10 times the original schedule and costs may increase over 50-100 times.[7] One delayed or canceled test mission due to the unavailability of telemetry spectrum may cost in excess of $1 million. Significant resources are devoted to flight testing, including support equipment, people, and range costs. For a flight test requiring 500 people and assuming an industry average labor rate of $100 per hour,

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[4] "Partnering in the Global Context," Report of the Aerospace Industry Action Agenda, Department of Industry, Tourism, and Resources, Australia, November 2003.

[5] Real-time implies that the process delay is sufficiently short so that personnel can interact with the test as it happens.

[6] Based on numerous expert interviews.

[7] Based on interview with Company A.

a one-hour delay would cost $50 thousand in labor; a four-hour delay would cost $200 thousand in labor. There are also costs involved to fly labor and other resources to a flight test facility located in a different part of the country. Furthermore, the delay of testing by one day may cause a delay of several additional days due to unavailability of all of the required resources and assets (e.g., chase aircraft, equipment calibration, and range availability) which in turn must be re-scheduled. Flight test delays due to insufficient telemetry spectrum impact time-to-market competition, as some sales are delayed and other sales may be lost to the competition. A company study on time-to-market competition found that flight test delays in the last six to eight months of a program slow the time-to-market, which increases the cost of delay by a factor of ten.[8] MITRE's case study interviews with over twelve aerospace organizations revealed estimated consequences of insufficient telemetry spectrum for each company. Thus, the allocation of additional telemetry spectrum as proposed by the WRC 2007 Agenda Item 1.5 is important to mitigating the adverse direct and indirect effects on a critical sector of our national economy.

1.3 Problem

Aeronautical telemetry cannot exist without RF spectrum. However, other telecommunications applications (e.g., cellular, satellite broadcasting) also rely on spectrum. The use of a frequency at a given location usually excludes that frequency from being used by others in the same geographic area. Spectrum is allocated for various applications at the international level by the WRC.

Multinational telecommunications and broadcasting companies are better positioned than aerospace organizations to influence global spectrum allocations because they tend to view spectrum as a revenue-generating resource. In contrast, the aerospace and defense industry generally views spectrum as a cost to minimize. This industry typically generates low growth, low margins, unstable revenue, and heavily depends on a single, major, and unpredictable customer – the government.[9]

In addition to the commercial sector, telemetry is also highly valued by DoD. DoD is increasingly demanding more telemetry spectrum. This increasing demand can be represented by the significant historical growth of mission data rates. At the same time, the supply, or available bandwidth, of telemetry spectrum has decreased considerably. This growing disparity of telemetry demand and supply is illustrated in the following figure.[10]

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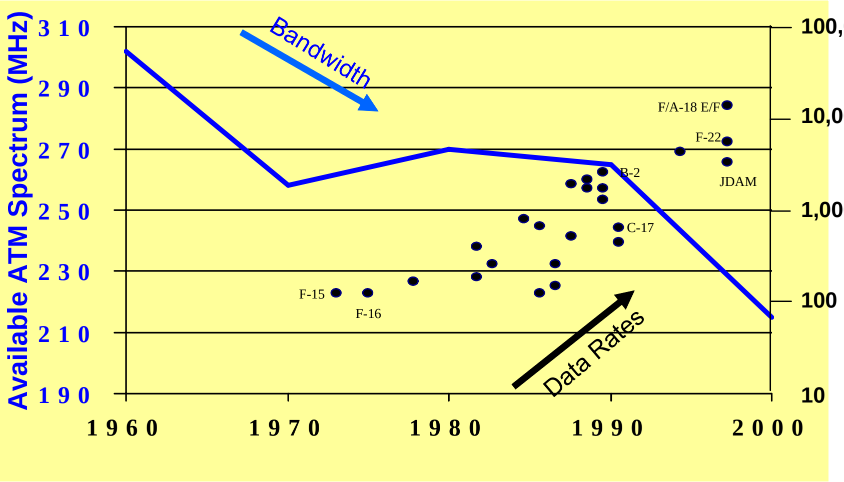
[8] According to a 1997 Company B study.

[9] "Final Report of the Commission on the Future of the United States Aerospace Industry," Aerospace Commission, November 2002.

[10] Ernst, Darrell, The MITRE Corporation, 19 March 2003.



Blue line shows amount of ATM spectrum available for DOD use (left scale)
Black dots show ATM data rates of major aircraft and missiles (right scale)

Figure 1-1. Disparity of Telemetry Spectrum Demand and Supply

David L. Seeholzer, Vice President of Engineering at Teledyne Systems Company, summarizes the ATM spectrum problem: "The continual increase in flight test activities, requiring not only higher [Pulse Code Modulation] (PCM) bit rates, but also the concurrent use of real-time video is demanding wider telemetry channel bandwidths."[11]

The amount of spectrum now allocated for aeronautical telemetry is not sufficient to meet today's needs, and requirements have been steadily growing. The demand for ATM spectrum escalates as the number of new and existing programs rise while, at the same time, their systems become increasingly complex. Unmanned Aerial Vehicles (UAVs) will require much greater bandwidths as this technology emerges in the future. Aerospace programs demand better, faster testing to achieve more rapid acquisition cycles and time-to-market.

Further exacerbating the spectrum problem, twenty-two percent of the bandwidth available for telemetry in 1980 has already been reallocated to consumer applications.[12] The following figure shows Test and Evaluation (T&E) spectrum losses.[13]

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[11] Seeholzer, David L., Vice President of Engineering, Teledyne Systems Company, letter to FCC Chairman, 20 March 1991.

[12] Ernst, Darrell, Yan-Shek Hoh, and David Portigal, "Projected Growth of Spectrum Requirements for Aeronautical Telemetering," The MITRE Corporation, MTR 03W0000015, March 2004.

[13] "WRC 2007 Agenda Item 1.5 Critical to US Weapon Superiority," DOT&E, August 2004.

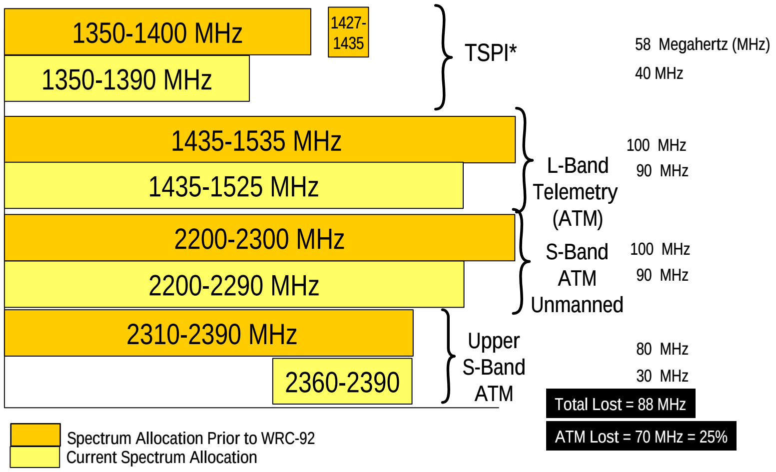

Figure 1-2. Summary of T&E Spectrum Losses

Encroachment has already limited the amount of ATM spectrum available in a timeframe that has seen the largest increase in the number of users and their desired bandwidths.

The amount of spectrum allocated for aeronautical telemetry is inadequate. Support for WRC Agenda Item 1.5 will help avoid the adverse effects from insufficient telemetry spectrum.

1.4 Study Methodology

MITRE solicited input from numerous aerospace industry and government experts from the test community in developing the methodology used for this study. The study team brainstormed on several occasions and gained consensus on the methodology definition. This methodology includes the following steps: data collection, development of assumptions, demand analysis, scenario and gap assessment, economic analysis, findings, and conclusions.

In the data collection step, MITRE conducted extensive research to identify existing sources of information on the economic impacts of inadequate ATM spectrum access. We identified research, government, international, academic, and market reports from a wide variety of sources. Sources of research reports include the Commission on the Future of the US Aerospace Industry, American Enterprise Institute, and Aerospace Industries Association. Government reports from the Government Accountability Office (GAO), Congressional Budget Office (CBO), US Senate, Defense Science Board (DSB), DOT&E,

and Industrial College of the Armed Forces were examined. The International Chamber of Commerce, ITU WRC Agenda Item 1.5 Working Group, and governments worldwide provided an international perspective. The team investigated academic papers on testing, spectrum economics, regulation, and technology introduction and diffusion. Market reports from the Strategis Group, RCR Wireless, Spaceflight Now, Cellular News, Aviation Week and Space Technology, and CNN were also explored.

We leveraged results of three earlier requirements studies which estimated current and future ATM spectrum requirements. The first requirements study is the 1998 New Mexico State University study by Sheila Horan, entitled "DoD Aeronautical Telemetry Resources Survey. The second study is the 2004 Sarnoff study, "RDT&E Spectrum Requirements Assessment.[14] Third, MITRE leveraged its 2004 study on "Projected Growth of Spectrum Requirements for Aeronautical Telemetering" by Darrell Ernst, Yan-Shek Hoh, and David Portigal. The New Mexico and Sarnoff studies documented estimated requirements for a test range. The MITRE report provided estimated program requirements.

In addition to the requirements studies, MITRE conducted extensive expert interviews to obtain additional information. MITRE again drew on a wide variety of sources from both the public and private sectors in the US and abroad. We met with experts at test ranges, manufacturing companies, and contractors. MITRE interviewed approximately 80 experts, often conducting multiple interviews with each expert. Much of the data gained through the expert interviews is proprietary. The MITRE Corporation, a not-for-profit corporation working in the public interest, is a trusted partner and protected the proprietary nature of the economic data provided by these organizations by not including any organization identifying information in the report. Rather, the report refers to organizations in an anonymous fashion. The original data gained from the technical experts forms a vital component of the study, and the MITRE team leveraged its valuable list of contacts throughout the analysis.

In the second step, MITRE developed the parameters and assumptions for the economic model based on the data gathered in the first step. MITRE examined data intervals and obtained and used conservative assumptions to avoid bias to the results. These assumptions as well as projections of future spectrum allocation were defined in specific, credible scenarios. For each assumption, MITRE documented the rationale and data source.

For the third step, the study team developed a time series demand analysis to estimate current and future requirements of ATM spectrum. MITRE built a robust bottoms-up ATM bandwidth demand model (BDM) using a combination of statistical analysis of historical data, information from the program office of a new aircraft development program, and an

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[14] The Horan and Sarnoff reports were originally prepared for DoD using DoD studies. Some of these studies have not been cleared for public release. Contact TRMC for further information.

estimate of future flight test profiles based on the profile of the new development program. The model incorporates both recent and planned technology developments.

Fourth, MITRE conducted a scenario and gap assessment. The team defined a set of probable future scenarios on a test range over a 20+ year period. These scenarios are used to evaluate the potential spectrum environment in the future. We conducted sensitivity analyses among the scenarios. MITRE also analyzed the difference between demand and supply, or the gap. This gap, or disparity between ATM requirements and supply over time, forms the basis of the economic analysis.

In the fifth step, MITRE developed an economic model to assess economic implications associated with the gap. We identified and incorporated cost impacts of the gap. These economic impacts include costs for technology investment, test delays, test infrastructure enhancements, and inadequate testing. Multiple scenarios were analyzed to understand sensitivities.

Finally, we reported our findings from the economic model and drew conclusions. For each defined scenario in the economic model, MITRE computed a total cost of the inadequate ATM spectrum access. We performed sensitivity analyses on the findings to test whether the conclusion of an economic analysis will change significantly if a cost, benefit, or other variable changes. MITRE's analysis methodology relied extensively on the data provided by industry and government experts, but conservatively forecasted future scenarios and tested the results for a range of possible assumptions and outcomes.

1.5 Limitations and Constraints

There were several limitations and constraints that influenced the course of this study; however, the methodology was tailored to minimize the impact of these limitations on the results. A principal limitation concerned data availability. As mentioned, the study leveraged previous statistical analyses of historic telemetry requirements at a test range complex, and built estimates of current and future telemetry spectrum requirements from incorporating projected influence of current technology developments. Our forecasts are based on these projections combined with the opinion of test community experts consulted. Data to analyze and substantiate specific cost or economic impacts is generally not readily available, mostly because it is not collected or is difficult to measure or quantify. The study relied on significant anecdotal information and select data points provided by a number of contractors and government personnel in the course of expert interviews, and the study analysts used best judgment in applying such data conservatively in the economic model. Another challenge is that both contractor and test range data are frequently proprietary and competitively sensitive. Organizations want to promote positive images and ensure that they do not lose business to their competitors. The T&E community has already been burdened with numerous surveys related to this topic, so there is a natural reluctance to respond to further questions. There remains a possibility of unanticipated legislative mandates, and the economic impacts of such unforeseen political developments have not been incorporated into the economic model. As a Federally Funded Research and Development Center (FFRDC), MITRE developed a trusting relationship with the organizations and individual experts it consulted and protected proprietary data. Analytical challenges included the need for assumptions and best estimates based on expert engineering judgment. For example, the consequences of not testing or inadequate testing are indefinite, their cause hard to determine, and their cost difficult to analytically measure and prove. The development and analysis of economic impact for multiple scenarios, based on well-documented and conservative assumptions, determines a variety of possible economic consequences and mitigates some of the study limitations. MITRE conducted a comprehensive review of the results.

1.6 Organization of Paper

This paper is organized as follows. Section 2 highlights key study findings. Section 3 provides a general overview of the economic impacts of ATM spectrum allocation. Section 4 introduces the economic model. Section 5 describes the gap analysis and Section 6 presents the economic model. Section 7 discusses supporting findings. The paper concludes with final remarks in Section 8.

2.0 Key Findings

This study discovered many economic implications of ATM spectrum accessibility. These implications are summarized in the key economic findings presented below.

- Inadequate ATM spectrum access imposes significant increased costs to aerospace programs, aeronautical system contractors and ultimately the government and commercial consumers of their products. Specific costs include those incurred as a result of test delays and inadequate testing, as well as technology investments and test infrastructure enhancements necessary to work within limited spectrum allocations. Spectrum augmentation is critical to minimizing these costs.
- Test delays cost programs an estimated $60 million a year on a test range. Inadequate testing, resulting from a reduction in the number of test measurements, places a program at increased risk of catastrophes and fatalities and may cost almost $1.6 billion per incident.
- Technology investments and test infrastructure enhancements may help reduce the telemetry spectrum shortfall.
    - For example, research and development of the Integrated Network Enhanced Telemetry (iNET) project offers the possibility of a wireless network to supplement point-to-point telemetry capabilities. However, research initiatives that do not reach their intended capability will not improve bandwidth utilization or reduce the spectrum shortfall.
    - Test infrastructure enhancements reduce excess demand at a given range through geographic separation. Use of additional test resources is only possible if there are alternative ranges available far enough away from existing ranges to allow for spectrum reuse. New test ranges are only possible at huge expense, and thus are not realistic in the present environment due to the significant geographic, legal, environmental, political, and upfront investment hurdles.
- Insufficient access to ATM spectrum will cost an estimated $11.3 billion with Integrated Network Enhanced Telemetry (iNET), or $22.9 billion without iNET, over the next twenty years without spectrum augmentation or new test range resources.
- For the scenarios defined in this study, the economic model projects cost impacts at a test range complex of almost $23 billion in the worst case scenario to over $1 billion in the best case over the next twenty years. The worst case scenario considers no augmentation of spectrum allocation, while the best case provides an additional 650Mhz of wideband telemetry spectrum. Projected costs of other

scenarios, defined by varying levels of spectrum allocation and test resource investment, fall within this range.

- In twenty years, the worst case shows an annual cost of almost $3 billion and a spectrum shortfall of 977 Megahertz, whereas the best case shows an annual cost of under $58 million and a spectrum shortfall of zero.
- Telemetry spectrum augmentation provides a benefit, or cost savings, as compared to the status quo case of no augmentation of telemetry spectrum. WRC spectrum augmentation of 650 MHz with iNET provides an annual benefit of $2.6 billion and is the only scenario in which requirements are met in the base case over the next twenty years.
- According to the World Technology Evaluation Center, "There is no other industry more international than commercial aircraft, and the trend toward further internationalization is increasing."[15] Worldwide frequency allocation facilitates interoperability of equipment both internationally and nationally, lowers costs through manufacturing economies of scale, and provides more stability and certainty in frequency planning.
- The future use of spectrum must be carefully planned so it can adequately support commercial and government flight test missions.

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[15] World Technology Evaluation Center, http://www.wtec.org/loyola/polymers/c2_s5.htm, April 1994.

3.0 Model Overview

To estimate the economic impact of the future ATM spectrum environment, MITRE developed a robust model-of-models. This economic model-of-models integrates several comprehensive analysis frameworks that examine current and projected demand and supply of ATM spectrum and determine the gaps between demand and supply. The model then assesses cost impacts of these gaps, measured over a 20 year period in the context of a single test range complex, for a set of potential future scenarios. The model builds in ‘toggles’ for the underlying drivers and key assumptions in each area to permit sensitivity analysis.

The first component of the economic model is MITRE’s ATM bandwidth demand model (BDM). The BDM is an important bottoms-up analysis of future ATM bandwidth demand that addresses trends in aeronautical system design and complexity, test requirements and methods, and programmatic constraints that are increasing the need for aeronautical telemetry. The BDM also incorporates assessments of current research into emerging technologies and development efforts that may increase the efficiency of bandwidth utilization thus potentially offsetting some of the ATM demand growth. The BDM forecasts the demand for bandwidth by the flight test community at a test range complex. Forecasts are based on statistical analysis of historic test range data, projections of test demand for new complex aeronautical development programs, and recent and planned technology developments.

The BDM is used in the economic model to develop 11 cases of ATM spectrum demand and incorporate toggles to test the sensitivity of test range operations and technology impact assumptions. MITRE developed 6 future scenarios of ATM spectrum supply, defined by the current spectrum available for ATM (215 MHz) and possible alternative WRC decision outcomes that range from 0 to 650 MHz of spectrum augmentation. The economic model applies additional factors to these supply scenarios to address the rate that new spectrum will be accessed and utilized (driven by rate of investment in new equipment), and the rate of technology diffusion within the test community.

Based upon the demand and supply models, the economic model estimates the annual ATM spectrum gaps at the test range complex over a 20 year period. Details of the ATM demand, supply, and gap analysis incorporated in the model are provided in following sections. The model next calculates estimated cost impacts of the gap. This study identified several cost impacts of insufficient ATM spectrum. These include significant additional direct costs that programs bear when tests must be delayed due to telemetry spectrum shortfalls, as well as costs of moving testing to a different geographic location to access different test resources. Programs that have difficulty accessing telemetry spectrum may choose to use less efficient test methods or to scale back testing. This may result in inadequate testing, leading to more costly system failures and required redesign later in the development cycle; another consequence is the more serious potential loss of assets and lives either during testing or, if flaws remain undetected until the aircraft is deployed, operations. Insufficient ATM spectrum access intensifies the need to invest in new technologies in an attempt to realize higher bandwidth utilization efficiencies. It may also create the need to invest in new or additional test resources in different locations that, through geographic separation, may not experience spectrum interference.

Details of the analysis and assessment of each of these cost impacts and how they are applied in the economic model are provided in Section 6 of this report. Costs were developed from data and anecdotal information provided by subject matter experts from industry and test ranges. The economic model assesses each of these costs in estimating a total annual and 20 year cost impact against the estimated ATM spectrum gap. Thus the model provides insight into the economic impacts of the WRC spectrum augmentation decision, built upon current technical and operational aspects of complex aeronautic testing environments, projections of future ATM spectrum demand and supply, and analysis of costs that result from constraints imposed by ATM spectrum limitation.

4.0 Bandwidth Demand

Section 4.1 provides background on driving factors of bandwidth demand. Section 4.2 describes the details of MITRE's BDM model.

4.1 Driving Factors of Demand

This study defines demand as requirements for ATM spectrum. Many factors drive ATM spectrum demand growth. Some of these factors contribute to increased growth, while other factors have the potential to help mitigate the effects of the demand growth in the short-term. Section 4.1.1 discusses factors which contribute to the growth of ATM spectrum demand. Section 4.1.2 covers factors which may potentially offset the growth of ATM spectrum demand until more spectrum access can be secured.

4.1.1 Factors Contributing to the ATM Spectrum Demand Growth

Several factors contribute to the growth in ATM spectrum demand. System complexity, larger footprints, and shorter acquisition cycles drive requirements for higher data rates. These drivers are discussed in Sections 4.1.1.1 through 4.1.1.4.

4.1.1.1 Increased System Complexity

Aeronautical vehicles are incorporating increasingly complex technology. This growing complexity contributes to increased demand for spectrum. More testing is needed for these complex systems to address increases in avionic systems speed and integrated sensors and avionics. Flight testers must evaluate integrated system-of-systems test articles. Many of these systems must be tested in an operationally representative integrated environment. Commercial test programs may require integration with existing and other new systems. Military aircraft test programs may require multiple aircraft attacking multiple intruder targets. Future Net Centric Warfare concepts will introduce a higher degree of complexity that could require even more spectrum to adequately test the performance of the networked complex of systems.

4.1.1.2 Greater Use of High Definition Video

Telemetry experts predict that high definition video will be used increasingly in flight test for monitoring airframe components, cockpit instrumentation, and personnel condition and actions. It is anticipated that demand for data capacity will experience an order-of-magnitude increase in the next ten years as real-time, high definition video is used in flight testing.[16]

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[16] Kahn, Carolyn A., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," The MITRE Corporation, MTR 04B0000016, December 2003.

4.1.1.3 Larger Footprints

New aircraft are anticipated to operate both at higher altitudes and faster speeds. Testing at these higher altitudes and faster speeds require greater distances for flight tests, or larger footprints.

Modern aircraft have large footprints of 70 to 150 nautical miles. Supersonic vehicles may extend over several ranges. Figure 4-1 shows the coverage of typical telemetry signals when operating at 36,000 feet.[17]

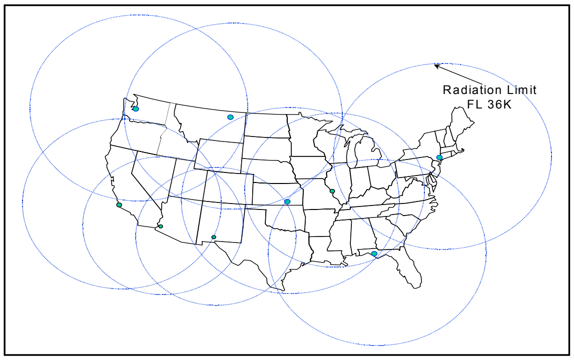

Figure 4-1. Typical Telemetry Signal Coverage

As footprints increase in size, geographic reuse is reduced. Geographic reuse is a widely used technique to increase the efficiency of spectrum usage where multiple users are contending for ATM spectrum resources. On a range, highly directional receiving antennas and carefully planned flight paths allow two or more aircraft to use the same frequency allocation concurrently. At multiple range complexes, the ability to exploit geographic reuse is highly dependent on local topography features that prevent the RF telemetry transmissions from a flight on one range from interfering with receives at another range. The larger footprints required by new aircraft will cause a loss in geographic reuse relative to the current practice. This geographic reuse loss translates into additional requirements for ATM spectrum allocation.

4.1.1.4 Shorter Acquisition Cycles

The need for a shorter acquisition cycle drives the need for higher telemetry rates. Typically, as acquisitions are accelerated, the time and budget allocated for tests are correspondingly cut. On past programs, many corporations have been able to substantially shorten test cycles by conducting more of the analysis and evaluation in real time, thus

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[17] Ryan, Mikel, Chief, Mid-Atlantic Area Frequency Coordination Office, Patuxent River Naval Air Station, MD, December 1997.

allowing more tests to be conducted in a shorter time period. Avionic flight test is increasingly relying on real-time imaging data. This also allows the tester to be more responsive to anomaly identification and correction, reduces test risk, and increases the safety margins.

The time at which a product reaches the market may determine its success or failure. The chief technology officer of Hewlett-Packard (HP) revealed that getting a product to market one month earlier was typically worth more to HP than its entire engineering and development cost; reaching the market either six months earlier or later increased or decreased, respectively, a product's lifetime profits by one-third.[18] The tight competition and high development costs of the aerospace industry make time to market particularly important. Aerospace companies have disclosed that time to market can "make or break a program." One company reported that the use of telemetry cuts its flight testing period in half.[19]

4.1.2 Factors with Potential to Offset ATM Spectrum Demand Growth Until More Spectrum Access Can Be Secured

There are other factors – namely research initiatives – which may potentially help offset ATM spectrum demand growth in the short-term, or until more spectrum access can be secured. These research efforts have the potential for increasing telemetry efficiency. However, even if these efforts reap their potential benefits, they still cannot meet the demand for ATM, which is growing exponentially.

The following table describes existing or emerging technologies that may improve spectrum utilization. Key examples of each technology are also included in the table.[20]

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[18] John T. Preston, "Steps to High-Tech Success," The Industrial Physicist, American Institute of Physics, August/September 2003.

[19] Kahn, Carolyn A., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," The MITRE Corporation, MTR 04B0000016, December 2003.

[20] "Spectrum Management: Better Knowledge Needed to Take Advantage of Technologies That May Improve Spectrum Efficiency," GAO, May 2004. Note that this table emphasizes applications to voice transmission technologies, but analogous advances would improve telemetry spectrum utilization.

Table 4-1. Existing or Emerging Technologies That May Improve Spectrum Utilization

Technology	Description	Key Examples
Radio frequency component-level	Encompasses a broad set of radio frequency components – transmitters, receivers, and antennas (and their enabling technologies) – that can improve spectrum utilization.	• "Smart" antennas that can selectively amplify desired signals while canceling out competing signals. • Modulation and channel coding can also influence how much spectrum is needed to transfer encoded voice data.
Other component-level	Encompasses a broad set of other (non-radio frequency) radio components including digital processors and associated algorithms to compress data, and batteries for handheld devices.	• More advanced algorithms to encode and digitally compress a human voice can greatly reduce the radio's data transfer requirements. • Improving the efficiency of a handheld radio's battery can allow it to accomplish more sophisticated data compression, modulation and coding, and thus indirectly, influence the radio's ability to use spectrum more efficiently.
Other enabling technologies	Includes investments in various technologies that may yield improvements to spectrum utilization and efficiency.	• Advancements in microelectronics and semiconductors have enabled greater processing power in smaller lighter weight packages. These advancements continue with the development of semiconductor technologies that may greatly improve upon the performance of today's radio-frequency components. • Research directed toward improving models of the ionosphere can lead to more efficient use of some frequency bands.
Off-loading technologies	Technologies that are being developed, which would facilitate "off-loading"—that is, relocating certain communications requirements from highly congested radiofrequency spectrum to higher radio-frequency bands and non-radio-frequency portions of the electromagnetic spectrum.	• Research is under way to further the use of lasers to communicate at very high data rates.

In fiscal year 2004, there were 335 US federally funded projects – and approximately $1.8 billion – that may have funded spectrum efficient technologies. The military services and the Defense Advanced Research Projects Agency (DARPA) are the largest federal investors in these new technologies. The following table shows funding for spectrum efficiency projects by agency in FY 2004. Major areas of investment are also highlighted.[21]

Table 4-2. US Federal Funding in Spectrum Efficient Technologies by US Agency

Agency	Areas of Major Investment Related to Spectrum Efficiency	Total Funding for Fiscal Year 2004 ($M)
DARPA	Antenna technologies, laser communications, transistor technologies, and cognitive communications	$339.7
US Air Force	Software defined radio/laser communications	649.4
US Army	Software defined radio	381.9
US Navy/Marine Corps	Software defined radios	172.4
NASA	Optical (laser) communications	41.8
DOJ		0
DHS		0
FAA	Air traffic control communications and digital radar	165.8
NSF	Interference avoidance and measurement, networking, antenna technologies, data compression, error correction, and cognitive radio research	14.8

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[21] "Spectrum Management: Better Knowledge Needed to Take Advantage of Technologies That May Improve Spectrum Efficiency," GAO, May 2004. Note that investments include amounts invested in projects undertaken with a stated goal of improving radio frequency spectrum and projects where spectrum efficiency is not a stated goal but a possible outcome (including enabling technologies like software defined radios). These investments also include projects to off-load/achieve communications in non-radio portions of the electromagnetic spectrum, for example, laser communications. Because of the difficulty identifying relevant projects and quantifying relevant investments in projects where spectrum efficiency may be only a small component, actual investment numbers may be higher or lower. Note also that DOJ focuses on the acquisition of commercial-off-the-shelf equipment. DHS expects to fund research and development into technologies to provide improved spectrum efficiency. The table includes NSF grants funded in fiscal year 2003. According to agency officials, NSF has recently initiated a number of spectrum efficiency projects, including a study of programmable wireless networking, on which it plans to allocate at least $8 million per year.

Research efforts with the potential for increasing spectral efficiency are described below. These efforts include: Advanced Range Telemetry, including Tier 1 and Tier 2 technologies, and Integrated Network Enhanced Telemetry.

4.1.2.1 Advanced Range Telemetry

The Advanced Range Telemetry (ARTM) project, sponsored by the Office of the Secretary of Defense (OSD), DOT&E, and the Central Test and Evaluation Investment Program (CTEIP), was a program to improve the efficiency, reliability, and utility of aeronautical telemetry systems for test and training ranges. This project developed high quality telemetry system components to allow more users to utilize the allocated frequency spectrum to test and train with systems with high data rate, imaging data, and multiple targets/player requirements. Advances in the commercial telecommunications industry primarily drove ARTM's technical approach. The development of new capabilities focused on adapting these advances to aeronautical telemetry. The key technical concept areas were:

- **Efficient Bandwidth Modulation.** A vast majority of the current aeronautical telemetry systems use the legacy “Pulse Code Modulation/Frequency Modulation (PCM/FM)” waveform. Higher order modulation techniques were implemented into upgraded airborne transmitters and ground receivers. The Tier 1 and Tier 2 technologies discussed below were developed under ARTM.
- **Multipath Mitigation.** In order to improve data quality at the higher data rates, system improvements were made. These improvements included the use of equalization, error coding and correction, and space or frequency diversity.
- **Channel Management.** Existing frequency scheduling and deconfliction tools were not designed to optimize the use of the aeronautical telemetry spectrum. An improved system was developed and integrated with range scheduling systems. Fielded in 2004, the Integrated Frequency Deconfliction System (IFDS) uses terrain and equipment characteristics, the geographical area of operation, and mission characteristics to determine if two simultaneous missions are in conflict or will cause interference to each other.

The major benefit of ARTM was the improvement in the telemetry capabilities and capacities at DoD test ranges. These improvements directly resulted in the avoidance of increased cost and schedule slippage due to the limited amount of spectrum or unreliable telemetry data links. Additional benefits of ARTM were commonality, interoperability, and standardization. Through this cooperative effort, Major Range and Test Facility Base (MRTFB) ranges improved the overall test infrastructure and provided a baseline that is economical to establish, operate, and maintain.

4.1.2.2 Tier 1 Technology

Tier 1 technology is a more efficient modulation scheme than the Tier 0 waveform, the baseline against which the performance of the advanced waveform technologies is compared. Tier 0 is the legacy PCM/FM waveform that has been the most popular legacy telemetry waveform since around 1970. Tier 1 consists of any one of three interoperable waveforms that are characterized by constant or nearly constant envelopes and which occupy a much narrower band than does the Tier 0 waveform. Two of the Tier 1 waveforms are patented waveforms developed by K. Fehr, while the third Tier 1 waveform was developed under the ARTM program. Characteristics of allowable telemetry waveforms are discussed in Appendix A of "[Inter-Range Interchange Group] (IRIG) Standard 106-04: Telemetry Standards" that is issued by the Range Commanders Council Telemetry Group. The spectrum occupied by any waveform is proportional to the data rate of the transmitted information. Spectrum occupancy can be quantified by various measures that are discussed in IRIG 106-04. Basic guidance concentrates on the required minimum frequency separation between transmissions. If we take, as a basic measure, the required minimum frequency separation between signals transmitting the same tier waveform at the same data rate, then the required minimum separation between Tier 0 transmissions that implement a legacy receiver design is approximately twice the require separation between Tier 1 transmissions. By this measure, the transmission of information at a given data rate using Tier 1 technology requires half as much radio spectrum as does the transmission of the same information using Tier 0 technology. Actually, the allowable Tier 0 frequency separation can be decreased through use of improved receiver technologies, as discussed in IRIG 106-04, and one such advanced technology provides an allowable separation that is just somewhat greater than the separation associated with the Tier 1 waveform. However, this study does not explicitly consider use of advanced receiver technologies. The Tier 1 technology has been implemented and the associated hardware is available.

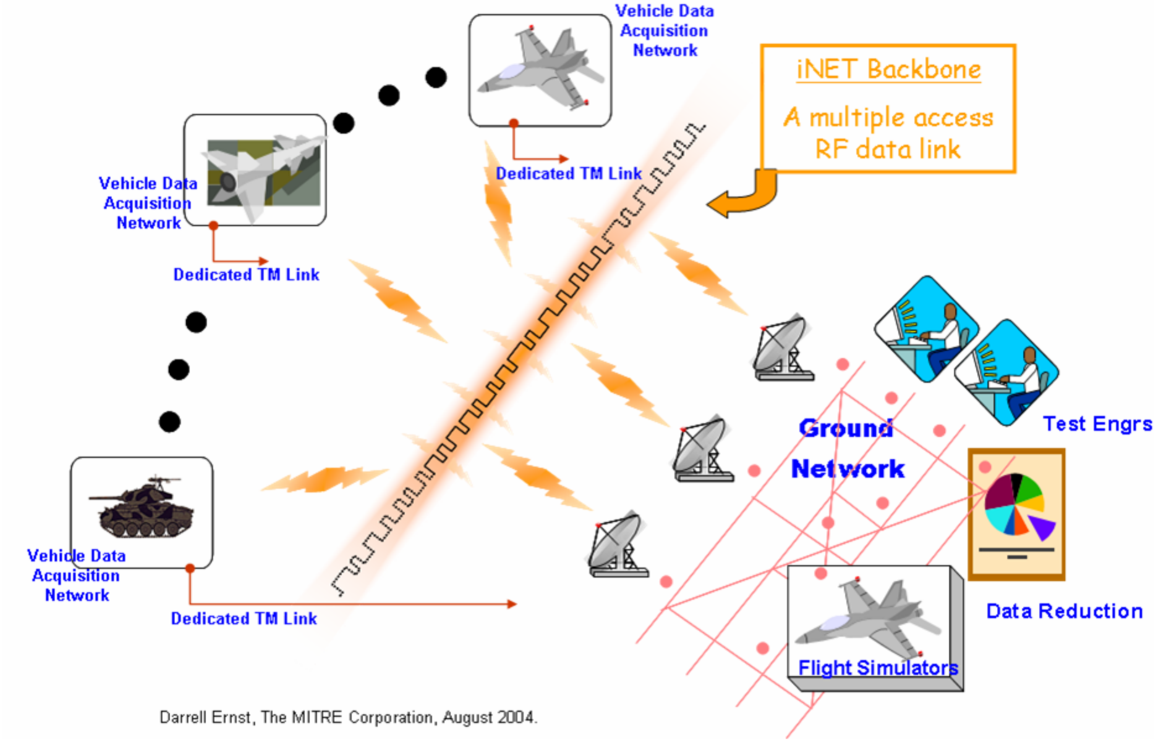
4.1.2.3 Tier 2 Technology

The Tier 2 waveform, which IRIG 106-04 calls the ARTM Continuous Phase Modulation (CPM) waveform, implements a scheme which alternates between two different frequency modulations. The Tier 2 waveform occupies an even narrower band than does Tier 1, in that the required separation for Tier 1 transmissions is approximately 30% larger than for Tier 2 transmissions. However, tests on the implementation of Tier 2 technology found that Tier 2 signals were readily lost and that it was difficult to recover those signals. Consequently, the current ARTM CPM Tier 2 waveform implementation cannot be used in general telemetry applications and more research is required in order to develop a practical Tier 2 waveform.

4.1.2.4 Integrated Network Enhanced Telemetry

Several of the research efforts initiated by the ARTM program have spun-off into the Integrated Network Enhanced Telemetry (iNET) project. The concept of iNET is to use internet-like architectures (Transmission Control Protocol/Internet Protocol (TCP/IP), Space

Communications Protocol Standards (SCPS), and Consultative Committee on Space Data Systems (CCSDS)) to form a wireless network to supplement point-to-point telemetry capabilities. While some critical/safety data will always need a dedicated point-to-point reliable link, a significant portion of the data may be more efficiently handled by a network topology. iNET is currently in the architectural definition phase. The iNET concept is depicted in Figure 4-3.



Darrell Ernst, The MITRE Corporation, August 2004.

Figure 4-2. iNET Wideband Network

4.2 Bandwidth Demand Model

The BDM model forecasts the demand for radio bandwidth by the flight test community at a test range complex. This complex of test ranges share a common electromagnetic space which imposes concentrations of demand for access to that space while also imposing operational constraints on the usage of the spectrum.

The demand model was developed using a combination of an earlier statistical analysis of historical data, a more recent but unpublished statistical analysis of historical data, data from the program office of a new aircraft development program, and an estimate of future flight test profiles based on the profile for the new development program. The model incorporates both recent and planned technology developments.

The statistical analyses, based on 32 years of historical data, are used to develop a projection of the routine daily bandwidth demand, referred to in a recent study as “future on-going,” now referred to here as FOG. This is combined with historical, planned and estimated future peak demands. This peak demand was referred to in the recent study as “system-of-systems” demand; it is referred to in this paper as “maximum user” or just “max user.” The specific model components and their derivations are detailed in Section 4.2.1 below.

4.2.1 BDM Components

The BDM consists of two components. The first part is the estimate of the average day-to-day demand as a result of routine flight test operations. This demand constitutes the large majority of spectrum usage at the test range complex. This component is referred to as “FOG” as described above. The second component of the demand estimate is referred to as “max user” and represents an estimate of the bandwidth needed to support a major new project. Both of these components are described in detail below.

Mathematically, the bandwidth demand model in its simplest form is represented as follows.

$$\mathcal{D} = \mathcal{F} + \mathcal{M}$$

Where

$\mathcal{D}$ = the demand function (explained in preceding paragraph)

$\mathcal{F}$ = the FOG function

$\mathcal{M}$= the max user function

For any given year i, the value of the demand function is given by

$$D_i = F_i + M_i \qquad 2003<i<2025 \qquad \text{(Eq. 1)}$$

4.2.1.1 Derivation of FOG

The FOG function is derived from a statistical analysis of historical data from a test range complex during the period 2001-2004. This analysis, used to study telemetry spectrum usage in the area, concluded that the distribution of user bandwidth demand is highly skewed and recommended the use of the median rather than the mean as a general indicator of spectrum usage. Although there were only four data points, a regression curve was calculated, obtaining an R^2 value of 0.89. The results of the regression were compared against measured data obtained in 1999. The measured data yielded a median user bandwidth demand of 9.6 MHz. The value predicted by the regression analysis was 10.5, a difference of 0.9 MHz. The curve yields a doubling rate of about 13 years. This curve represents the expected growth of median bandwidth demand for individual users at the range complex. The curve is given by the following equation:

$$Y_X = (8.418\text{x}10^{-47})(1.0557^X) \qquad \text{(Eq. 2)}$$

where Y_X = Estimated median bandwidth demand for an individual user in year X.

In order to estimate FOG, it is necessary to multiply the estimated individual user demand by an appropriate factor that represents the typical aggregate demand. The range's statistical analysis shows that in the period 2001-2004 the average maximum demand (termed "utilization" in the range study) was running between 80% and 90% of the total available bandwidth, with demand showing an increase over time.[22]

To estimate the total demand, assume that total maximum bandwidth utilization remains proportional to median bandwidth that supports an individual user operation. Dividing total utilization in MHz by median bandwidth per user in MHz gives the average daily maximum number of simultaneous users. Since the base year for estimating median bandwidth is 2001 and the maximum utilization in 2001 was 0.8 of the available 215 MHz, the mean number of users is 14.3. Use this as the multiplier of median bandwidth to get average daily maximum demand. Since the data that produced the statistics was obtained prior to the usage of the advanced modulation technologies referred to as Tier 1, Tier 2, and a hypothetical modulation technology called Tier 3, this estimate of demand is referred to as "Tier 0" (i.e., the estimate of FOG if no technology factors are incorporated). Thus,

$$F_{(\text{Tier }0)X} = 14.3\, Y_X \qquad \text{(Eq. 3)}$$

The estimate for FOG has to be corrected for the new technologies, Tier 1 (now in deployment), Tier 2 (in development), and Tier 3 (not started). This is accomplished by applying a "technology deployment" curve and the bandwidth efficiency factor for each technology. The technology deployment curves are a simple 10% per year adoption rate starting at the programmed deployment availability date for each technology. Table 4-3 lists the deployment dates and efficiency factors for the three technologies.

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[22] The value for year 2003 is low because of missing data.

Table 4-3. Technology Deployment Dates and Efficiency Factors for the Advanced Modulation Technologies

Technology (t)	**Deployment Start Date**	**Deployment Complete Date**	**Efficiency Factor(e_t)**
Tier 0	2004	2004	1
Tier 1	2005	2014	0.5 x Tier 0 B/W
Tier 2	2010	2019	0.33 x Tier 1 B/W
Tier 3	2015	2024	0.25 x Tier 2 B/W

Thus, the estimate for FOG corrected for technology is given by:

$F_{(\text{Tier } t)\boldsymbol{i}} = F_{(\text{Tier } t-1)\boldsymbol{i}} (1- e_t T_{t\,\boldsymbol{i}})$ See note[23] (Eq. 4)

Where:

$F_{(\text{Tier } 0)\boldsymbol{2004}} = 14.3\ \boldsymbol{Y_{2004}}$ (from Eq. 3)

t = technology index (t=1, 2, 3)

e_t = efficiency factor for technology t (increase 0.1 per year from 0.1 to 1)[24]

$T_{t\,\boldsymbol{i}}$ = fraction of technology t deployed in year *i*

For t=1, *i*=2005 to 2009

For t=2, *i*=2010 to 2014

For t=3, *i*=2015 to 2025

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[23] In the actual calculations, the values for the $F_{(\text{Tier } t)\boldsymbol{i}}$ terms must be calculated for the entire period 2004-20252025 since the values for succeeding technologies depend on the values of the preceding technologies. However, it is important that the terms be summed only until the succeeding technology starts deploying.

[24] The values for Tier 1 (1.2 Hz/bps) and Tier 2 efficiency gains were provide by personal communication with Mr. Gene Law, NAWCWD Pt. Mugu.

4.2.1.2 Derivation of “Max User”

The determination of the max user values (see Eq. 1) uses a combination of actual data, planned data for a particular program, and the use of a growth parameter determined in the Ernst et al. growth study[25].

“Max user” is the periodic "maximum user" requirements to support a major new project. This peak demand for system-of-systems testing is scheduled to begin in 2007. The bandwidth demand for a specific max user program (referred to here as MUP) increases over time, culminating in the system-of systems (SoS) test referred to as “4V4,” meaning a test involving 4 aircraft, 4 targets, and 8 missiles. An April 2005 range complex paper reports the maximum demands for 2001-2004 and clearly shows that these are not daily demands, but do occur relatively frequently. These maximum demands occur because of missions similar to the 4V4 planned for the MUP. Accordingly, the range data and data provided by the MUP program office[26] were used to construct the maximum user data set. Since there are currently no program plans for flight testing at the range complex beyond the MUP time frame, the MUP test scenario is combined with a growth factor from the Ernst et al. report to provide projections of maximum user growth after the MUP program through the year 2025. The advanced modulations technologies (Tiers 1, 2, and an option for 3) are incorporated into the bandwidth estimates.

Table 4-4 shows max user values from 2004 to 2008. The value of max user for year 2004 (M_{2004}) is taken directly from the April 2005 range paper. Although the range data does not cover year 2005, the 2005 max user value (M_{2005}) was assumed to be the same since the maximum user flight test programs at the range complex remained approximately the same.

Table 4-4. Max User Values, 2004-2008

Year	Max User (MHz)
2004	194
2005	194
2006	162
2007	147
2008	169

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[25] Darrell Ernst, Yan-Shek Hoh, David Portigal, *Projected Growth of Spectrum Requirements for Aeronautical Telemetering,* the MITRE Corporation, McLean, VA, March 2004

[26] MUP Program Office, “Telemetry Data Rates,” e-mail to D. Ernst, 8 December 2004.

The maximum user profile at the test range complex should remain relatively stable from 2004 until the advent of the MUP testing beginning in 2007. The use of Tier 1 is expected to be adopted relatively soon by the maximum bandwidth users because of the spectrum congestion problems at the range complex. Tier 1 technology provides a 50% bandwidth occupancy reduction over the current technology[27]. Accordingly, the max user demands for 2006-2008 are estimated by tapering the year 2005 demand by a Tier 1 adoption rate of 1/3 per year (each of the 3 current major use programs) plus the MUP demand beginning in 2007.

The MUP program office stated in December 2004 that each aircraft would have a 10 megabits per second (Mbps) data stream. A range chief subsequently reported that the MUP may have to use 15 Mbps per aircraft to meet its needs. The 15 Mbps data rate is used here. The MUP program plans to use Tier 1 technology from the beginning, so the bandwidth demand for the MUP is calculated by multiplying the data rate by 1.2 hertz/bits per second (Hz/bps) (see footnote 24).

Combining these factors, the estimated max user values for 2006-2008 are obtained as follows:

$$M_{2006} = M_{2005}(1- 0.5/3) \qquad \text{(Eq. 5)}$$

$$M_{2007} = M_{2005}(1- 2x0.5/3) + MUP_{2007}$$

$$M_{2008} = 0.5M_{2005} + MUP_{2008}$$

The remaining factors are determined as follows:

$$M_{X} = \text{Max}\{MUP_{X}, NMU_{iX} \mid i= 1,2,3,4; X=2009:2025\} \qquad \text{(Eq. 6)}$$

The values for MUP_{X} and NMU_{iX} are given in Table 4-5, and their derivation is described below. NMU stands for “New Maximum User.”

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[27] The current technology is technically referred to as “PCM/FM,” but is referred to here as “Tier 0” for consistency and simplicity.

Table 4-5. Values for MUP_X and NMU_{iX}

Year (X)	MUP_X	NMU_{1X}	NMU_{2X}	NMU_{3X}	NMU_{4X}
2007	18				
2008	72				
2009	119				
2010	119				
2011	119	24			
2012	192	96			
2013	192	158			
2014	192	158			
2015		158	36		
2016		256	144		
2017		256	238		
2018		256	238		
2019			238	72	
2020			384	288	
2021			384	475	
2022			384	475	
2023				475	144
2024				768	576
2025				768	951

The Ernst et al. study showed a new maximum user appears at the range complex about every 4 years and that the new bandwidth demanded is about double that of the previous maximum user. If the MUP program is used as a model, then a new maximum user (NMU_1) will appear in 2011 and will increase its demand similarly to the MUP build-up but at double the bandwidth demand. Since the new user will be able to use the Tier 2 technology, it will be able to reduce its bandwidth demand by 33% (new user demand = 2x MUP x 0.667). Similarly, a new max user appears every four years and the bandwidth demand doubles. All of the remaining new users only have access to the Tier 3 technology which gives an improvement in efficiency of 25% over that of the Tier 2 technology. Tier 3 capability is not used in the model's baseline estimate because implementation of this technology has yet to be defined or funded.

The value for maximum user for each of the years from 2009 to 2025 is simply the maximum of the values for each of the 5 users. The rational for this is that even though the programs overlap, the historical data shows that a maximum single user demand occurs infrequently, and when it does, the flight test schedule can be adjusted such that two maximum users do not fly at the same time. The assumption is that one maximum user can fly at any given time in addition to the routine daily flight testing, or FOG.

4.2.1.3 Total Demand

The total bandwidth demand is given by Equation 1:

$$D_{\boldsymbol{X}} = F_{\boldsymbol{X}} + M_{\boldsymbol{X}} \qquad 2003<\boldsymbol{X}<2025$$

where the values of F and M are the values for FOG and max user as described above.

Examination of the resulting data set shows the demand increasing and decreasing over time which is very much true in the real world: historical data from the range complex shows increases and decreases over the years as old programs reduce their demand and new programs begin testing and ramp up to more complex tests that require substantially more data. Since the Ernst et al. study showed that the variation in the time of appearance of a new user is on the order of +/- 2 years, and since the variances of the FOG and max user estimates are on the order of several megahertz, a least squares approximation of the values of $D_{\boldsymbol{X}}$ was fitted, producing a smooth function given by the following:

$$\text{Smoothed } D_{\boldsymbol{X}} = (2.209\text{x}10^{-27})(1.0347^{\boldsymbol{X}}) \qquad \text{(Eq. 7)}$$

The next step in estimating total demand is to factor in the efficiency gain expected from the iNET technology. The iNET technology, currently in development, is a radio network for telemetry that is expected to combine the efficiencies of advanced modulation with those of network concepts to achieve an overall reduction in the amount of bandwidth needed to continue flight testing of advanced weapon systems at the current tempo. The architecture concept for iNET embodies 3 data links: a small dedicated link for time and life-critical telemetry data; a network downlink for the majority of the telemetry data; and a return link from the ground. Each of these links will contribute in different ways to the aggregate spectrum efficiency of the iNET network, but since the design is still in the very early stages, there is no estimate of the individual or aggregate gains. For purposes of this study, the iNET system is treated as a simple radio with a gain in efficiency over the current systems. Since the expected gain is unknown, the iNET efficiency factor is incorporated into the demand model as a user-selected variable. The variable is incorporated as a "bandwidth reduction percentage," i.e., the user enters the percent of bandwidth reduction expected. The value of this factor is set to 80% in the accompanying spreadsheet model. The user should keep in mind that the efficiency factors from the Tier 1, 2, and 3 technologies is already incorporated into the values for the D_X , so it is unnecessary to allow for these technologies when setting the iNET efficiencies. The Tier technologies will be used whether or not a program uses iNET, and iNET will build on the Tier technologies if appropriate – they are not an integral part of iNET.

Another factor must be incorporated into the iNET-corrected demand model. Not all flight test vehicles will be able to take advantage of iNET for various reasons such as flight duration, cost, and size. Therefore, it is not appropriate to simply multiply the D_X by the iNET efficiency factor. It must also be corrected for the expected fraction of users who will not be able to use iNET. However, as with the iNET efficiency factor, there is currently no estimate of the fraction of users who will use iNET, so it also is incorporated as a user-defined variable. The current value is set to 0.75 (75% will use iNET) within the model.

Finally, the iNET-corrected demand model must account for the time necessary for iNET to be deployed. This technology deployment curve is different from that of the Tier technologies because it is not just a simple equipment replacement. Specific assumptions were developed to specifically characterize iNET program manager and subject matter expert expectations for iNET. The model assumes that the iNET technology has an initial operating capability in 2010 and continues spiral development to 2025. Every year reaches a 5% higher adoption rate up to 70%, at which point, iNET is assumed to be adopted by 100% of all of the users who will ever use iNET. (The iNET adoption rate represents the total iNET user base that adopts iNET in the given year. It does not represent the total number of range users. There will always be some users who do not adopt iNET.) Care must be taken not to confuse iNET deployment with iNET adoption or usage. iNET adoption or usage addresses the fraction of all flight test users who adopt iNET. iNET deployment addresses the fraction of the iNET capability that gets deployed. Eventually, 100% of the capability will be deployed, but only 70% of users will adopt iNET.

From a pure mathematical viewpoint, the three iNET factors – efficiency, usage and deployment – combine as a simple single multiplier of D_X. However, they are incorporated into the model as individual components so that various assumptions about each factor can be explored. The total demand corrected for iNET can now be expressed as follows:

$$\text{iNET } D_X = (\text{smoothed } D_X)[1-(\text{iNET efficiency})(\text{iNET usage})(\text{iNET deployment}_X)] \quad \text{(Eq. 8)}$$

The forgoing equations constitute an accurate representation of the model. However, they may be expressed somewhat differently in the spreadsheet for ease of computation. The spreadsheet also contains a multiplier factor for the max user estimates. This allows the user of the model to easily adjust the estimate of max user demand to explore different assumptions such as the implications of over- or underestimating the expected growth in max user demand.

4.2.2 BDM Summary and Conclusion

The bandwidth model described here uses a statistical approach as contrasted with an engineering approach. The statistical approach allowed the extensive use of historical information while permitting the incorporation of engineering estimates of future technological capabilities. The straight engineering approach used in other studies requires extensive assumptions about basic communications design elements such as coding gains, protocol overhead, compression gains and other factors. This engineering approach is absolutely essential in the design of the future iNET system but, because of the immaturity of the design, such a model is too sensitive to the assumptions for purposes of this study. The engineering model is also difficult to use for estimating growth in demand over time. For these reasons and others, the statistical approach was judged more appropriate for purposes of this study. It reduces the number of fundamental assumptions needed to just four:

- ➢ User demand will continue to grow in the same fashion as in the past 32 years (combined period of time covered by the Ernst and range data)
- ➢ Technology will continue to improve the efficiency of spectrum usage within the period covered by this study
- ➢ The revolution in telemetry data communications promised by iNET are achievable
- ➢ The relatively few technical factors used as multipliers in the model are reasonable estimates of expected outcomes

The model was built from the bottom up, with the outcome unknown and untargeted in advance. The final results are within the realm of the expected for those familiar with the problem of increasing demand for bandwidth within the flight test community. The demand is driven by the growth in information technology, the very same driver of bandwidth demand growth by private Internet consumers. The reason is that weapon systems and the systems used to test weapon systems are all users of the advances in information technology. No limits to the growth of these technologies are foreseen within the time period of this study. However, the same technologies that are driving the demand for bandwidth can be used to devise ways for equitable sharing of the electromagnetic spectrum.

5.0 Probable Future Scenarios and Gap Analysis

This section provides details on the estimates of probable future scenarios and ATM spectrum shortfall gaps on a test range. It also integrates these assessments into the overall study model.

5.1 Probable Future Scenarios

MITRE developed probable future scenarios of the ATM spectrum environment on a test range complex. The team investigated a total of 17 scenarios, including 11 different cases of ATM spectrum demand (described in Section 5.1.1) and 6 cases of ATM spectrum supply (described in Section 5.1.2).

5.1.1 Demand Scenarios

MITRE analyzed 11 different cases of ATM spectrum demand. The model incorporates six built-in toggles to easily explore demand assumptions. In particular, the following demand assumptions may be varied:

- Range operations base
- Range operations factor
- iNET usage factor
- iNET bandwidth reduction factor
- Maximum user factor
- Tier 3 toggle

5.1.1.1 Demand Assumptions and Baseline Case

This section provides further details on the six demand assumptions listed above and a description of the baseline demand case.

5.1.1.1.1 Range Operations Base

The range operations base is the number of simultaneous user operations on a range. The range study shows the growth in median bandwidth per operation for scheduled tests. In 2001-2004, the average maximum utilization was running between 80% and 90%, with utilization showing an increase over time.[28] To estimate total bandwidth needed, assume that total max bandwidth utilization remains proportional to median bandwidth. Dividing utilization in MHz by median bandwidth per user operation in MHz gives the average daily maximum number of simultaneous user operations. Since the base year for estimating median bandwidth is 2001, the maximum utilization in 2001 was 0.8 of the available 215 MHz and the median bandwidth per

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[28] Year 2003 is artificially low because of missing data.

user operation was 12 MHz, the mean number of user operations is 14.3 for scheduled operations. According to the Sarnoff study, there is 17% unmet demand. To incorporate unmet demand, 14.3 is multiplied by 1.17 to get a range operations base of 16.7. The range operations base may be used as the multiplier of median bandwidth to get average daily maximum demand. If a different base value for the number of simultaneous operations is desired, enter the value in the range operations base toggle. The baseline demand case uses 16.7.

5.1.1.1.2 Range Operations Factor

The range operations factor allows the exploration of the effects of growth in the number of simultaneous *operations*, also referred to here as *users*. In order to explore the effects of a growth in the number of simultaneous users, a growth factor is incorporated into the model starting in the year 2005. This growth factor is expressed as a multiple of the range operations base. Thus, a growth factor of 2 means that starting in 2006 the number of simultaneous operations grows linearly, reaching a value of two times the range operations base (e.g., 2 x 16.7=33.4) in the year 2025. A growth factor of 1 implies no growth. Any value can be used, but values less than 1 or negative values should be used cautiously. Also, the factor is specific to the conditions of this model. It assumes a growth starting in 2006 and reaching its maximum in 2025. If any other time period is desired, the equations will have to be modified (the base year and the denominator terms). The baseline demand case for the range operations factor is 1, or no growth.

5.1.1.1.3 iNET Usage Factor

The iNET usage factor is the fraction of spectrum expected to be used for iNET. The number of users of iNET is expected to be high. Only missiles and a very small number of small bandwidth users are expected to not use iNET. The iNET usage factor may be varied between 0 and 1.00 to explore the effects of various usage scenarios. When iNET is fully deployed, a typical factor should be on the order of 0.75, the baseline demand case.

5.1.1.1.4 iNET Bandwidth Reduction Factor

The iNET bandwidth reduction factor is the expected percentage reduction in the amount of data a vehicle needs to send using iNET as compared to current methods. The current concept for iNET postulates that each vehicle will have a dedicated point-to-point link for time-critical/safety critical data, a network (multiple access shared) link for less critical data, and an uplink for telemetry command and control. The combination of these three links will result in an overall reduction in bandwidth demand relative to current practice because the user will only need to transmit a fraction of the amount of data transmitted currently. For purposes of this analysis, no distinction is made between the three different links vis-à-vis their individual bandwidth. Instead, the analysis addresses the aggregate bandwidth demand of the three postulated iNET links. For example, if an aircraft sends 10 Mbps today, then if iNET has a reduction factor of 80%, the aircraft need send only 2 Mbps. This factor may be varied from 0 to 100 to see the effects of different efficiency factors. The baseline demand case incorporates an iNET bandwidth reduction factor of 80.

5.1.1.1.5 Maximum User Factor

The maximum user factor is a multiplier used for varying the maximum user data as a percent of the original estimate. Earlier studies have shown that a new telemetry user appears at a test range requiring more bandwidth than previous users. The studies are based on 28 years of data, during which period the basic telemetry technology did not change – PCM/FM was the standard. Forecasting this value into the future is problematic because of the planned introduction of new, more spectrum efficient technologies. The estimate of maximum user bandwidth demand used in this analysis is based on the documented assumptions. However, the assumptions are prone to error, and the maximum user demand estimates comprise a significant portion of the total demand calculation. To allow the maximum user parameter to be investigated in more depth, a multiplier has been incorporated into the equations starting in the year 2009. This allows the basic estimate to be varied as a percentage of the original estimate. To obtain the original estimate, set the adjustment to 1.0. To see what effect a 50 % reduction in max user demand yields, set the value to 0.5. The baseline demand scenario assumes a maximum user factor of 1.

5.1.1.1.6 Tier 3 Toggle

The Tier 3 toggle was created to provide the capability of turning on or off the incorporation of Tier 3 technology. A concept for Tier 3 technology does not exist today. However, when the toggle is turned on, the model assumes that a new technology after Tier 2 will be developed and deployed to further increase spectral efficiency. In the baseline demand case, the Tier 3 toggle is set to zero to turn this option off.

5.1.1.2 Definition of Demand Cases

Twelve cases of ATM spectrum demand were defined, and the analysis explored sensitivities among these various scenarios. These cases are defined in Table 5-1. The baseline assumptions are applied to two cases, baseline demand both with and without iNET. Case 9 is considered the optimistic scenario, while Case 10 is pessimistic.[29]

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[29] Case 9 assumes a range operations base of 14.3, the mean number of users for scheduled operations (according to the range data). Case 10 incorporates a range operations base of 17.5, which includes the mean number of users for scheduled operations (range data) plus unmet demand of 22% (higher than Sarnoff’s 17% estimate).

Table 5-1. Definition of Demand Scenarios

Sensitivity Scenarios										*Optimistic*	*Pessimistic*
	Baseline	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**	**Case 10**
Range Ops Base	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	14.3	17.5
Range Ops Factor	1	2	1	1	1	1	1	1	1	0.9	2
iNET Usage	0.75	0.75	0.50	1.00	0.75	0.75	0.75	0.75	0.75	1.00	0.50
iNET BW Reduction	80	80	80	80	30	90	80	80	80	90	30
Max Use Factor	1	1	1	1	1	1	0.5	1.5	1	0.5	1.5
Tier 3 Toggle	0	0	0	0	0	0	0	0	1	1	0

5.1.1.3 Demand Results and Sensitivity Analysis

MITRE estimated bandwidth demand by imputing the assumptions for each case, as described in Section 5.1.1.2, into its BDM. The team compared the annual demand forecasts of the baseline scenario with and without iNET to the remaining 10 cases. The annual (non-cumulative) bandwidth demand estimates at a test range complex are presented in Table 5-2 and shown graphically in Figure 5-1.

Table 5-2. Demand Sensitivity Analysis

	Sensitivity Analysis										*Optimistic*	*Pessimistic*
Year	**Baseline**	**Baseline No iNET**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**	**Case 10**
2004	424	424	424	424	424	424	424	424	424	424	391	436
2005	425	425	437	425	425	425	425	425	425	425	391	448
2006	393	393	416	393	393	393	393	393	393	393	358	428
2007	378	378	412	378	378	378	378	378	378	378	342	425
2008	398	398	444	398	398	398	398	398	398	398	361	457
2009	346	346	402	346	346	346	346	286	405	346	249	475
2010	335	335	400	335	335	335	335	275	394	335	239	473
2011	314	323	383	317	310	320	312	256	371	314	218	464
2012	361	384	434	369	354	376	358	271	452	361	231	562
2013	338	371	411	349	327	359	334	251	425	338	210	548
2014	315	358	387	329	300	341	309	230	399	315	189	532
2015	277	326	356	294	261	308	271	210	345	274	164	491
2016	349	426	433	375	324	397	340	244	454	342	188	639
2017	338	428	426	368	308	394	327	237	439	328	175	645
2018	326	429	418	361	292	391	313	229	424	313	161	651
2019	301	412	396	338	264	370	287	214	387	285	143	630
2020	398	568	501	455	341	504	376	263	532	378	173	854
2021	449	670	559	522	375	587	421	289	608	426	183	1000
2022	435	680	554	517	354	589	405	283	588	409	168	1020
2023	422	692	547	512	332	591	388	277	567	392	153	1043
2024	578	997	711	718	439	840	526	355	801	545	191	1460
2025	691	1192	838	858	525	1004	629	416	967	653	226	1740

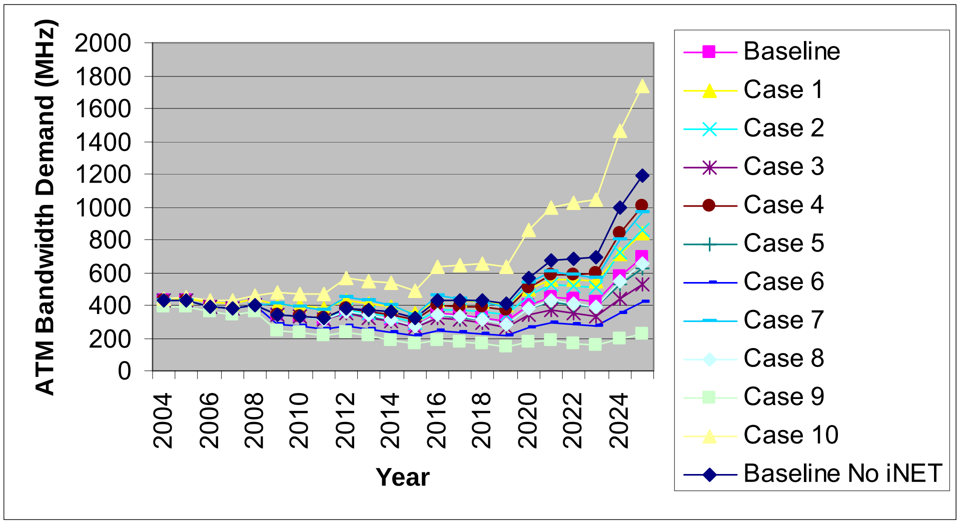

Figure 5-1. Demand Sensitivity Analysis

As shown in the figure, the baseline demand with iNET falls roughly in the middle of the twelve demand cases. Baseline demand without iNET is very high, second only to the pessimistic case.

5.1.2 Supply Scenarios

In addition to the twelve demand cases, six future scenarios of available ATM spectrum supply were defined. There are currently 215 MHz of spectrum available for ATM. The cases vary according to different assumptions of spectrum augmentation that may or may not be attained at WRC 2007. Two of the cases – the baseline supply and WRC zero scenarios – assume that no additional spectrum is attained at WRC. These scenarios differ by whether or not spectrum may be accessed by other means. The baseline supply scenario assumes that no additional spectrum is attained at WRC and that additional spectrum may not be accessed by other means. The WRC 0 scenario assumes that no additional spectrum is attained at WRC, but may be accessed by other means, as described in Section 6.3. The remaining 4 cases of ATM supply assume that spectrum augmentation is gained at WRC. The WRC 60, WRC 200, WRC 425, and WRC 650 cases assume 60, 200, 425, and 650 MHz, respectively, of spectrum augmentation attained at WRC.[30]

5.1.2.1 Supply Assumptions

This section discusses the supply assumptions for projecting annual available ATM spectrum over the next twenty years. In the baseline supply and WRC 0 scenarios, available supply is forecasted at 215 MHz for each year throughout the study period. Available supply in the remaining scenarios increase based on the assumptions for spectrum augmentation described in this section.

Available spectrum, or supply is calculated as follows:

$S_i = S_0 + WRC_i$ and,

$S_0 = 215$ MHz, where: S = ATM Spectrum supply and WRC = WRC spectrum augmentation for any given year i ($2003<i<2025$) (Eq. 9)

There is a specific process associated with spectrum augmentation, and these assumptions are incorporated into the WRC_i variable. The WRC periodically reviews and, if necessary, revises the international treaty governing the use of RF spectrum. The general scope of WRC conferences is established 4-6 years in advance, and the final agenda is set 2 years prior to the conference. WRC 2007 Agenda Item 1.5 proposes spectrum augmentation for wideband ATM in the 3-30 GHz band. At the time of this study, it is uncertain if and how much spectrum will be allocated at the WRC. The economic model considers various scenarios within the 0 to 650 MHz range of spectrum augmentation.

If the Agenda Item is successful, new technologies and policies must be introduced to facilitate the use of telemetry applications over the spectrum augmentation. New

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[30] WRC 60 is based on another country's minimal requirement for ATM spectrum; WRC 200 and WRC 425 are intermediary scenarios; and, WRC 650 is the stated DOT&E requirement.

technologies are needed to support the augmentation at higher frequency bands, and new policies must allow for spectrum sharing with any incumbent users at the allocated frequency. New technologies to support the spectrum augmentation are adopted over time by range and program managers. Additional spectrum allocated by WRC will likely not be usable until the year 2010. The model incorporates adoption of new technology over time to support spectrum augmentation. Technology adoption and diffusion is discussed in the following paragraphs.

5.1.2.1.1 Technology Adoption and Diffusion

In general, new technologies are adopted over time by customers. Spectrum users rely on technologies to utilize spectrum. Many of these technologies must be specific to the frequency allocation. The model incorporates the diffusion of this new technology by range and program managers. "Diffusion" is a market research term that refers to the spread of a technology through its potential user base.

MITRE conducted extensive research to identify typical diffusion rates. There are widely accepted diffusion models in the literature. However, after evaluating the diffusion models it was determined that they typically apply to consumer products and are often based on the success of advertising campaigns. Telemetering technologies have a very specific industrial market, namely range and program flight test managers and, thus, the diffusion models in the literature do not apply in this case. Given the lack of relevant information in the literature, MITRE examined specific historic cases of telemetry technology diffusion to gain an understanding of applicable diffusion rates for the economic model.

5.1.2.1.2 Technology Diffusion Examples

A team member interviewed range and program flight test managers to collect empirical data describing the diffusion of telemetry technology. Three cases of telemetry technology diffusion were identified, and this paper refers to these cases as: Low, Medium, and High. These technology diffusion cases are described below.

5.1.2.1.2.1.1 Low Diffusion Example

In the Low diffusion case, technology adoption was very difficult. As described by the program manager, it was "like pulling teeth" to get programs to adopt this new telemetry software technology. It took 5-10 years for programs to start adopting the technology. Seventeen years after its introduction to the market, this technology is only used by about 5% of programs. This 13% growth rate[31] is applied across the 20 years of the study period. In Year 20, only about 7% of the market has adopted the technology.

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[31] The growth formula is ((Future value/present value)$^{(1/\text{Number of years over which growth occurred})}$-1). The low 13% growth rate is derived as follows: Since it took 5-10 years for programs to start adopting the technology, it

5.1.2.1.2.1.2 Medium Diffusion Example

The Medium case is modeled after Tier 1 technology. Tier 1 has been on the market for a couple of years. There is currently only one of forty aircraft on the range – or 3% of the market – using this new technology. Assuming 3% of the market in Year 3, the study applies this 73% growth rate[32] to the Medium case. In this case, the technology is fully adopted in the market in Year 10 and beyond.

5.1.2.1.2.1.3 High Diffusion Example

The High technology diffusion case refers to the 106 standards. In this case, a new technology was developed to foster compatibility at multiple ranges for flight testing. The IRIG adopted the new technology immediately. It took about four years for the technology to become a standard. This case assumes the technology is fully adopted in Year 4 and beyond. A 364% growth rate[33] is estimated in Years 2 and 3. The High telemetry technology diffusion case represents the market adoption of a standard, or enforced new technology.

5.1.2.1.2.1.4 Summary of Diffusion Examples

The Low, Medium, and High diffusion rate examples are shown by year in Table 5-3.

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is conservatively assumed that in Year 4, 1% of the market adopted it. The difference between Year 17 and Year 4 is 13. The growth equation is $((0.05/0.01)^{1/13}-1)$. It shows a 5% adoption rate 13 years after the 1% rate.

[32] The medium 73% growth rate is derived as follows: The growth equation assumes a 1% adoption rate in Year 1 and a 3% adoption rate in Year 3. The difference between Year 3 and Year 1 is 2 years. The growth equation is therefore computed as $((0.03/0.01)^{1/2}-1)$.

[33] The high 364% growth rate is derived as follows: The growth equation assumes a 1% adoption rate in Year 1 and a 100% adoption rate in Year 4. The difference between Year 4 and Year 1 is 3 years. The growth equation is therefore computed as $((1/0.01)^{1/3}-1)$.

Table 5-3. Summary of Diffusion Examples

Tech Adoption Rate			
Growth Rate	0.13	0.73	3.64
Year	**Low**	**Medium**	**High**
0.00	0.00	0.00	0.00
1.00	0.00	0.01	0.01
2.00	0.00	0.02	0.05
3.00	0.00	0.03	0.22
4.00	0.01	0.05	1.00
5.00	0.01	0.09	1.00
6.00	0.01	0.16	1.00
7.00	0.01	0.27	1.00
8.00	0.02	0.47	1.00
9.00	0.02	0.81	1.00
10.00	0.02	1.00	1.00
11.00	0.02	1.00	1.00
12.00	0.03	1.00	1.00
13.00	0.03	1.00	1.00
14.00	0.03	1.00	1.00
15.00	0.04	1.00	1.00
16.00	0.04	1.00	1.00
17.00	0.05	1.00	1.00
18.00	0.06	1.00	1.00
19.00	0.06	1.00	1.00
20.00	0.07	1.00	1.00

The model applies the intermediary, or Medium, diffusion rates to the new technologies needed support the spectrum augmentation. These diffusion rates are incorporated into the model starting in 2008, the year following the decision at WRC.

5.1.2.2 Supply Results

The technology adoption and diffusion assumptions were incorporated into the supply scenarios to project annual supply through the year 2025. Annual (non-cumulative) available ATM bandwidth supply estimates at a test range complex are presented in Table 5-4 and Figure 5-2.

Table 5-4. Supply Sensitivity Analysis

Relative Year	Actual Year	Baseline Supply	WRC 0	WRC 60	WRC 200	WRC 425	WRC 650
-1	**2004**	215	215	215	215	215	215
0	**2005**	215	215	215	215	215	215
1	**2006**	215	215	215	215	215	215
2	**2007**	215	215	215	215	215	215
3	**2008**	215	215	215	215	215	215
4	**2009**	215	215	216	217	219	222
5	**2010**	215	215	216	218	222	226
6	**2011**	215	215	217	221	228	235
7	**2012**	215	215	218	225	237	249
8	**2013**	215	215	220	233	253	274
9	**2014**	215	215	224	246	281	316
10	**2015**	215	215	231	269	330	391
11	**2016**	215	215	243	309	414	519
12	**2017**	215	215	264	377	559	742
13	**2018**	215	215	275	415	640	865
14	**2019**	215	215	275	415	640	865
15	**2020**	215	215	275	415	640	865
16	**2021**	215	215	275	415	640	865
17	**2022**	215	215	275	415	640	865
18	**2023**	215	215	275	415	640	865
19	**2024**	215	215	275	415	640	865
20	**2025**	215	215	275	415	640	865

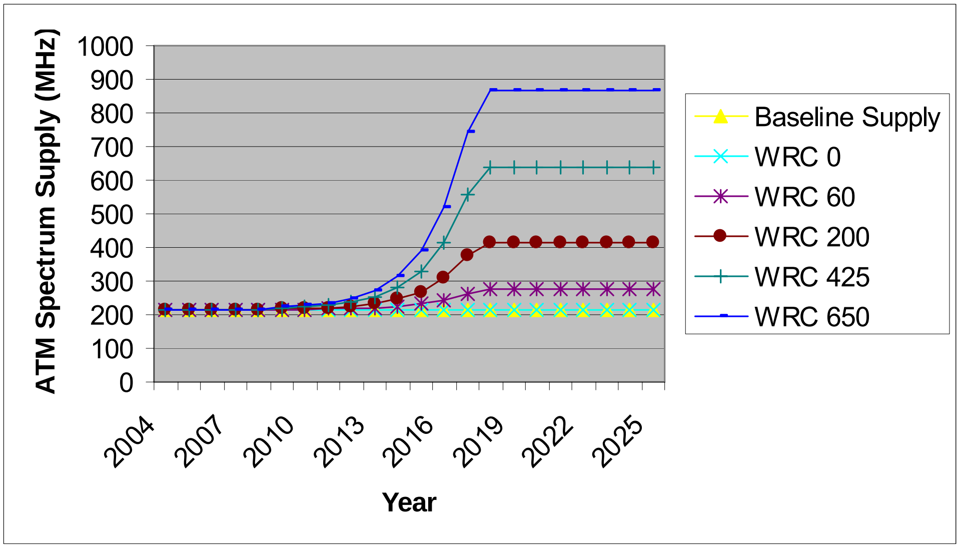


Figure 5-2. Supply Sensitivity Analysis

5.2 Gap Analysis

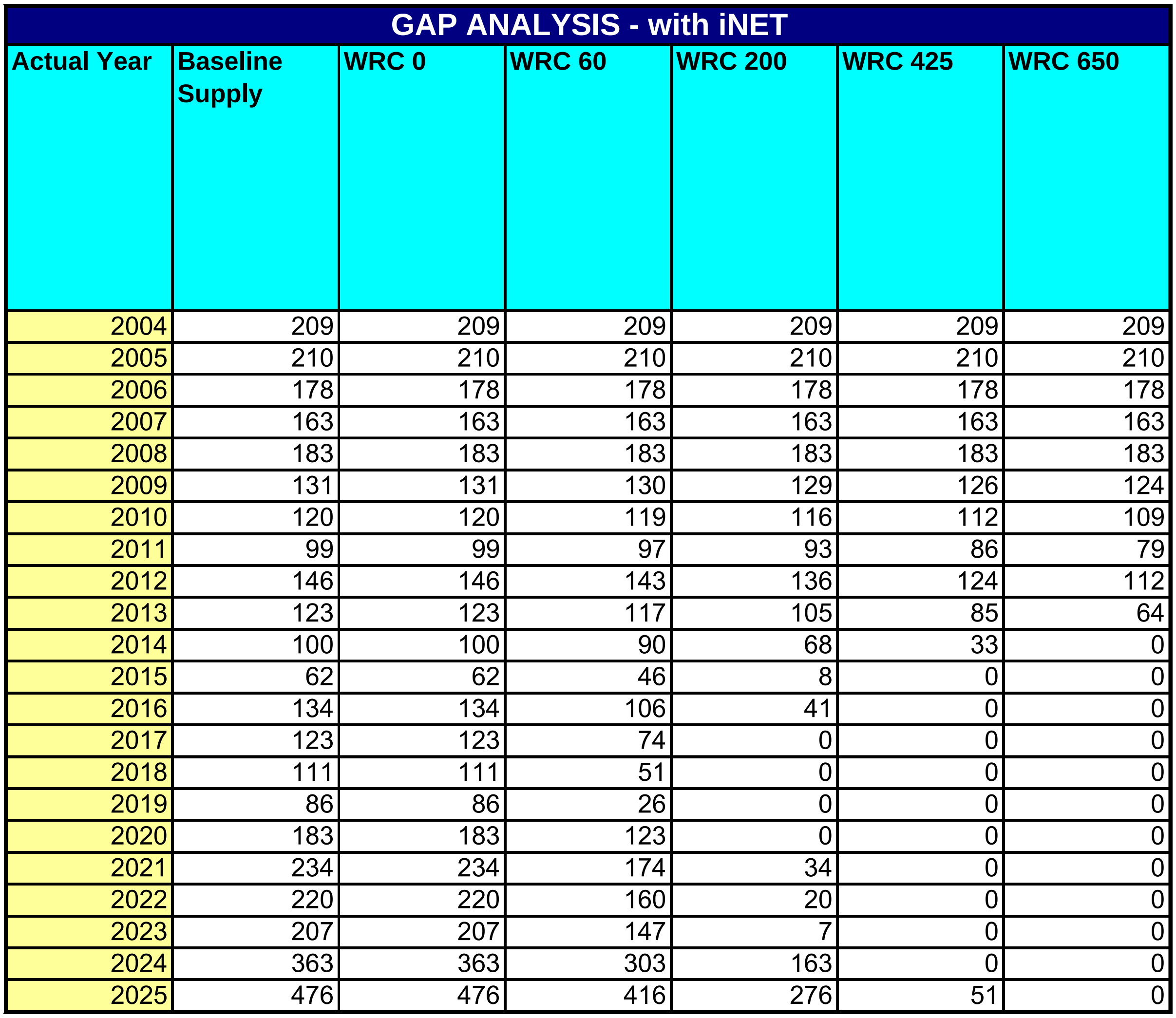
The gap analysis forecasts and compares available ATM spectrum requirements, or demand, and available spectrum supply at a range complex. *Gap* is defined as the demand of ATM spectrum above and beyond the given supply. It specifies the spectrum shortfall, or amount of insufficient spectrum available, for flight testing on an annual (non-cumulative) basis. The gap analysis provides an important input into the economic model. Once the gap is calculated, the model estimates the economic implications of that gap.

To estimate the gap, MITRE compared the baseline demand, both with and without iNET, to the six supply scenarios – baseline supply, WRC 0, WRC 60, WRC 200, WRC 425, and WRC 650. It applied the following equation:

$$\text{Gap}_i = \text{Demand}_i - \text{Supply}_i, \text{ for any given year } i \ (2003<i<2025) \qquad \text{(Eq. 10)}$$

The resulting ATM spectrum gap analysis is displayed annually in Table 5-5. As shown, spectrum augmentation plays a crucial role in reducing the gap.

Table 5-5. Estimated Annual Gap



GAP ANALYSIS - with iNET						
Actual Year	**Baseline Supply**	**WRC 0**	**WRC 60**	**WRC 200**	**WRC 425**	**WRC 650**
2004	209	209	209	209	209	209
2005	210	210	210	210	210	210
2006	178	178	178	178	178	178
2007	163	163	163	163	163	163
2008	183	183	183	183	183	183
2009	131	131	130	129	126	124
2010	120	120	119	116	112	109
2011	99	99	97	93	86	79
2012	146	146	143	136	124	112
2013	123	123	117	105	85	64
2014	100	100	90	68	33	0
2015	62	62	46	8	0	0
2016	134	134	106	41	0	0
2017	123	123	74	0	0	0
2018	111	111	51	0	0	0
2019	86	86	26	0	0	0
2020	183	183	123	0	0	0
2021	234	234	174	34	0	0
2022	220	220	160	20	0	0
2023	207	207	147	7	0	0
2024	363	363	303	163	0	0
2025	476	476	416	276	51	0

GAP ANALYSIS - without iNET

Actual Year	Baseline Supply	WRC 0	WRC 60	WRC 200	WRC 425	WRC 650
2004	209	209	209	209	209	209
2005	210	210	210	210	210	210
2006	178	178	178	178	178	178
2007	163	163	163	163	163	163
2008	183	183	183	183	183	183
2009	131	131	130	129	126	124
2010	120	120	119	116	112	109
2011	108	108	107	102	96	89
2012	169	169	166	159	147	136
2013	156	156	151	138	118	98
2014	143	143	133	111	76	41
2015	111	111	95	57	0	0
2016	211	211	183	118	12	0
2017	213	213	164	51	0	0
2018	214	214	154	14	0	0
2019	197	197	137	0	0	0
2020	353	353	293	153	0	0
2021	455	455	395	255	30	0
2022	465	465	405	265	40	0
2023	477	477	417	277	52	0
2024	782	782	722	582	357	132
2025	977	977	917	777	552	327

The gap analysis is depicted graphically below. Figure 5-3 shows the estimated gap with iNET and Figure 5-4 without iNET. Significant upward spikes occur in the gap when a new max user ramps up to full testing. Note that the gap is identical in both the baseline supply and WRC 0 scenarios.

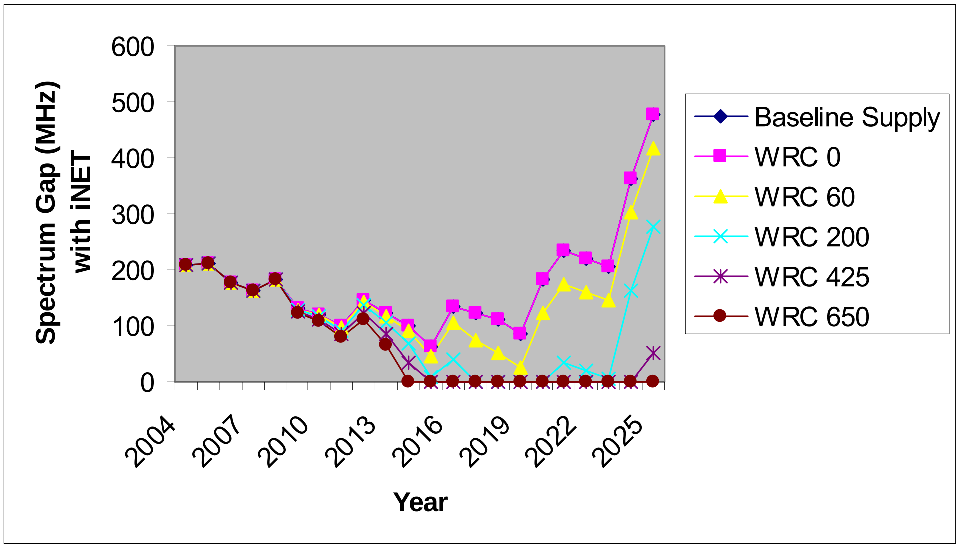


Figure 5-3. Estimated Gap with iNET

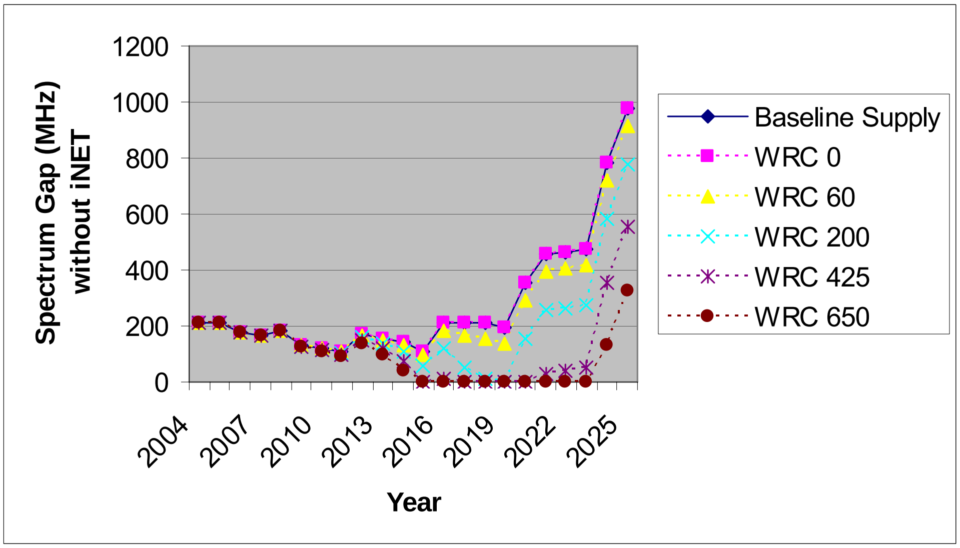


Figure 5-4. Estimated Gap without iNET

6.0 Economic Impacts

MITRE identified and estimated economic impacts of the spectrum shortfall, or gap described in Section 5.2. The following factors have been identified as cost drivers resulting from the gap:

- Technology Investments;
- Test Delays;
- Test Infrastructure Enhancements; and,
- Inadequate Testing.

Figure 6-1 depicts an overview of the economic impacts of the gap. The dollar graphic on the left side of the figure represents costs. The line graph on the right side of the figure symbolizes the gap. A solid red arrow emerging from a cost variable (numbered one through four) indicates that the variable works to increase the cost. A dotted green arrow denotes the variable works to lower the gap. An arrow emerging from the gap graphic indicates that the economic impact of the variable is a function of the gap.

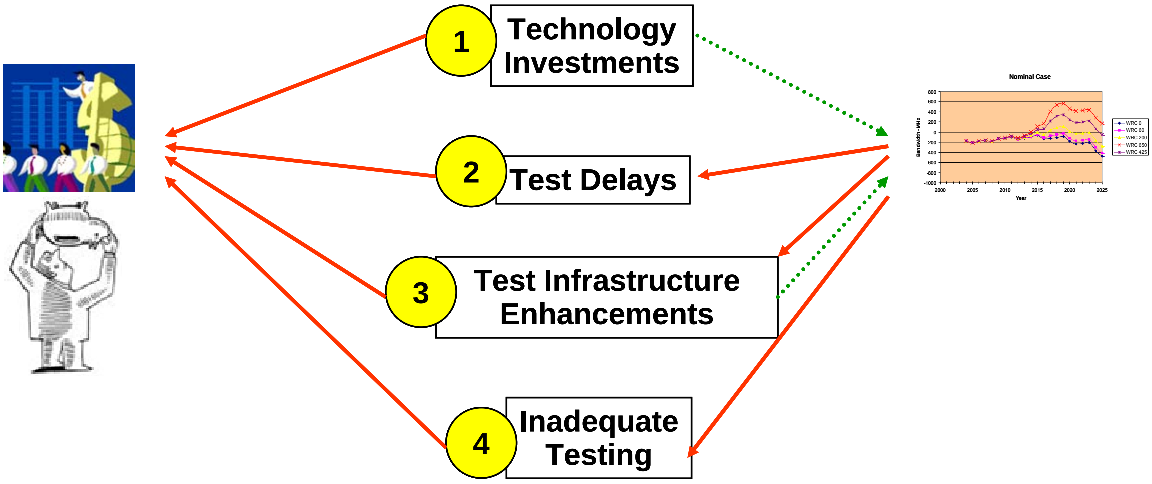


Figure 6-1. Economic Impacts of Gap

The remainder of this section describes these economic factors in detail.

6.1 Technology Investments

Technology investments is an economic factor that, as indicated in Figure 6-1, both increases costs and partially offsets the gap. Investments in technology research initiatives offer the prospect of increasing the bandwidth efficiency of ATM spectrum. Increased bandwidth efficiency results in lower spectrum demand. However, there is technical risk for technologies not yet proven. Research initiatives that do not reach their intended capability will not benefit spectrum demand. Technology investments are very important in a limited spectrum environment. However, even if this research achieves its intended outcome, it will not eliminate the gap; the demand for ATM is growing exponentially. Technological benefits may partially offset ATM spectrum demand until more spectrum access may be secured. Potential benefits of these technology investments are incorporated within the BDM. This section addresses the significant costs associated with these investments.

Costs were examined for the following technology research initiatives: ARTM, Tier 1 and 2, iNET, extreme frequency bands (e.g., 8 GHz), and other, unforeseen technology research programs. MITRE developed rough estimates based on data provided by a test range. A detailed cost analysis was not conducted, and there may be additional contractor or other costs of using these new technologies. The basis of the technology cost analysis is detailed in Sections 6.1.1 through 6.1.6.

6.1.1 ARTM

ARTM is estimated to have cost $26 million in Central Test and Evaluation Investment Program (CTEIP) funds from 1998 to 2004. Over this seven-year period, MITRE calculated an annual cost of about $3.7 million. Since these expenses were incurred during or prior to 2005, they are considered sunk costs.

6.1.2 Tier 1 and 2

Tier 1 and 2 technologies are estimated to cost CTEIP $12.5 million over six years, from 2000 through 2005. This figure includes $10 million for aircraft transmitters and $2.5 million for ground tracking stations. On an annualized basis during this investment period, about $2.1 million is spent on Tier 1 and Tier 2 technologies. These are considered sunk costs.

6.1.3 iNET

CTEIP is expected to spend about $80 million on iNET from 2005 to 2010. This estimated cost will pay for two waveform developments and accommodations for higher frequencies and other possible variances. The annual cost amounts to $13.3 million per year. Since this annual expenditure will likely continue beyond 2010 for an indefinite period, MITRE assumes $13.3 million from 2005 to 2025. Year 2005 costs are regarded as sunk.

6.1.4 Extreme Frequency Bands

The technology cost analysis includes investments in technologies for very high, or extreme, frequency bands. Range personnel provided estimated Science and Technology (S&T) and CTEIP cost data for extreme frequency technology investments. Studies for these new technologies commenced in 2002. S&T costs consist of $2.2 million in 2002, $2.1 million in 2003, $1.8 million in 2004 and 2005, and $5 million in 2010. Between $1.8 million in 2005 and

$5 million in 2010, MITRE computed an estimated annual growth rate of 23%. Costs incurred prior to 2006 are considered sunk.

In addition, nonrecurring engineering (NRE) is required. Antennas compatible at the higher frequency bands are needed. A bottoms-up cost estimate was computed for these antenna costs. MITRE and range experts assume that two antennas each year will provide capability on an extreme frequency band. Of these antennas, 25% will be purchased new at $900 thousand and 75% will use modified, legacy antennas at a cost of $400 thousand. Based on estimates from range personnel, the model assumes the range will obtain two antennas per year during the years 2011 to 2019; an additional one-third of the antennas will be acquired as spares. Therefore, the annual cost of NRE from the year 2011 to 2018 is about $1.2 million, or (((900000*0.25)+(400000*0.75))*2.33). In year 2019, the analysis assumes only half the previous years' NRE, or $600 thousand. According to the bottoms-up estimate, total NRE (in years 2011 to 2019) is about $10.4 million. MITRE compares this bottoms-up estimate to a top-down estimate for NRE. CTEIP funding may be considered a top-down cost estimate for NRE. CTEIP funding is estimated to range from $7 million to $26 million from 2011 to 2024. The $10.4 million bottoms-up NRE estimate falls conservatively at the low end of the CTEIP top-down cost estimate. Therefore, the cost estimate applies the conservative bottoms-up NRE estimate.

6.1.5 Other

This section describes other potential technology investments. Section 6.1.5.1 discusses unforeseen technologies, included in the economic model since they pertain directly to improving the efficiency of ATM spectrum access. Section 6.1.5.2 addresses indirect research initiatives, which are not included in the economic model since they are not targeted specifically for ATM spectrum.

6.1.5.1 Unforeseen Technologies

Other unforeseen technologies may prove moderately promising in the future. According to government range managers, total investments will likely continue at $5-10 million a year if a new technology shows promise. The benefit of these new technologies is not expected until the year 2028. The cost analysis incorporates a conservative estimate of $5 million a year for other, unforeseen technology investments.

6.1.5.2 Indirect Research

MITRE is tracking other projects that do not directly target ATM spectrum efficiency, but that could be applied to do so in the future. The model only includes technology investments specifically aimed at improving the efficiency of ATM spectrum access. Hence, this other, indirect research is not included in the cost calculations.

Currently, the most cited project within the DoD for spectrum enhancement is DARPA's neXt Generation (XG) project, now in its Phase 3 portion. This initiative is developing a capability to opportunistically access the spectrum based on the observed radio frequency environment. Such an access scheme could improve spectrum efficiency. The costs for the Phase 3 effort include about $24 million over 27 months for the performer and an unknown amount for the government team consisting of about five or more engineers.

Other R&D projects are examining advanced phased array antennas, other “smart” antennas, and radio techniques such as Multiple-Input-Multiple-Output (MIMO) systems that exploit the spatial dimension to improve telecommunication capacity and, hence, efficiency. DARPA’s MIMO project is called the Mobile Network MIMO (MNM).

Also, the DoD Spectrum Management community is initiating efforts to improve the spectrum management processes which could increase efficiency by improving the planning and automation of operations. The Global Electromagnetic Spectrum Information System (GEMSIS) effort, for example, is helping to define new approaches to spectrum usage. It is expected to cost millions of dollars.

6.1.6 Summary and Total

Investment costs, targeted at improving the efficiency of ATM spectrum access, are summarized by technology and year in Table 6-1. Note that the annual costs are shown as non-cumulative figures. MITRE applied a trend analysis[34] to the data in years 2012 through 2025 to incorporate expert opinion that technology investment costs will continue to rise annually at a steady rate. An annual inflation rate was also applied. Estimated technology investment costs total about $550 million over twenty years.

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[34] The trend analysis projects the future growth rate (in years 2012-2025) based on the growth rate of previous years (1998-2011).

Table 6-1. Technology Investment Costs

	Year	**AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)**	**ARTM**	**Tier 1&2**	**iNET**	**Extreme Frequencies (e.g., 8 GHz)**	**Other**	**Total By Year**	**Trend**
Sunk	**1998**		$3,714,286					$3,714,286	$3,714,286
	1999		$3,714,286					$3,714,286	$3,714,286
	2000		$3,714,286	$2,083,333				$5,797,619	$5,797,619
	2001		$3,714,286	$2,083,333				$5,797,619	$5,797,619
	2002		$3,714,286	$2,083,333		$2,200,000		$7,997,619	$7,997,619
	2003		$3,714,286	$2,083,333		$2,100,000		$7,897,619	$7,897,619
	2004	1.012	$3,714,286	$2,083,333		$1,800,000		$7,597,619	$7,597,619
	2005	1.032		$2,083,333	$13,333,333	$1,800,000		$17,216,667	$17,216,667
Not Sunk	**2006**	1.054			$13,333,333	$2,208,066		$15,541,399	$15,541,399
	2007	1.076			$13,333,333	$2,708,641		$16,041,975	$16,041,975
	2008	1.099			$13,333,333	$3,322,699		$16,656,032	$16,656,032
	2009	1.122			$13,333,333	$4,075,966		$17,409,299	$17,409,299
	2010	1.145			$13,333,333	$5,000,000		$18,333,333	$18,333,333
	2011	1.169			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$19,556,583
	2012	1.194			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$21,882,814
	2013	1.219			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$23,245,551
	2014	1.245			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$24,608,289
	2015	1.271			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$25,971,026
	2016	1.298			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$27,333,764
	2017	1.325			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$28,696,501
	2018	1.353			$13,333,333	$1,223,250	$5,000,000	$19,556,583	$30,059,239
	2019	1.381			$13,333,333	$611,625	$5,000,000	$18,944,958	$31,421,977
	2020	1.410			$13,333,333		$5,000,000	$18,333,333	$32,784,714
	2021	1.440			$13,333,333		$5,000,000	$18,333,333	$34,147,452
	2022	1.470			$13,333,333		$5,000,000	$18,333,333	$35,510,189
	2023	1.501			$13,333,333		$5,000,000	$18,333,333	$36,872,927
	2024	1.532			$13,333,333		$5,000,000	$18,333,333	$38,235,664
	2025	1.564			$13,333,333		$5,000,000	$18,333,333	$38,235,664
	Total (years 2005 to 2025)		$0	$2,083,333	$280,000,000	$29,512,997	$75,000,000	$386,596,330	$549,761,059

These annual (non-cumulative) technology investment costs are illustrated graphically in Figure 6-2.

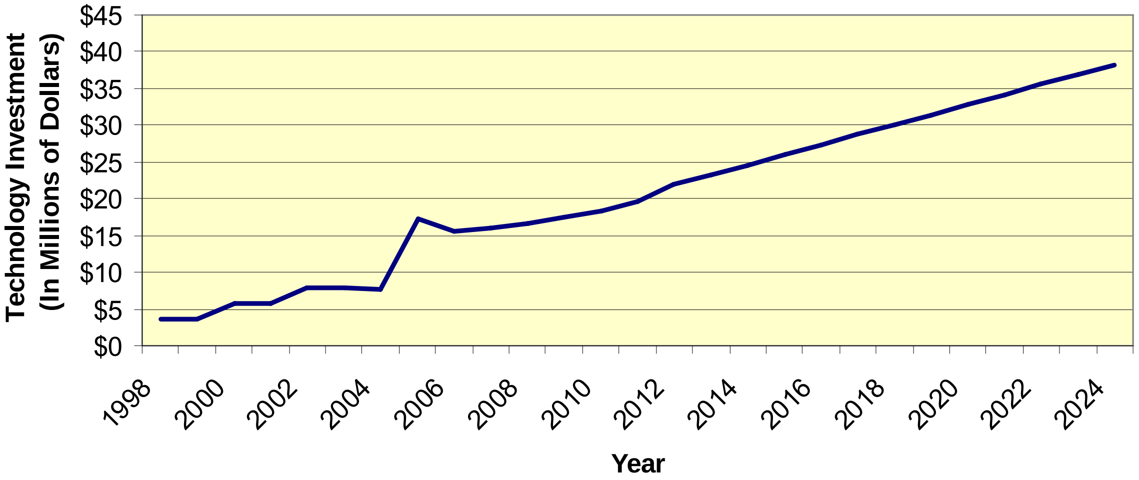

Figure 6-2. Annual (Non-Cumulative) Technology Investment Costs

6.2 Test Delays

Flight test delays are modeled as a function of the gap – the higher the gap, the more flight test delays – and these delays contribute to increased costs, as illustrated in Figure 6-1. This section provides background information on test delays and discusses their costs.

Programs must submit their flight test scheduling requests to the frequency management office at the test facility. The frequency management office uses an intelligent scheduling system to schedule flight tests at its test range based on requests received, priority, and spectrum availability. Programs scheduled for flight testing sometimes must be removed from the schedule by the frequency management office due to last minute conflicts and priorities for the limited ATM spectrum. As a result of inadequate ATM spectrum, programs will suffer unplanned test delays, and there is an economic cost associated with such delays. Programs incurring unplanned test delays have already devoted significant resources to flight testing, including support equipment, people, and range costs.

Based on 2003 data (re-verified in 2006) from a typical test range, one relatively large-scale and three relatively small-scale tests incur unplanned test delays each week on a range because of unavailability of ATM spectrum. According to a 2005 estimate an unplanned test delay can cost a program about $3 million for a large test.[35] The economic model, however, takes a conservative approach and assumes that an unplanned test delay costs a program about $1 million for a large

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[35] Based on information from a large test program, 2005.

test and $50 thousand for a small test.[36] On an annual basis, this amounts to a loss of almost $60 million (($1,000,000+(3*$50,000))*52) to programs on a single test range.

This $60 million applies only to today's environment. According to a Sarnoff report, there is currently an ATM spectrum gap of 17%.[37] As the gap changes over time, the MITRE team expects the cost of unplanned test delays to change proportionally. The economic model, therefore, adjusts the cost of test delays by the same rate of change as the gap. The gap rate of change is calculated as the percentage difference of the future gap as compared to the present gap, and the model applies an annual inflation rate.

6.3 Test Infrastructure Enhancements

Shown in Figure 6-1, costs and benefits of accessing additional or providing new range resources for flight testing in other geographic areas were considered in this analysis. Test infrastructure enhancements may theoretically mitigate a portion of the spectrum gap. However, use of additional range resources would increase cost to programs and test range facilities while construction of new test range resources would represent a huge cost to the national economy. Regardless of the cost consideration, test infrastructure enhancements are not a realistic option in the present environment because of two issues: (1) It is unlikely that there are sufficient alternative ranges available far enough away from existing ranges to allow for spectrum reuse; and, (2) the legal, environmental, and political obstacles for obtaining consent to provide new range resources far enough away from existing ranges may be insurmountable .

Despite its impracticality, test infrastructure enhancement was examined in the economic model. The model considers potential costs and benefits if certain enhancements are attainable. Section 6.3.1 examines accessing additional range resource, and Section 6.3.2 examines new range resource enhancements.

6.3.1 Additional Range Resources

The economic model incorporates the costs and benefits of providing additional range resource enhancements for flight testing. The costs of these enhancements are detailed in Section 6.3.1.1, and the benefits are described in Section 6.3.1.2.

6.3.1.1 Costs

MITRE estimated the costs to provide additional range resources in a different geographic area. Costs include both recurring program costs for moving flight tests to a different location, as

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[36] Assumptions based on approximate averages reported by experts, Kahn, Carolyn A., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," The MITRE Corporation, MTR 04B0000016, December 2003.

[37] "RDT&E Spectrum Requirements Assessment," Sarnoff Corporation, 5 August 2004.

well as non-recurring range costs for equipment to accommodate the flight tests. The recurring, program costs for conducting these are described in Section 6.3.1.1.1. Non-recurring range costs required to support these additional flight tests are addressed in Section 6.3.1.1.2.

6.3.1.1.1 Recurring, Program Costs

This study used a bottoms-up methodology to calculate the cost of moving a flight test, based on information provided by the chief engineer of a flight test program that conducts telemetry flight tests in differing locations. The cost was derived from an average cost to move aircraft certification testing; experts consider this cost representative of an average cost to move a telemetry flight test. Assumptions surrounding the relocated flight test include the following: The average relocated flight test continues for a duration of two-weeks. Due to safety issues, tests may only be conducted during daylight hours. After a sortie, the program must prepare and reconfigure the aircraft for the next sortie. Pre-test preparations and post-test briefings are required. Each sortie lasts for 2-3 hours.

Programs incur expenses for moving a flight test to a different geographical location. To access additional range resources, programs must pay additional costs for test crew members, engineering crew, quality assurance, ground support equipment, pre-trip planning, travel, transportation of the test aircraft, transportation of a corporate airplane, and utilities. These program costs are described in Sections 6.3.1.1.1.1 through 6.3.1.1.1.9.

6.3.1.1.1.1 Test Crew Members

The flight test requires an average of four crew members on eight-hour shifts. At an average labor rate of $46 per hour, this results in a per day cost of $1,472 (4 x $46 x 8), a per week cost of $7,360 ($1,472 x 5), or a per trip cost of $14,720 ($7,360 x 2).

6.3.1.1.1.2 Engineering Crew

The testing requires a four man engineering crew (e.g., technician, mechanic, electrician, instrumentation experts) per shift to support the aircraft. There are two shifts as follows: 7:00 to 3:30 for flying and 3:30 to midnight for maintenance and reconfiguration. The engineering crew costs $2,944 (4 x 2 x $46 x 8) per day, $14,720 ($2,944 x 5) per week, or $29,440 ($14,720 x 2) per trip.

6.3.1.1.1.3 Quality Assurance

The flight testing requires 1 quality assurance expert per shift. This costs $736 (8 x $46 x 2) per day, $3,680 ($736 x 5) per week, or $7,360 ($3,680 x 2) per trip.

6.3.1.1.1.4 Ground Support Equipment

It costs about $10 thousand (K) per day to rent ground support equipment. This amounts to $50K ($10K x 5) per week and $100K ($50K x 2) per trip. These costs could include ground support equipment for telemetering.

6.3.1.1.1.5 Pre-Trip Planning

Pre-trip planning is required to move flight testing to a different geographic area. About 100 hours of pre-trip planning is necessary. This costs $4,600 (100 x $46) per trip.

6.3.1.1.1.6 Travel

Round-trip air fare costs about $1,000 per person. For twelve people, this costs $12,000 per week or $24K per trip. The analysis assumes that the remaining crew member is transported in the test aircraft (Section 6.3.1.1.1.7). People must travel three days prior to the flight test to begin preparations. A hotel room costs about $65 per night, $3,380 (4 x $65 x 13) per week, or $6,760 ($3,380 x 2) per trip. Per diem meal and other miscellaneous costs are about $1,934(($27.90 x 2 days) + ($31 x 3 days) x 13) per week or $3,869 ($1,934 x 2) per trip. Three rental cars needed at a per car cost of approximately $55. The rental cars total about $165 (3 x $55) per day, $825 ($165 x 5) per week, or $1,650 ($825 x 2).

6.3.1.1.1.7 Transportation of Test Aircraft

The test aircraft and pilot must travel to the new location at a cost of $3K per hour. Air travel time is about 4 hours round trip. Test aircraft transportation, therefore, costs $12K per trip. The analysis assumes one trip per week.

6.3.1.1.1.8 Transportation of Company Airplane

In addition to the travel requirements described in Sections 6.3.1.1.1.6 and 6.3.1.1.1.7, a company airplane flies twice a week to transport data, people, and/or replacement parts. This costs $12K per trip or $24K per week.

6.3.1.1.1.9 Utilities

While the additional range may not charge the program rental costs for use of its space, it will likely charge utility fees. Programs typically use utilities in hanger, office, and lab space at the test range. Based on estimates from a test range, hanger utilities cost $3,926 per week for just over 32,000 square foot of space; office utilities cost $146 a week for two people, assuming about 100 square foot of space per person; and, lab utilities are estimated at $1,361 per week for over 7,000 square feet of space.[38]

6.3.1.1.2 Non-Recurring, Range Costs

Test ranges also incur expenses to accommodate additional flight tests moved to its location. A range must acquire additional antennas to support the additional flight test telemetry links. The economic model assumes the test range must acquire 1 new antenna per test vehicle. Toggles have been created in the model to input assumptions about the number of vehicles per test and the

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[38] Based on estimates from the Cost Office of a test facility, November 2005.

maximum number of new antennas needed by the range. For the base case, the model assumes there are an average of 10 vehicles per test and the maximum number of additional antennas acquired by US ranges due to flight test moves is 20 (based on equipping two ranges and moving two system-of-systems tests with 10 vehicles each).The team assumes antenna costs will be comparable to the 8 GHz frequency antenna costs, about $900K for a new antenna purchase.

6.3.1.1.3 Summary and Total

Table 6-3 summarizes the costs of moving flight testing to access additional range resources. It costs a program approximately $240K to move a flight test, plus the ranges must pay on average about $900K per antenna.

Table 6-2. Costs to Acquire Additional Range Resources

		Per Day	Per Trip/Week	Total
Test crew members		$1,472	$7,360	$14,720
Engineering crew		$2,944	$14,720	$29,440
Quality Assurance person		$736	$3,680	$7,360
Ground support equipment		$10,000	$50,000	$100,000
Pre-trip planning				$4,600
Travel				
	Air fare		$12,000	$24,000
	Per diem		$1,934	$3,869
	Hotel	$65	$3,380	$6,760
	Rental car	$165	$825	$1,650
Transportation of test aircraft			$12,000	$12,000
Transportation of company airplane			$12,000	$24,000
Range facility utility costs				
	Hanger		$3,926	$7,853
	Offices		$146	$293
	Lab space		$1,361	$2,723
Total Recurring Cost To Move				**$239,267**
Additional Non-Recurring Cost - Range antennas				**$900,000**

The model computes annual costs of accessing additional range resources as the number of tests moved multiplied by the total cost to move a test ($239,267). Section 6.3.1.2 explains how the number of tests moved is calculated. The cost of additional range antennas ($900,000 each) is incorporated in year 0, since ranges need these antennas now to accommodate additional tests. The model also applies an annual inflation factor to the data.

6.3.1.2 Benefits

The use of additional range resources is factored into the economic model. Two toggles were created to help estimate these benefits. The Average MHz per Test toggle allows for various inputs of this variable and is pre-set at 13 (based on 215 MHz supply/17 programs on the range)[39]. The Additional Range Denominator toggle incorporates the number of tests without sufficient spectrum that are conducted at additional range resources. This toggle is pre-set at “2” to assume that half the tests without sufficient spectrum conduct tests at additional range resources. As a result, the gap after these range supplements is reduced to half. The total number of tests moved is calculated on an annual basis as follows: (Gap_n/Average MHz per Test)/Additional Range Denominator, or (Gap_n/13)/2 with the pre-set toggle estimates.

6.3.2 New Range Resouces

The economic model also incorporates costs and benefits of acquiring new range resources for flight testing. The costs of these enhancements are detailed in Section 6.3.2.1, and the benefits are described in Section 6.3.2.2.

6.3.2.1 Costs

The costs of acquiring new range resources in a different geographic area are huge. A new range resource is considered a public good, and its costs are, therefore, born by a national government and/or economy. This study applied a top-down methodology to develop a ballpark estimate of the cost of building a new test facility. The estimate is based on discussions with DoD cost experts at the Institute for Defense Analyses (IDA) and internal DoD documents.

The team assumes a new range resource with ATM capabilities will be added to an existing range, located in a remote geographic area, which does not currently have substantial ATM capabilities. New resources must be added to this existing range to enable it to support flight testing using ATM. Building ATM capabilities on an existing range is a more conservative cost estimating approach than building an entirely new range with ATM capabilities.

To develop this cost estimate, the research team examined and compared the plant replacement value (PRV) of an existing range without ATM capabilities to the PRV of an existing range with ATM capabilities. PRV represents the cost of replacing the specific facilities or assets identified. The PRV of an existing range without substantial ATM capabilities is about $109 million in 1990 dollars. The PRV of an existing range with extensive ATM capabilities is about $1.2 billion dollars in 1990 dollars. The difference between the two PRVs is about $1.1 billion in 1990 data. In 2005 dollars, the difference in PRVs is $1.3 billion.

Experts estimate that it takes ten years to build a new range resource. The economic model spreads the PRV difference across ten years. It, therefore, costs about $133 million per year for ten years in current year dollars. The model assumes the decision to build a new national range resource is made in 2007. Development costs are accrued in 2007 to 2016, so an inflation factor has been applied to the annual $133 million cost.

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[39] Range provided data for number of programs at their facility.

Operational costs of the new range resource begin to be incurred in the year 2017. MITRE estimated the annual operating costs for this new range resource by comparison to costs at an existing range. Operational costs at an existing range with ATM resources are about $219 thousand per year in current year dollars. Since the development costs of a range without ATM resources is about 9% of those of a range with ATM resources ($109 million/$1.2 billion), the model assumes additional operational costs at a range without preexisting ATM resources is 91% (100% - 9%), of $219 thousand or $199 thousand per year in 2005 dollars. The model applies an inflation factor to estimate then-year dollars.

A ballpark estimate of the costs a country must incur to develop and operate a new range resource is itemized by year below. To convert annual dollars into then-year dollars, Base Year (BY) 2005 Air Force weighted inflation rates for research, development, testing, and evaluation were applied. As shown in the table below, the bottom line cost of a new range resource over the twenty-year period is estimated at $1.5 billion.

Table 6-3. National Costs for Providing a New Range Resource

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Cost to Provide New Range Resources
-1	2004	0.992	$0
0	2005	1.012	$0
1	2006	1.032	$0
2	2007	1.054	$140,626,698
3	2008	1.076	$143,579,859
4	2009	1.099	$146,595,036
5	2010	1.122	$149,673,532
6	2011	1.145	$152,816,676
7	2012	1.169	$156,025,826
8	2013	1.194	$159,302,368
9	2014	1.219	$162,647,718
10	2015	1.245	$166,063,320
11	2016	1.271	$169,550,650
12	2017	1.298	$257,573
13	2018	1.325	$262,982
14	2019	1.353	$268,504
15	2020	1.381	$274,143
16	2021	1.410	$279,900
17	2022	1.440	$285,778
18	2023	1.470	$291,779
19	2024	1.501	$297,907
20	2025	1.532	$304,163
0 to 20 (total)	2005 to 2025		$1,549,404,411

A New Range Resource Factor toggle was created in the model to vary the proportion of new range resources that will become available, as compared to the current test range. For example, a value of “1” assumes that one additional ATM range capability will be built.

6.3.2.2 Benefits

Benefits of a new range resource are represented in the economic model. The model assumes that one new range resource will provide access to an existing 215 MHz of ATM spectrum through geographic separation, with the effect of reducing excess demand at a given range by 215

MHz, starting in the year 2017. A caveat is that despite the new range resource assumption, a large max user may need to split up testing among multiple ranges or geographical areas.

6.4 Cost of Inadequate Testing

This section explains the final economic impact identified in Figure 6-1 – the cost of inadequate testing. The telemetry band is being reduced to such an extent that many of the wideband (high data rate) systems, such as those used in advanced avionics or engines, will not be able to be tested effectively with current data transmission limitations. When a tester is forced to reduce the desired amount of real-time data, the flight test program is negatively affected. The anticipated result is that some systems will choose to work around the interference with an increased program risk. Some programs will choose to greatly reduce testing in order to avoid cost impacts. Thomas Christie, Director, Operational Test and Evaluation, has warned about inadequate testing, testifying that "program offices and developers appear at times to be learning faster how to avoid testing than…learning to do it better."[40] Lack of access to ATM spectrum leads to test point shedding, which in turn leads to reduction in test quality. At some point, not testing results in catastrophes and fatalities. Christie maintains that "the costs of skipping tests, of avoiding adequate tests, of skimping on either developmental testing or operational testing can be huge (as well as cause loss of lives)."[41] Correcting defects has been estimated to add over 1030 percent to the cost of each item.[42] Managers who test adequately identify risks earlier and, thus, have less costly and less difficult corrective measures available to them.

The economic model incorporates the cost of inadequate testing. MITRE bases this cost on a specific case, referred to in this paper as the inadequate testing case or program. No better data exist for approximating general costs of inadequate testing. This inadequate testing case is a good example of a major program that encountered technical and cost problems in development, yet attempted to hold to a schedule that provided little, if any, slack to address those problems. After nearly 20 years in development at the time, the urgency of replacing the aging legacy vehicles drove decisions to severely reduce development testing to save dollars and stay on schedule. The GAO states explicitly that the problems associated with this case were in part due to inadequate test and evaluation, and T&E is the only explanation provided by GAO. According to GAO, "actual testing

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[40] Christie, Honorable Thomas, Director, Operational Test and Evaluation, OSD, "Test and Evaluation in the 'New World of 2004,'" NDIA Test and Evaluation Conference, 2 March 2004.

[41] Ibid.

[42] Australian National Audit Office, 2002.

conducted was less than a third of that originally planned"[43] and the program's primary components "remain inadequate or untested."[44]

According to the official report from the investigation, the original plan called for 103 test conditions to be flown. In an effort to recover costs and schedule, the conditions to be tested were reduced to 49, focusing on aft center-of-gravity conditions that were thought to be most critical. Of the 49 conditions, 33 were actually flight-tested. Thus, roughly one-third of the planned test events were actually flown, and particularly critical test points were not flown at all. This series of events, culminating in multiple crashes, brought the program to a halt, nearly resulting in termination. In the end, the program recovered, executed the full range of technical testing that should have been done previously, and now appears to be on its way to introduction, nearly 25 years after the decision to initiate the program. While the reason for inadequate testing in this case was schedule pressure, not lack of spectrum, the resulting economic impact would not differ. Furthermore, increased spectrum can ease schedule pressure by providing the resources necessary to conduct simultaneous testing.

MITRE analyzed the economic impact of the inadequate testing case. The team examined Research, Development, Test, and Evaluation (RDT&E) cost data from internal DoD documents to identify return to flight (RTF) costs. RTF costs are required for a program's safety and operational readiness. To estimate RTF costs, MITRE compared budgeted RDT&E program costs before and after the program's accidents. Program costs were budgeted at $6.906 billion before the accidents and $8.374 billion afterwards.[45] RTF costs, therefore, are estimated at $1.468 billion.

Furthermore, the inadequate flight testing cost human lives. During testing, the program endured four crashes, three of which were fatal. In total, 30 people were killed during the program's flight testing. The loss of life is catastrophic and, while the study team does not equate loss of life to financial loss, it did apply a financial factor in attempt to incorporate the lost lives into the economic model. It applied a $3.5 million cost per lost life,[46] or $105 million. The cost of an inadequate testing case, therefore, is $1.468 billion plus $105 million – or $1.573 billion. These costs are summarized below in Table 6-4.

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[43] "Defense Acquisitions," GAO, 20 February 2001, http://www.gao.gov/new.items/d01369r.pdf.

[44] G2mil, http://www.g2mil.com/.

[45] Calculation based on RDT&E data in internal DoD document.

[46] "Techniques Used to Value Human Life," The MITRE Corporation, CASA.

Table 6-4. Costs of an Inadequate Testing Case

Example:	
Total Cost to Fix	$1,573,000,000
Total Cost After Inadeq Testing	$8,374,000,000
Total Cost Before Inadeq Testing	$6,906,000,000
Lives Lost - Number	30
Lives Lost - $	$105,000,000

The cost of inadequate testing on an annual basis is unknown. To include this cost in the economic model and provide a general representation of the economic impact of inadequate testing, further assumptions were developed. The study assumes there would be serious testing deficiencies if the future ATM spectrum gap increases beyond today's gap. The economic model applies an inadequate testing factor of 1 (i.e., one inadequate testing case is incurred at a cost of $1.573 billion) only in those years where the gap after range supplements is greater than today's gap. An annual inflation factor is also applied to the cost by the model. Spectrum augmentation will beget an improved supply, reduced gap, and lower risk of inadequate testing. However, the amount of spectrum augmentation would need to more than offset the projected growth in demand to minimize the risk of inadequate testing.

Evidence supports the assumption that the specific case of inadequate testing referred to above is representative of other inadequate testing cases. According to a News World Communications and Washington Times headline, the specific case's "record is comparable to other aircraft."[47]

In addition to inadequate testing costs, there are also costs incurred to programs due to accidents during operations. Class A accidents are defined as those with damage costs of $1 million or more; destruction of an aircraft, missile, or spacecraft; and/or fatality or permanent total disability. The Class A mishap rate refers to the number of Class A mishaps per 100 thousand flying hours. The Class A mishap rate dropped dramatically in the late 1940s and 1950s, and continued a fairly steady decline until 1992. In 1947, this benchmark was 44.22. Twelve years later, it fell below ten for the first time. In 1983, the rate declined to two for the first time. Even since, it has been in the "ones," but progress beyond that has been difficult to achieve. Although it has not been feasible to correlate any specific accident with inadequate testing, many such accidents may result from defects that were not detected due to inadequate testing during system development.

Flight testing is a high risk business, and studies show that most accidents resulted from poor situational awareness during flight. Additional spectrum would provide needed resources for

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[47] Charles, Robert, Former Staff Director to the US House of Representatives' National Security Subcommittee, News World Communication, The Washington Times, 13 March 2001.

more and better real-time telemetering to improve situational awareness during flight. Studies also provide evidence of a correlation between increased operational tempo (i.e., pressure to accelerate schedule and acquisition cycles), stress, and mishap rates. Donald Rumsfeld tasked personnel and readiness director, David S.C. Chu to lead the mishap reduction effort.[48]

Telemetry systems not only provide data to the test engineer during a flight test but also before a flight test is conducted. For example, telemetry is the only means of detecting a Global Positioning System (GPS) antenna/amplifier problem in some programs during a pre-flight check. Telemetry solutions in such instances save thousands of dollars and increase mission efficiency.[49]

6.5 Associated Factors

There are other, associated factors of inadequate ATM spectrum access. These associated factors will be discussed in this section. The economic model, however, takes the conservative position and does not incorporate these costs. The ancillary costs include enforcement, deconfliction, night, and time-to-market economic impacts.

6.5.1 Enforcement Costs

Test ranges typically pay enforcement costs to ensure that its allocated ATM spectrum is utilized for its intended purposes and by its intended users. A growing problem among test ranges is the unlawful interference of wireless devices operating in the ATM spectrum band allocation. To minimize this interference, test ranges often attempt to identify and impede such unauthorized interference. MITRE learned from a test range that it spends $274 an hour to operate an enforcement van. Two personnel travel in this van at cost of $51/hour for a civil servant and $41/hour for a contractor.

6.5.2 Deconfliction Costs

To improve spectrum efficiencies, test ranges have invested in frequency scheduling and deconflicting systems. Such a system performs frequency scheduling and deconfliction within a geographic area based upon equipment and terrain characteristics. According to data from a test range, it costs about $25K per year to pay for a full-time contractor to operate this system.

6.5.3 Night Costs

Flight testing during non-daylight hours, or the “night,” has additional restrictions and costs associated with it. It interferes with the surrounding community and creates additional noise pollution. Many communities place restrictions on this type of testing. Testing during non-daylight hours is a safety issue since visibility is greatly reduced. The cost to fly at night is also

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[48] Hebert, Adam J., “A Plague of Accidents,” February 2004.

[49] Edgington, Brigadier General David, “40 Years of Telemetry Success Stories,” International Telemetry Conference, 20 October 2004.

significantly more expensive; higher, overtime rates are required. According to a flight test manager, it is 2.5 times more expensive to fly at night as compared to during daylight hours.

6.5.4 Time-to-Market Costs

Flight test delays due to insufficient telemetry spectrum impact time-to-market competition, as some sales are delayed and other sales may be lost to the competition. According to a previous MITRE study, time-to-market competition further increases costs by a factor of ten, and serious delays can result in program cancellation.[50] These costs – like those of the other, associated factors – have not been incorporated into the economic model.

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[50] Kahn, Carolyn A., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," The MITRE Corporation, MTR 04B0000016, December 2003.

7.0 Results of Economic Model

Section 7.0 describes the results of the economic model. It explains how the ATM bandwidth demand, supply, probable future scenarios, gap analysis, and economic impact projections are rolled up to calculate the overall economic impact of insufficient ATM spectrum access.

7.1 Roll-Up of Model Elements

This section details the roll up of the various elements of the economic model. The economic impact is calculated for each of the six future scenarios of available ATM spectrum supply. The roll-up of elements is summarized in Table 7-1. Sections 7.1.1 to 7.1.6 further describe each scenario and the economic results with iNet.

Table 7-1. Roll-Up of Model Elements

Roll-Up of Model Elements				
Scenarios	**Spectrum Augmentation**	**Additional Test Resources**	**New Test Resources**	**Inadequate Testing Factor**
Baseline	0	No	No	1 only in those years where the gap is greater than today's gap
WRC 0	0	Yes	Yes	1 only in those years where the gap after range supplements is greater than today's gap
WRC 60	60	Yes	Yes	1 only in those years where the gap after range supplements is greater than today's gap
WRC 200	200	Yes	No	1 only in those years where the gap after range supplements is greater than today's gap
WRC 425	425	Yes	No	1 only in those years where the gap after range supplements is greater than today's gap
WRC 650	650	Yes	No	1 only in those years where the gap after range supplements is greater than today's gap

7.1.1 Baseline

The baseline scenario assumes:

- No spectrum augmentation will be granted at WRC;
- No new or additional test resources will be obtained; and,

- An inadequate testing factor of 1.00 (i.e., one inadequate testing case is incurred at a cost of $1.573 billion plus annual inflation) only in those years where the gap is greater than today's gap.

The economic model combines the BDM baseline demand and supply to calculate the gap. ATM bandwidth demand is tapered by increases in bandwidth efficiency assumed to be realized from technology investments. Sizeable cost increases are correlated with projected new max user spectrum requirements, with a new max user appearing at a test range complex about every four years and ramping up to full testing. The model applies projected costs of technology investment, testing delays, and inadequate testing. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-2 presents the detailed results of the economic model's baseline scenario.

Table 7-2. Baseline Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Final Gap
-1	2004	0.992	215	0.00%	0	424	215	209
0	2005	1.012	215	1.00%	0	425	215	210
1	2006	1.032	215	1.73%	0	393	215	178
2	2007	1.054	215	3.00%	0	378	215	163
3	2008	1.076	215	5.20%	0	398	215	183
4	2009	1.099	215	9.00%	0	346	215	131
5	2010	1.122	215	15.59%	0	335	215	120
6	2011	1.145	215	27.00%	0	314	215	99
7	2012	1.169	215	46.77%	0	361	215	146
8	2013	1.194	215	81.00%	0	338	215	123
9	2014	1.219	215	100.00%	0	315	215	100
10	2015	1.245	215	100.00%	0	277	215	62
11	2016	1.271	215	100.00%	0	349	215	134
12	2017	1.298	215	100.00%	0	338	215	123
13	2018	1.325	215	100.00%	0	326	215	111
14	2019	1.353	215	100.00%	0	301	215	86
15	2020	1.381	215	100.00%	0	398	215	183
16	2021	1.410	215	100.00%	0	449	215	234
17	2022	1.440	215	100.00%	0	435	215	220
18	2023	1.470	215	100.00%	0	422	215	207
19	2024	1.501	215	100.00%	0	578	215	363
20	2025	1.532	215	100.00%	0	691	215	476

Relative Year	Actual Year	Technology Investment Costs	Percent Difference of Future Gap Compared to Present Gap	Cost of Testing Delays	Inadequate Testing	Total Cost
-1	2004	$7,535,135	0%	$59,506,552	$0	**$0**
0	2005	$17,417,890	0%	$60,398,144	$0	**$77,816,033**
1	2006	$16,044,507	-15%	$52,163,941	$0	**$68,208,448**
2	2007	$16,909,074	-22%	$48,766,927	$0	**$65,676,001**
3	2008	$17,925,006	-13%	$55,966,351	$0	**$73,891,357**
4	2009	$19,129,110	-38%	$40,742,105	$0	**$59,871,215**
5	2010	$20,567,460	-43%	$38,190,810	$0	**$58,758,271**
6	2011	$22,400,512	-53%	$32,102,801	$0	**$54,503,313**
7	2012	$25,591,390	-30%	$48,585,225	$0	**$74,176,615**
8	2013	$27,755,963	-41%	$41,678,112	$0	**$69,434,075**
9	2014	$30,000,163	-52%	$34,504,291	$0	**$64,504,453**
10	2015	$32,326,378	-70%	$22,060,522	$0	**$54,386,900**
11	2016	$34,737,065	-36%	$48,505,408	$0	**$83,242,473**
12	2017	$37,234,744	-41%	$45,329,835	$0	**$82,564,579**
13	2018	$39,822,007	-47%	$41,864,977	$0	**$81,686,984**
14	2019	$42,501,514	-59%	$32,933,645	$0	**$75,435,159**
15	2020	$45,276,000	-13%	$71,664,255	$0	**$116,940,255**
16	2021	$48,148,270	12%	$93,579,386	$2,217,946,740	**$2,359,674,396**
17	2022	$51,121,209	5%	$90,163,057	$2,264,523,621	**$2,405,807,888**
18	2023	$54,197,778	-1%	$86,444,487	$0	**$140,642,265**
19	2024	$57,381,019	73%	$154,822,554	$2,360,632,269	**$2,572,835,841**
20	2025	$58,586,020	127%	$207,355,775	$2,410,205,546	**$2,676,147,341**
0 to 20	2005 to 2025	**$715,073,080**		**$1,347,822,608**	**$9,253,308,176**	**$11,316,203,864**

In this scenario, there is no mechanism for mitigating the gap. The economy suffers high costs of inadequate testing, and the aerospace industry faces high testing delay costs.

7.1.2 WRC 0

The WRC 0 scenario assumes:

- No spectrum augmentation will be granted at WRC;
- Additional and new test resources will be obtained (according to the pre-set toggles, half of the tests without sufficient telemetry spectrum can be conducted at additional range resources, and one new range resource becomes available for flight testing); and,
- An inadequate testing factor of 1.00 only in those years where the gap after range supplements is greater than today's gap.

The economic model combines the BDM baseline demand and WRC 0 supply to calculate the gap. ATM bandwidth demand is tapered both by increases in bandwidth efficiency assumed to be realized from technology investments as well as by access to additional and new test resources. The model applies projected costs of technology investment, testing delays, inadequate testing. It also includes the costs and benefits of providing additional and new range resources. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-3 presents the detailed results of the economic model’s WRC 0 scenario.

Table 7-3. WRC 0 Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Gap	Gap After Range Supplements
-1	2004	0.992	215	0.00%	0	424	215	209	105
0	2005	1.012	215	1.00%	0	425	215	210	105
1	2006	1.032	215	1.73%	0	393	215	178	89
2	2007	1.054	215	3.00%	0	378	215	163	81
3	2008	1.076	215	5.20%	0	398	215	183	92
4	2009	1.099	215	9.00%	0	346	215	131	65
5	2010	1.122	215	15.59%	0	335	215	120	60
6	2011	1.145	215	27.00%	0	314	215	99	49
7	2012	1.169	215	46.77%	0	361	215	146	73
8	2013	1.194	215	81.00%	0	338	215	123	61
9	2014	1.219	215	100.00%	0	315	215	100	50
10	2015	1.245	215	100.00%	0	277	215	62	31
11	2016	1.271	215	100.00%	0	349	215	134	67
12	2017	1.298	215	100.00%	0	338	215	123	0
13	2018	1.325	215	100.00%	0	326	215	111	0
14	2019	1.353	215	100.00%	0	301	215	86	0
15	2020	1.381	215	100.00%	0	398	215	183	0
16	2021	1.410	215	100.00%	0	449	215	234	9
17	2022	1.440	215	100.00%	0	435	215	220	3
18	2023	1.470	215	100.00%	0	422	215	207	0
19	2024	1.501	215	100.00%	0	578	215	363	74
20	2025	1.532	215	100.00%	0	691	215	476	131
0 to 20	2005 to 2025								

Relative Year	**Actual Year**	**Technology Investment Costs**	**Percent Difference of Future Gap Compared to Present Gap**	**Percent Difference of Future Gap After Range Supplements Compared to Present Gap**	**Cost of Testing Delays**	**Inadequate Testing**	**Number of Moved Tests**	**Cumulative Number of Moved Tests**	**Antenna Costs**	**Cost to Provide Additional Range Resources**	**Cost to Provide New Range Resources**	**Total Cost**
-1	2004	$7,535,135	0%	0%	$59,506,552	$0	0	0	$0	$1,912,053	$0	**$0**
0	2005	$17,417,890	0%	0%	$60,398,144	$0	16	16	$18,000,000	$19,956,795	$0	**$115,772,828**
1	2006	$16,044,507	-15%	-15%	$52,163,941	$0	14	30		$1,690,021	$0	**$69,898,469**
2	2007	$16,909,074	-22%	-22%	$48,766,927	$0	13	42		$1,579,964	$140,626,698	**$207,882,663**
3	2008	$17,925,006	-13%	-13%	$55,966,351	$0	14	56		$1,813,212	$143,579,859	**$219,284,428**
4	2009	$19,129,110	-38%	-38%	$40,742,105	$0	10	67		$1,319,973	$146,595,036	**$207,786,225**
5	2010	$20,567,460	-43%	-43%	$38,190,810	$0	9	76		$1,237,316	$149,673,532	**$209,669,118**
6	2011	$22,400,512	-53%	-53%	$32,102,801	$0	8	83		$1,040,075	$152,816,676	**$208,360,064**
7	2012	$25,591,390	-30%	-30%	$48,585,225	$0	11	95		$1,574,077	$156,025,826	**$231,776,518**
8	2013	$27,755,963	-41%	-41%	$41,678,112	$0	9	104		$1,350,298	$159,302,368	**$230,086,742**
9	2014	$30,000,163	-52%	-52%	$34,504,291	$0	8	112		$1,117,879	$162,647,718	**$228,270,051**
10	2015	$32,326,378	-70%	-70%	$22,060,522	$0	5	116		$714,723	$166,063,320	**$221,164,943**
11	2016	$34,737,065	-36%	-36%	$48,505,408	$0	5	122		$785,745	$169,550,650	**$253,578,868**
12	2017	$37,234,744	-41%	-100%	$0	$0	0	122		$0	$257,573	**$37,492,317**
13	2018	$39,822,007	-47%	-100%	$0	$0	0	122		$0	$262,982	**$40,084,989**
14	2019	$42,501,514	-59%	-100%	$0	$0	0	122		$0	$268,504	**$42,770,019**
15	2020	$45,276,000	-13%	-100%	$0	$0	0	122		$0	$274,143	**$45,550,143**
16	2021	$48,148,270	12%	-91%	$7,470,535	$0	1	122		$242,032	$279,900	**$56,140,737**
17	2022	$51,121,209	5%	-97%	$2,245,921	$0	0	123		$72,764	$285,778	**$53,725,671**
18	2023	$54,197,778	-1%	-100%	$0	$0	0	123		$0	$291,779	**$54,489,557**
19	2024	$57,381,019	73%	-29%	$63,174,126	$0	6	128		$2,046,732	$297,907	**$122,899,783**
20	2025	$58,586,020	127%	25%	$113,782,730	$0	10	138		$3,686,363	$304,163	**$176,359,275**
0 to 20	2005 to 2025	**$715,073,080**			**$710,337,948**	**$0**			**$18,000,000**	**$40,227,969**	**$1,549,404,411**	**$3,033,043,408**

In this scenario, the only mechanism for partially offsetting the gap is the provision of additional and new range resources. The economy does not suffer any inadequate testing costs, but the economy incurs costly new range resource expenses. The aerospace industry must pay high testing delay costs and extra expenditures to acquire additional range resources.

7.1.3 WRC 60

The WRC 60 scenario assumes:

- 60 MHz of spectrum augmentation will be granted at WRC;
- Additional and new test resources will be obtained; and,
- An inadequate testing factor of 1.00 only in those years where the gap after range supplements is greater than today's gap.

The economic model combines the BDM baseline demand and WRC 60 supply projections to calculate the gap. ATM bandwidth demand is tapered by increases in bandwidth efficiency assumed to be realized from technology investments, spectrum augmentation granted at WRC, and access to additional and new test resources. The model applies projected costs of technology investment, testing delays, inadequate testing. It also includes the costs and benefits of providing additional and new range resources. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-4 presents the detailed results of the economic model’s WRC 60 scenario.

Table 7-4. WRC 60 Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Gap	Gap After Range Supplements
-1	2004	0.992	215	0.00%	0	424	215	209	105
0	2005	1.012	215	1.00%	0	425	215	210	105
1	2006	1.032	215	1.73%	0	393	215	178	89
2	2007	1.054	215	3.00%	0	378	215	163	81
3	2008	1.076	215	5.20%	0	398	215	183	92
4	2009	1.099	215	9.00%	1	346	216	130	65
5	2010	1.122	215	15.59%	1	335	216	119	59
6	2011	1.145	215	27.00%	2	314	217	97	48
7	2012	1.169	215	46.77%	3	361	218	143	72
8	2013	1.194	215	81.00%	5	338	220	117	59
9	2014	1.219	215	100.00%	9	315	224	90	45
10	2015	1.245	215	100.00%	16	277	231	46	23
11	2016	1.271	215	100.00%	28	349	243	106	53
12	2017	1.298	215	100.00%	49	338	264	74	0
13	2018	1.325	215	100.00%	60	326	275	51	0
14	2019	1.353	215	100.00%	60	301	275	26	0
15	2020	1.381	215	100.00%	60	398	275	123	0
16	2021	1.410	215	100.00%	60	449	275	174	0
17	2022	1.440	215	100.00%	60	435	275	160	0
18	2023	1.470	215	100.00%	60	422	275	147	0
19	2024	1.501	215	100.00%	60	578	275	303	44
20	2025	1.532	215	100.00%	60	691	275	416	101
0 to 20	2005 to 2025								

Relative Year	Actual Year	Technology Investment Costs	Percent Difference of Future Gap Compared to Present Gap	Percent Difference of Future Gap After Range Supplements Compared to Present Gap	Cost of Testing Delays	Inadequate Testing	Number of Moved Tests	Cumulative Number of Moved Tests	Antenna Costs	Cost to Provide Additional Range Resources	Cost to Provide New Range Resources	Total Cost
-1	2004	$7,535,135	0%	0%	$59,506,552	$0	0	0	$0	$1,912,053	$0	**$0**
0	2005	$17,417,890	0%	0%	$60,398,144	$0	16	16	$18,000,000	$19,956,795	$0	**$115,772,828**
1	2006	$16,044,507	-15%	-15%	$52,163,941	$0	14	30		$1,690,021	$0	**$69,898,469**
2	2007	$16,909,074	-22%	-22%	$48,766,927	$0	13	42		$1,579,964	$140,626,698	**$207,882,663**
3	2008	$17,925,006	-13%	-13%	$55,966,351	$0	14	56		$1,813,212	$143,579,859	**$219,284,428**
4	2009	$19,129,110	-38%	-38%	$40,554,842	$0	10	66		$1,313,906	$146,595,036	**$207,592,895**
5	2010	$20,567,460	-43%	-43%	$37,859,650	$0	9	76		$1,226,587	$149,673,532	**$209,327,229**
6	2011	$22,400,512	-54%	-54%	$31,517,169	$0	7	83		$1,021,101	$152,816,676	**$207,755,459**
7	2012	$25,591,390	-32%	-32%	$47,549,580	$0	11	94		$1,540,524	$156,025,826	**$230,707,320**
8	2013	$27,755,963	-44%	-44%	$39,846,653	$0	9	103		$1,290,962	$159,302,368	**$228,195,947**
9	2014	$30,000,163	-57%	-57%	$31,265,495	$0	7	110		$1,012,948	$162,647,718	**$224,926,324**
10	2015	$32,326,378	-78%	-78%	$16,332,958	$0	4	114		$529,159	$166,063,320	**$215,251,816**
11	2016	$34,737,065	-49%	-49%	$38,376,648	$0	4	118		$621,668	$169,550,650	**$243,286,032**
12	2017	$37,234,744	-64%	-100%	$0	$0	0	118		$0	$257,573	**$37,492,317**
13	2018	$39,822,007	-76%	-100%	$0	$0	0	118		$0	$262,982	**$40,084,989**
14	2019	$42,501,514	-88%	-100%	$0	$0	0	118		$0	$268,504	**$42,770,019**
15	2020	$45,276,000	-41%	-100%	$0	$0	0	118		$0	$274,143	**$45,550,143**
16	2021	$48,148,270	-17%	-100%	$0	$0	0	118		$0	$279,900	**$48,428,170**
17	2022	$51,121,209	-23%	-100%	$0	$0	0	118		$0	$285,778	**$51,406,987**
18	2023	$54,197,778	-30%	-100%	$0	$0	0	118		$0	$291,779	**$54,489,557**
19	2024	$57,381,019	45%	-58%	$37,597,821	$0	3	121		$1,218,104	$297,907	**$96,494,850**
20	2025	$58,586,020	99%	-4%	$87,669,322	$0	8	129		$2,840,334	$304,163	**$149,399,838**
0 to 20	2005 to 2025	**$715,073,080**			**$625,865,503**	**$0**			**$18,000,000**	**$37,655,285**	**$1,549,404,411**	**$2,945,998,280**

In this scenario, the gap is partially offset by both the 60 MHz of spectrum augmentation and the provision of additional and new range resources. The economy does not suffer any inadequate testing costs, but the economy incurs costly new range resource expenses. The aerospace industry must pay high testing delay costs and extra expenditures to acquire additional range resources.

7.1.4 WRC 200

The WRC 200 scenario assumes:

- 200 MHz of spectrum augmentation will be granted at WRC;
- Additional test resources will be acquired;
- No new test resources will be obtained; and,
- An inadequate testing factor of 1.00 only in those years where the gap after range supplements is greater than today's gap.

The economic model combines the BDM baseline demand and WRC 200 supply projections to calculate the gap. ATM bandwidth demand is tapered by increases in bandwidth efficiency assumed to be realized from technology investments, spectrum augmentation granted at WRC, and access to additional test resources. The model applies projected costs of technology investment, testing delays, inadequate testing. It also includes the costs and benefits of acquiring additional range resources. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-5 presents the detailed results of the economic model's WRC 200 scenario.

Table 7-5. WRC 200 Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Gap	Gap After Range Supplements
-1	2004	0.992	215	0.00%	0	424	215	209	105
0	2005	1.012	215	1.00%	0	425	215	210	105
1	2006	1.032	215	1.73%	0	393	215	178	89
2	2007	1.054	215	3.00%	0	378	215	163	81
3	2008	1.076	215	5.20%	0	398	215	183	92
4	2009	1.099	215	9.00%	2	346	217	129	64
5	2010	1.122	215	15.59%	3	335	218	116	58
6	2011	1.145	215	27.00%	6	314	221	93	46
7	2012	1.169	215	46.77%	10	361	225	136	68
8	2013	1.194	215	81.00%	18	338	233	105	52
9	2014	1.219	215	100.00%	31	315	246	68	34
10	2015	1.245	215	100.00%	54	277	269	8	4
11	2016	1.271	215	100.00%	94	349	309	41	20
12	2017	1.298	215	100.00%	162	338	377	-39	0
13	2018	1.325	215	100.00%	200	326	415	-89	0
14	2019	1.353	215	100.00%	200	301	415	-114	0
15	2020	1.381	215	100.00%	200	398	415	-17	0
16	2021	1.410	215	100.00%	200	449	415	34	17
17	2022	1.440	215	100.00%	200	435	415	20	10
18	2023	1.470	215	100.00%	200	422	415	7	4
19	2024	1.501	215	100.00%	200	578	415	163	82
20	2025	1.532	215	100.00%	200	691	415	276	138
0 to 20	2005 to 2025								

Relative Year	Actual Year	Technology Investment Costs	Percent Difference of Future Gap Compared to Present Gap	Percent Difference of Future Gap After Range Supplements Compared to Present Gap	Cost of Testing Delays	Inadequate Testing	Number of Moved Tests	Cumulative Number of Moved Tests	Antenna Costs	Cost to Provide Additional Range Resources	Cost to Provide New Range Resources	Total Cost
-1	2004	$7,535,135	0%	0%	$59,506,552	$0	0	0	$0	$1,912,053	$0	**$0**
0	2005	$17,417,890	0%	0%	$60,398,144	$0	16	16	$18,000,000	$19,956,795	$0	**$115,772,828**
1	2006	$16,044,507	-15%	-15%	$52,163,941	$0	14	30		$1,690,021	$0	**$69,898,469**
2	2007	$16,909,074	-22%	-22%	$48,766,927	$0	13	42		$1,579,964	$0	**$67,255,964**
3	2008	$17,925,006	-13%	-13%	$55,966,351	$0	14	56		$1,813,212	$0	**$75,704,569**
4	2009	$19,129,110	-39%	-39%	$40,117,896	$0	10	66		$1,299,750	$0	**$60,546,756**
5	2010	$20,567,460	-44%	-44%	$37,086,943	$0	9	75		$1,201,552	$0	**$58,855,956**
6	2011	$22,400,512	-56%	-56%	$30,150,696	$0	7	82		$976,830	$0	**$53,528,038**
7	2012	$25,591,390	-35%	-35%	$45,133,076	$0	10	93		$1,462,233	$0	**$72,186,699**
8	2013	$27,755,963	-50%	-50%	$35,573,249	$0	8	101		$1,152,511	$0	**$64,481,724**
9	2014	$30,000,163	-67%	-67%	$23,708,306	$0	5	106		$768,108	$0	**$54,476,576**
10	2015	$32,326,378	-96%	-96%	$2,968,644	$0	1	107		$96,179	$0	**$35,391,201**
11	2016	$34,737,065	-81%	-81%	$14,742,876	$0	2	108		$238,822	$0	**$49,718,763**
12	2017	$37,234,744	-119%	-100%	$0	$0	0	108		$0	$0	**$37,234,744**
13	2018	$39,822,007	-142%	-100%	$0	$0	0	108		$0	$0	**$39,822,007**
14	2019	$42,501,514	-155%	-100%	$0	$0	0	108		$0	$0	**$42,501,514**
15	2020	$45,276,000	-108%	-100%	$0	$0	0	108		$0	$0	**$45,276,000**
16	2021	$48,148,270	-84%	-84%	$13,478,129	$0	1	110		$436,668	$0	**$62,063,067**
17	2022	$51,121,209	-90%	-90%	$8,379,674	$0	1	111		$271,487	$0	**$59,772,370**
18	2023	$54,197,778	-97%	-97%	$2,943,653	$0	0	111		$95,369	$0	**$57,236,800**
19	2024	$57,381,019	-22%	-22%	$69,568,203	$0	6	117		$2,253,889	$0	**$129,203,110**
20	2025	$58,586,020	32%	32%	$120,311,082	$0	11	128		$3,897,870	$0	**$182,794,972**
0 to 20	2005 to 2025	**$715,073,080**			**$661,457,789**	**$0**			**$18,000,000**	**$39,191,260**	**$0**	**$1,433,722,130**

In this scenario, additional range resources partially offset the gap until the spectrum augmentation is granted and utilized. The 200 MHz of spectrum augmentation makes it possible to fulfill the gap in several, but not all, years. The economy does not suffer any inadequate testing costs, but the aerospace industry must pay for testing delays and the acquisition of additional range resources.

7.1.5 WRC 425

The WRC 425 scenario assumes:

- 425 MHz of spectrum augmentation will be granted at WRC;
- Additional test resources will be acquired;
- No new test resources will be obtained; and,
- An inadequate testing factor of 1.00 only in those years where the gap after range supplements is greater than today's gap.

The economic model combines the BDM baseline demand and WRC 425 supply projections to calculate the gap. ATM bandwidth demand is tapered by increases in bandwidth efficiency assumed to be realized from technology investments, spectrum augmentation granted at WRC, and access to additional test resources. The model applies projected costs of technology investment, testing delays, inadequate testing. It also includes the costs and benefits of acquiring additional range resources. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-6 presents the detailed results of the economic model's WRC 425 scenario.

Table 7-6. WRC 425 Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Gap	Gap After Range Supplements
-1	2004	0.992	215	0.00%	0	424	215	209	105
0	2005	1.012	215	1.00%	0	425	215	210	105
1	2006	1.032	215	1.73%	0	393	215	178	89
2	2007	1.054	215	3.00%	0	378	215	163	81
3	2008	1.076	215	5.20%	0	398	215	183	92
4	2009	1.099	215	9.00%	4	346	219	126	63
5	2010	1.122	215	15.59%	7	335	222	112	56
6	2011	1.145	215	27.00%	13	314	228	86	43
7	2012	1.169	215	46.77%	22	361	237	124	62
8	2013	1.194	215	81.00%	38	338	253	85	42
9	2014	1.219	215	100.00%	66	315	281	33	17
10	2015	1.245	215	100.00%	115	277	330	-52	0
11	2016	1.271	215	100.00%	199	349	414	-64	0
12	2017	1.298	215	100.00%	344	338	559	-221	0
13	2018	1.325	215	100.00%	425	326	640	-314	0
14	2019	1.353	215	100.00%	425	301	640	-339	0
15	2020	1.381	215	100.00%	425	398	640	-242	0
16	2021	1.410	215	100.00%	425	449	640	-191	0
17	2022	1.440	215	100.00%	425	435	640	-205	0
18	2023	1.470	215	100.00%	425	422	640	-218	0
19	2024	1.501	215	100.00%	425	578	640	-62	0
20	2025	1.532	215	100.00%	425	691	640	51	26
0 to 20	2005 to 2025								

Relative Year	Actual Year	Technology Investment Costs	Percent Difference of Future Gap Compared to Present Gap	Percent Difference of Future Gap After Range Supplements Compared to Present Gap	Cost of Testing Delays	Inadequate Testing	Number of Moved Tests	Cumulative Number of Moved Tests	Antenna Costs	Cost to Provide Additional Range Resources	Cost to Provide New Range Resources	Total Cost
-1	2004	$7,535,135	0%	0%	$59,506,552	$0	0	0	$0	$1,912,053	$0	**$0**
0	2005	$17,417,890	0%	0%	$60,398,144	$0	16	16	$18,000,000	$19,956,795	$0	**$115,772,828**
1	2006	$16,044,507	-15%	-15%	$52,163,941	$0	14	30		$1,690,021	$0	**$69,898,469**
2	2007	$16,909,074	-22%	-22%	$48,766,927	$0	13	42		$1,579,964	$0	**$67,255,964**
3	2008	$17,925,006	-13%	-13%	$55,966,351	$0	14	56		$1,813,212	$0	**$75,704,569**
4	2009	$19,129,110	-40%	-40%	$39,415,660	$0	10	66		$1,276,999	$0	**$59,821,769**
5	2010	$20,567,460	-46%	-46%	$35,845,093	$0	9	75		$1,161,319	$0	**$57,573,872**
6	2011	$22,400,512	-59%	-59%	$27,954,578	$0	7	81		$905,680	$0	**$51,260,770**
7	2012	$25,591,390	-41%	-41%	$41,249,409	$0	10	91		$1,336,409	$0	**$68,177,208**
8	2013	$27,755,963	-60%	-60%	$28,705,279	$0	7	98		$930,001	$0	**$57,391,243**
9	2014	$30,000,163	-84%	-84%	$11,562,822	$0	3	100		$374,615	$0	**$41,937,601**
10	2015	$32,326,378	-125%	-100%	$0	$0	-4	96		-$599,683	$0	**$31,726,696**
11	2016	$34,737,065	-131%	-100%	$0	$0	0	96		$0	$0	**$34,737,065**
12	2017	$37,234,744	-206%	-100%	$0	$0	0	96		$0	$0	**$37,234,744**
13	2018	$39,822,007	-250%	-100%	$0	$0	0	96		$0	$0	**$39,822,007**
14	2019	$42,501,514	-262%	-100%	$0	$0	0	96		$0	$0	**$42,501,514**
15	2020	$45,276,000	-216%	-100%	$0	$0	0	96		$0	$0	**$45,276,000**
16	2021	$48,148,270	-191%	-100%	$0	$0	0	96		$0	$0	**$48,148,270**
17	2022	$51,121,209	-198%	-100%	$0	$0	0	96		$0	$0	**$51,121,209**
18	2023	$54,197,778	-204%	-100%	$0	$0	0	96		$0	$0	**$54,197,778**
19	2024	$57,381,019	-129%	-100%	$0	$0	0	96		$0	$0	**$57,381,019**
20	2025	$58,586,020	-75%	-75%	$22,385,802	$0	2	98		$725,261	$0	**$81,697,084**
0 to 20	2005 to 2025	**$715,073,080**			**$424,414,005**	**$0**			**$18,000,000**	**$31,150,593**	**$0**	**$1,188,637,679**

In this scenario, additional range resources partially offset the gap until the spectrum augmentation is granted and utilized. The 425 MHz of spectrum augmentation makes it possible to temporarily fulfill the gap. The economy does not suffer any inadequate testing costs, but the aerospace industry must pay for testing delays and the acquisition of additional range resources until the spectrum augmentation is realized.

7.1.6 WRC 650

The WRC 650 scenario assumes:

- 650 MHz of spectrum augmentation will be granted at WRC;
- Additional test resources will be acquired;
- No new test resources will be obtained; and,
- An inadequate testing factor of 1.00 only in those years where the gap after range supplements is greater than today's gap.

The economic model combines the BDM baseline demand and WRC 650 supply projections to calculate the gap. ATM bandwidth demand is tapered by increases in bandwidth efficiency assumed to be realized from technology investments, spectrum augmentation granted at WRC, and access to additional test resources. The model applies projected costs of technology investment and initial testing delays. It also includes the costs and benefits of acquiring additional range resources. Standard Air Force inflation rates for research, development, testing, and evaluation are incorporated. Table 7-7 presents the detailed results of the economic model’s WRC 650 scenario.

Table 7-7. WRC 650 Scenario

Relative Year	Actual Year	AF Weighted Inflation Rates - Research, Devt, Testing, Evaluation (BY 2005)	Baseline Supply	Tech Adoption Rate - Med	Spectrum Augmentation	Final Demand	Final Supply	Gap	Gap After Range Supplements
-1	2004	0.992	215	0.00%	0	424	215	209	105
0	2005	1.012	215	1.00%	0	425	215	210	105
1	2006	1.032	215	1.73%	0	393	215	178	89
2	2007	1.054	215	3.00%	0	378	215	163	81
3	2008	1.076	215	5.20%	0	398	215	183	92
4	2009	1.099	215	9.00%	7	346	222	124	62
5	2010	1.122	215	15.59%	11	335	226	109	54
6	2011	1.145	215	27.00%	20	314	235	79	40
7	2012	1.169	215	46.77%	34	361	249	112	56
8	2013	1.194	215	81.00%	59	338	274	64	32
9	2014	1.219	215	100.00%	101	315	316	-2	0
10	2015	1.245	215	100.00%	176	277	391	-113	0
11	2016	1.271	215	100.00%	304	349	519	-170	0
12	2017	1.298	215	100.00%	527	338	742	-404	0
13	2018	1.325	215	100.00%	650	326	865	-539	0
14	2019	1.353	215	100.00%	650	301	865	-564	0
15	2020	1.381	215	100.00%	650	398	865	-467	0
16	2021	1.410	215	100.00%	650	449	865	-416	0
17	2022	1.440	215	100.00%	650	435	865	-430	0
18	2023	1.470	215	100.00%	650	422	865	-443	0
19	2024	1.501	215	100.00%	650	578	865	-287	0
20	2025	1.532	215	100.00%	650	691	865	-174	0
0 to 20	2005 to 2025								

Relative Year	**Actual Year**	**Technology Investment Costs**	**Percent Difference of Future Gap Compared to Present Gap**	**Percent Difference of Future Gap After Range Supplements Compared to Present Gap**	**Cost of Testing Delays**	**Inadequate Testing**	**Number of Moved Tests**	**Cumulative Number of Moved Tests**	**Antenna Costs**	**Cost to Provide Additional Range Resources**	**Cost to Provide New Range Resources**	**Total Cost**
-1	2004	$7,535,135	0%	0%	$59,506,552	$0	0	0	$0	$1,912,053	$0	**$0**
0	2005	$17,417,890	0%	0%	$60,398,144	$0	16	16	$18,000,000	$19,956,795	$0	**$115,772,828**
1	2006	$16,044,507	-15%	-15%	$52,163,941	$0	14	30		$1,690,021	$0	**$69,898,469**
2	2007	$16,909,074	-22%	-22%	$48,766,927	$0	13	42		$1,579,964	$0	**$67,255,964**
3	2008	$17,925,006	-13%	-13%	$55,966,351	$0	14	56		$1,813,212	$0	**$75,704,569**
4	2009	$19,129,110	-41%	-41%	$38,713,424	$0	10	66		$1,254,248	$0	**$59,096,782**
5	2010	$20,567,460	-48%	-48%	$34,603,242	$0	8	74		$1,121,085	$0	**$56,291,787**
6	2011	$22,400,512	-62%	-62%	$25,758,460	$0	6	80		$834,529	$0	**$48,993,501**
7	2012	$25,591,390	-46%	-46%	$37,365,741	$0	9	89		$1,210,585	$0	**$64,167,716**
8	2013	$27,755,963	-69%	-69%	$21,837,308	$0	5	94		$707,491	$0	**$50,300,762**
9	2014	$30,000,163	-101%	-100%	$0	$0	0	94		-$18,877	$0	**$29,981,286**
10	2015	$32,326,378	-154%	-100%	$0	$0	-9	85		-$1,295,544	$0	**$31,030,834**
11	2016	$34,737,065	-181%	-100%	$0	$0	0	85		$0	$0	**$34,737,065**
12	2017	$37,234,744	-293%	-100%	$0	$0	0	85		$0	$0	**$37,234,744**
13	2018	$39,822,007	-357%	-100%	$0	$0	0	85		$0	$0	**$39,822,007**
14	2019	$42,501,514	-369%	-100%	$0	$0	0	85		$0	$0	**$42,501,514**
15	2020	$45,276,000	-323%	-100%	$0	$0	0	85		$0	$0	**$45,276,000**
16	2021	$48,148,270	-299%	-100%	$0	$0	0	85		$0	$0	**$48,148,270**
17	2022	$51,121,209	-305%	-100%	$0	$0	0	85		$0	$0	**$51,121,209**
18	2023	$54,197,778	-311%	-100%	$0	$0	0	85		$0	$0	**$54,197,778**
19	2024	$57,381,019	-237%	-100%	$0	$0	0	85		$0	$0	**$57,381,019**
20	2025	$58,586,020	-183%	-100%	$0	$0	0	85		$0	$0	**$58,586,020**
0 to 20	2005 to 2025	**$715,073,080**			**$375,573,538**	**$0**			**$18,000,000**	**$28,853,508**	**$0**	**$1,137,500,126**

In this scenario, additional range resources partially offset the gap until the spectrum augmentation is granted and utilized. Once realized, the 650 MHz of spectrum augmentation makes it possible to fulfill the gap during all years analyzed in the model. The economy does not suffer any inadequate testing or new range resource costs. In the early years, before the spectrum augmentation is realized, the aerospace industry pays for testing delays and the acquisition of additional range resources.

7.1.7 Summary of Results

MITRE's economic model projects costs of inadequate ATM spectrum access. Costs are mitigated by decreasing testing delays, reducing inadequate testing, and/or lowering the need for test infrastructure enhancements. The first two can be accomplished through spectrum augmentation and/or the provision of new or additional test resources. The last can only be achieved with spectrum augmentation. The model does not incorporate the risk that new or additional test resources may not be available or possible. Legal, environmental, political, and large upfront investment hurdles may not be overcome. In the present environment, such test infrastructure enhancements are not a realistic option.

Figure 7-1 shows the source of the costs for the scenarios with iNET. Results were computed for a twenty-year period, from 2005 to 2025. Even with iNET, the cost of inadequate ATM spectrum access is significant.

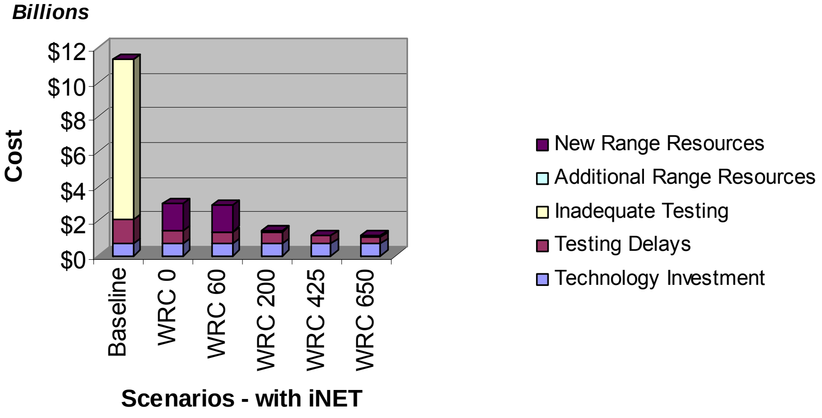

Figure 7-1. Source of Costs - with iNET

Figure 7-2 shows the cost breakdown for the scenarios without iNET. Again, results were computed for a twenty-year period, from 2005 to 2025. Without iNET, costs are higher, and inadequate testing becomes a major cost factor in every scenario but WRC 650.

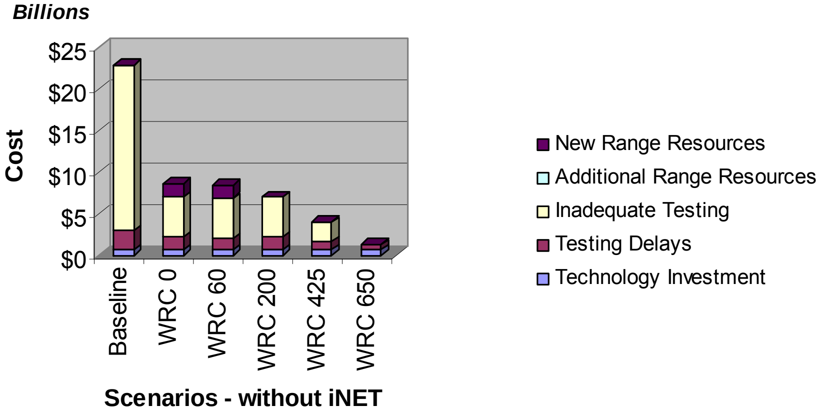

Figure 7-2. Source of Costs – without iNET

The results of the economic model (detailed in Sections 7.1.1 through 1.1.1) are summarized in Table 7-8 below.

Table 7-8. Summary Results of Economic Model

With iNET						
Scenarios	**Total Cost for Analysis Period (2005-2025)**	**Year 2025 Cost**	**Annual Benefit (in Year 2025)**	**Year 2025 Gap (After Supplments)**	**New Range Resources**	**Spectrum Augmentation**
Baseline	**$11,316,203,864**	**$2,676,147,341**	**$0**	476	No	0
WRC 0	**$3,033,043,408**	**$176,359,275**	**$2,499,788,066**	131	Yes - 1	0
WRC 60	**$2,945,998,280**	**$149,399,838**	**$2,526,747,503**	101	Yes -1	60
WRC 200	**$1,433,722,130**	**$182,794,972**	**$2,493,352,369**	138	No	200
WRC 425	**$1,188,637,679**	**$81,697,084**	**$2,594,450,258**	26	No	425
WRC 650	**$1,137,500,126**	**$58,586,020**	**$2,617,561,321**	0	No	650
Without iNET						
Scenarios	**Total Cost for Analysis Period (2005-2025)**	**Year 2025 Cost**	**Annual Benefit (in Year 2025)**	**Year 2025 Gap (After Supplments)**	**New Range Resources**	**Spectrum Augmentation**
Baseline	**$22,885,760,198**	**$2,894,061,314**	**$0**	977	No	0
WRC 0	**$8,660,052,563**	**$2,811,538,828**	**$82,522,486**	381	Yes - 1	0
WRC 60	**$8,483,120,642**	**$2,784,579,391**	**$109,481,923**	351	Yes -1	60
WRC 200	**$7,094,639,064**	**$2,817,974,525**	**$76,086,789**	389	No	200
WRC 425	**$4,075,861,150**	**$2,716,876,637**	**$177,184,678**	276	No	425
WRC 650	**$1,380,718,261**	**$205,573,202**	**$2,688,488,112**	164	No	650

These results show the projected cost of inadequate ATM spectrum access over the twenty year period (2005-2025), the annual cost in year 2025, the annual benefit (namely cost savings) achieved in year 2025 from any spectrum augmentation, and the year 2025 gap (after range supplements) for each given scenario. The annual benefit (namely cost savings) is derived by comparing the Year 2025 cost of a given scenario to that of the baseline scenario. This “benefit” is a result of potential bandwidth efficiency improvements from technology investments, test infrastructure enhancements, and any spectrum augmentation as defined in each particular scenario. Table 7-8 also displays whether or not the scenario includes the provision of new range resources. Insufficient access to ATM spectrum will cost an estimated $11.3 billion with iNET, or $22.9 billion without iNET, over the next twenty years without spectrum augmentation or new range resources. WRC spectrum augmentation of 650 MHz with iNET would provide an annual benefit of $2.6 billion and is the only scenario in which projected requirements are met in the base case over the next twenty years.

8.0 Supporting Findings

This section provides additional information in support of the economic analysis. Included are findings on:

- Testing mandates for commercial and government programs (Section 8.1);
- Consequences of inadequate testing (Section 8.2);
- Importance of regulation (Section 8.3);
- Importance of worldwide allocation (Section 8.4); and,
- Frequency band considerations (Section 8.5).

8.1 Testing Mandates

This section discusses testing mandates for commercial and government programs. In the commercial world, the FAA sets the minimal testing requirements. Commercial programs design testing programs that meet FAA requirements and maximize potential profitability. Some business models may lengthen testing schedules to achieve high reliability and low operations and maintenance costs throughout the lifecycle of the program. Other models may focus on shortened testing to reach reasonable reliability and rapid time-to-market, thereby capturing market share from its competitors. Programs that minimize testing reap the rewards of lower development costs and earlier time-to-market.

There are legislative mandates for testing of government programs. DoD is undertaking an effort to shorten testing schedules and accelerate acquisition cycles in attempt to meet warfighter needs. Shortening acquisition cycles is a primary goal of the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (ATL). The DoD 5000 series reform fosters initiative, speed, and efficiency. Thomas Christie asserts that "the testing community should be looking at ways of cutting testing turn-around times in half."[51] As former Under Secretary of Defense for ATL, E.C. "Pete" Aldridge, Jr. mandated evolutionary, spiral development of weapons systems to enable more rapid and less costly fielding of equipment. Paul G. Kaminski, a former Under Secretary of Defense for Acquisition and Technology, stated "without a doubt, our number one priority must be to shorten the cycle time for developing new weapon systems or inserting new technology into existing systems[;]… the military advantage goes to the nation who has the best cycle

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[51] Christie, Honorable Thomas, Director, Operational Test and Evaluation, OSD, "Test and Evaluation in the 'New World of 2004,'" NDIA Test and Evaluation Conference, 2 March 2004.

time."[52] To meet schedule and budget pressures, the Services may choose to minimize testing of some programs.

Driven by schedule and budgetary demands, programs conduct minimal and inadequate testing in some instances. According to Dr. Ernest Seglie, Science Advisor to DOT&E, the percent of systems meeting reliability requirements declined from 41% in 1998-1990 to 20% today.[53] Modeling and simulation "augments live testing, but does not replace it."[54] Early T&E intervention is needed to improve this reliability. Data indicates that Operational Testing (OT) is most often conducted if required by an oversight agency. The following figure shows that OT is conducted for systems on the highest level of OSD oversight – Acquisition Category (ACAT) ID – but is less common for smaller programs requiring a lower level of oversight and review (ACAT IC, II, and III programs).[55]

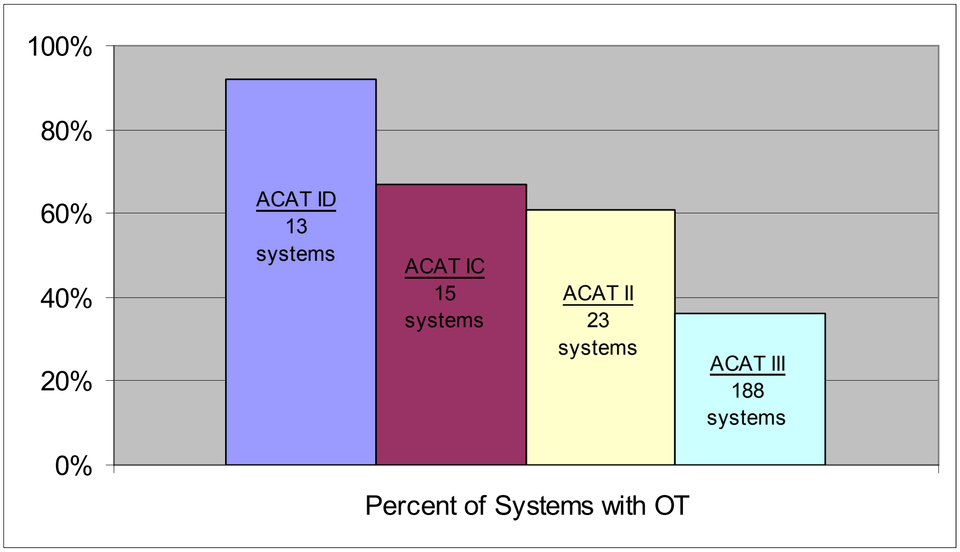

Figure 8-1. Percent of Systems with OT by ACAT

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[52] Kaminski, Paul G., Undersecretary of Defense for Acquisition and Technology, "Reinventing DoD Test and Evaluation," International Test and Evaluation Association Symposium, 3 October 1995.

[53] Dr. Ernest Seglie, Science Advisor, DOT&E, National Defense Industry Association, 17-18 August 2004.

[54] NDIA conference participants, "Test and Evaluation in the 'New World of 2004,'" NDIA Test and Evaluation Conference, 2 March 2004.

[55] "DT Results Vs. OT Results," DOT&E.

The United States Code, Section 149 of Title 10, establishes DOT&E as the principal advisor to the Secretary of Defense and the Under Secretary of Defense for ATL on operational test and evaluation. A primary function for DOT&E is oversight of the development of the Test and Evaluation Master Plan (TEMP) for major defense acquisition programs in accordance with DoD regulations.

Two examples are provided to illustrate legislative mandates for testing. Section 8.1.1 illustrates Congress' power to ensure adequate testing in the Ballistic Missile Defense program. Section 8.1.2 features spiral development and the Pathfinder programs, another example of Congressional oversight to increase testing.

8.1.1 Example of the Ballistic Missile Defense Program

Congress has a great interest in making sure DoD does not abandon sound and adequate T&E in an attempt to field systems faster, and in the guise of evolutionary or spiral development. Congress has the power to enforce more testing, and sometimes intervenes to strengthen oversight of testing programs. Congress intervened in the testing of the ballistic missile defense (BMD) programs. It established a more cooperative relationship between DOT&E and the Missile Defense Agency (MDA) to foster a successful execution of BMD programs. The Senate required DoD to submit to the Congressional defense committee's reports containing operational assessments of these programs by DOT&E and an annual review of the cost, schedule, and performance criteria of all BMD programs by the Joint Requirements Oversight Council (JROC). Congressional defense committees strongly urged DoD to ensure that assets used in an operational defense role undergo the full and rigorous testing required by law, prior to being placed in an operational status.[56]

Congress mandated the Secretary of Defense to ensure that BMD programs incorporate, to the greatest possible extent, operationally realistic test configurations to demonstrate system performance across a broad range of capability. During the final stages of OT, the Secretary must ensure that the reliable performance is established. Congress required that the testing baseline be developed in consultation with DOT&E and the Treaty Compliance Review Group of the DoD.[57] According to Congress, DOT&E shall each year assess the adequacy and sufficiency of the BMD test program during the preceding fiscal year, and submit a report on the assessment to the Congressional defense committees.[58]

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[56] "BMD Provisions in FY04 Defense Authorization Bill."

[57] "BMD Provisions in FY02 Defense Authorization Bill."

[58] "FY02 Defense Authorization Conference Report."

For the ballistic missile defense program, Congress records that funding for Command and Control, Battle Management and Communications (C2BMC) has increased significantly from fiscal year 2004, with efforts spread across blocks 2004, 2006, and 2008, even though block 2004 has not undergone full OT. While Congress supports the concept of spiral development, it also notes that successful spirals are grounded in successful testing of an initial baseline.

Congress further states that it understands that additional sustainment funds are needed for the Ground-Based Midcourse Defense (GMD) element to provide higher assurance that test and operational requirements can be met. The use of the operational capabilities of the missile defense test bed has been endorsed in testimony before Congress by both the Commander of US Strategic Command, representing the operational community, and DOT&E, who oversees Missile Defense Agency testing.[59] Congress mandated that the Secretary of Defense, in consultation with DOT&E, shall prescribe appropriate criteria for operationally realistic testing of fieldable prototypes and submit a copy of the prescribed criteria to the Congressional defense committees. DOT&E shall evaluate the results of each test conducted.[60]

8.1.2 Spiral Development and the Pathfinder Example

The Senate Armed Services Committee believes that properly structured spiral development programs can play an important role in enabling the DoD to rapidly field new technologies. The GAO has undertaken an extensive review of weapons systems acquisition issues at the request of the committee and has concluded that an evolutionary, or phased, approach to developing weapons systems could lead to significantly improved outcomes. At the same time, GAO has testified that "Measures for success need to be defined for each stage of the development process so that decision-makers can be assured that sufficient knowledge exists about critical facets of the product before investment [of] more time and money."[61] DoD must take a disciplined approach to spiral development to ensure that both Congress and DoD have the information they need to make acquisition and budget decisions.

For each increment of an evolutionary acquisition process, Congress requires the Secretary of Defense to report on the manner in which DoD plans to establish, approve, and meet requirements for operational testing and live fire testing. The spiral development plan

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[59] "BMD Provisions in FY05 Defense Authorization Bill."

[60] "FY05 Defense Authorization Conference Report."

[61] "FY03 Defense Authorization Bill."

must include a testing plan to ensure that performance goals, parameters, and exit criteria are met.[62]

The pathfinder programs have a goal of reducing acquisition cycle time by a ratio of 4:1.[63] Congress required the Secretary of the Air Force to submit a report describing the test and evaluation plan for the pathfinder programs and how that plan will provide an adequate assessment of each pathfinder program.[64]

8.2 Consequences of Inadequate Testing

This section describes consequences of inadequate testing. Although the specific consequences of not testing cannot be proven, nor reliably predicted, in many instances, there are numerous programs that have incurred astronomical costs because of their decision to reduce testing. Real examples and consequences of inadequate testing follow.

The Air Force's Joint Chemical Agent Detector (JCAD) Program Office persuaded officials to purchase 100 early models of a new hand-held chemical agent detector in 2002 for use in the second Iraq war. However, these officials knew that the manufacturer's tests showed that the detectors did not work well in hot areas or under battle conditions, and they did not wait for further planned tests to be conducted. These later tests, completed in March 2003, concluded that the detectors did not satisfy all JCAD operational requirements and did not add significant military capability over fielded units. The Air Force lost the $1 million they spent on the inadequately tested and faulty devices. In addition, these devices may have put airmen at increased risk while they depended on the equipment.

There are also positive outcomes from conducting tests. The program managers of the Cassini-Huygens probe decided not to test the communications system in an actual mission profile simulation because they thought it would reflect negatively on the designers of the communications system. After the spacecraft was launched, the new program manager haphazardly decided to perform the inexpensive test on the system while it was flying to Saturn. The test showed that the Cassini spacecraft could not receive the communication signal because the software in the receiver had been set to too narrow of a bandwidth (the engineers had forgotten to account for the Doppler effect). During the actual descent phase of the mission Cassini would be screaming almost straight towards Huygens, which would

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[62] "Congressional Reporting Requirements of Spiral Development Provisions Included in the FY03 Defense Authorization Bill."

[63] Marvin Sambur, Assistant Secretary of the Air Force, " Pathfinder Program Testing the Potential of Spiral Arms Development," Program Manager, July-August 2003.

[64] "Spiral Development in the FY03 National Defense Authorization Act."

make the receive signal appear higher in frequency; the engineer discovered that the Cassini receiver could not see this higher frequency. The software in the spacecraft receiver had not been designed to be changed remotely, so the mission team changed the spacecraft's mission profile so that when Huygens was descending to Titan, Cassini would be on a low trajectory that would make the relative speed between the two vehicles low enough that the Cassini receiver could capture the signal from Huygens. The inexpensive test saved the over one billion dollar investment.[65]

8.3 Importance of Regulation

Section 8.3 discusses the importance of regulation. Regulation is important to spectrum allocation because spectrum is an economic and public good. An economic good is any product or service which uses scarce resources and has utility. Spectrum is a limited resource that has multiple valued uses, which are constrained by the potential for interference, conflict, and congestion. It is a resource of significant and increasing commercial value as exemplified by the approximately $17 billion received by the federal government from Federal Communications Commission (FCC) auctions since 1994. The Congressional Budget Office projects that auctions of spectrum licenses will yield an additional $18 million in receipts from 2001 through 2010.[66]

Spectrum is also a public good, or an item that is perceived as good for the welfare of all. ATM spectrum allows testers to conduct safe, effective, and efficient missions by displaying and analyzing data in real-time which, in turn, increases efficiencies and reduces safety risks to the aerospace industry. The aerospace industry is important to the general public as established by the following excerpt of a previous MITRE study:[67]

> *The aerospace industry contributes greatly to the US economy. The aerospace industry generates 15% of the US gross domestic product (GDP) and over 11 million jobs. Aerospace products account for the largest positive balance of payments contribution of any sector of the nation's economy. Over 40% of the industry's products are exported. The largest US exporter is an aerospace company. The US depends on the aerospace industry to arm the military with superior weapons. The*

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[65] Darrell Ernst, The MITRE Corporation, e-mail, 21 January 2005.

[66] Federal government's $17 billion in receipts since 1994 is net of subsidies for licenses financed by federal loans. "The Budget and Economic Outlook: Fiscal Years 2001-2010," Congressional Budget Office, January 2000.

[67] Kahn, Carolyn A., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," The MITRE Corporation, MTR 04B0000016, December 2003.

> *US relies on air travel to move passengers and products rapidly across the nation and around the world. Each year, US airlines move over 600 million passengers and many times that number of pieces of cargo. The US depends on satellites for inexpensive and instantaneous global communications and navigation. A strong aerospace industry also enables scientific discovery.*[68] *A high priority should be placed on enhancing the health of the aerospace industry, considering its importance to the US economy.*

The social value of spectrum is not reflected in market or auction prices. Social value includes consumer surplus, or the benefit to a consumer above the market price. For such resources, market oversight with international political or administrative allocation would more nearly maximize the social value of the spectrum. Government organizations have recognized the importance of spectrum regulation, particularly for safety and test and evaluation systems. For instance, the US Office of Science and Technology issued a directive to develop a shared vision among civil and military stakeholders that includes "sensor and [Command and Control] (C2) capabilities necessary to safely conduct national security, civil, and commercial space launch operations, as well as test and evaluation of land and sea-based ballistic missiles and other systems.[69]

8.4 Importance of Worldwide Allocation

This section addresses the importance of worldwide allocation. There is an increasing movement toward globalization, indicated by the rise in multinational companies; collaboration between defense contractors; sharing of intellectual property, technologies, and markets; international approach of national governments, multinational research and development projects; and offering of competitive contracts to overseas bidders. ATM spectrum allocation should support the movement toward increasing globalization.

Aerospace companies operate in an international industry. The internationalization is fueled by the enormous costs and risks that are common in the aerospace sector. A single company – and country – often cannot withstand the entire burden of developing a new aircraft. Companies are compelled to cooperate with other countries whenever possible to purchase lower cost standardized components and to accept additional investment capital. According to the World Technology Evaluation Center, "there is no other industry more

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[68] Walker, Robert S. "US Aerospace Commission Letter to President Bush," Commission on the Future of the US Aerospace Industry, 20 March 2002. Further information on the US aerospace and aviation industry can be found in Appendix I.

[69] Crouch, Viv, "Network-Enabled Connectivity – Key to Full Spectrum RDT&E."

international than commercial aircraft, and the trend toward further internationalization is increasing."[70]

Worldwide frequency allocation provides commonly available spectrum for certain application. Worldwide allocation facilitates interoperability of equipment both internationally and nationally, lowers costs through manufacturing economies of scale, and provides more stability and certainty in frequency planning. Worldwide allocation also avoids future displacement costs from national governments reallocating spectrum. Absence of global harmonized frequencies is a risk area and has important interoperability consequences. One company in particular disclosed that it wants to perform flight tests in more than one country, but need additional worldwide spectrum allocation to do so.[71] Programs requiring another RF band in a different country may incur costs for additional radio equipment, expensive system redesigns, and expanded testing and evaluation.

The following figure shows the approximate telemetry operating areas around the world. The circles represent launch sites, scientific sites, and aircraft test facilities. There are very few nations that do not have some dependency on telemetry.[72]

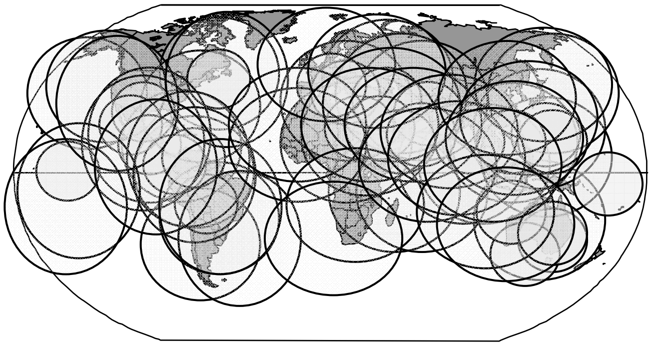

Figure 8.3. International Telemetry Spectrum Usage

Most countries have a national airline, committed to providing air service to its own country. These "flag carriers" are an important source of national pride and a symbol of national identity. A national airline fosters revenue from tourism and provides employment

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[70] World Technology Evaluation Center, http://www.wtec.org/loyola/polymers/c2_s5.htm, April 1994.

[71] Society of Flight Test Engineers (SFTE), 35th Annual Symposium, conversations attendees, Wichita, KS, 16 September 2004.

[72] Chalfant, Timothy A. and Darrell Ernst, "Telemetry Band Augmentation: An Agenda Item at the Next World Radiocommunication Council," The International Consortium for Telemetry Spectrum and The MITRE Corporation, 2004.

opportunities for its citizens. It is a resource for foreign exchange. A national airline is essential to island nations and other small countries lacking good road or rail service to other countries. It also maintains vital infrastructure to support the national economy. A list of national airlines is exhibited in Figure 8-2 below.[73]

Afghanistan – Ariana Afghan Airlines, Albania – Albanian Airlines, Algeria – Air Algérie, Angola – Linhas Aéreas de Angola, Argentina – Aerolíneas Argentinas, Armenia – Armenian Airlines, Australia – Qantas, Austria – Austrian Airlines, Azerbaijan – Azerbaijan Airlines, The Bahamas – Bahamasair, Bahrain – Gulf Air (regional), Bangladesh – Biman Bangladesh, Belarus – Belavia, Belgium – SN Brussels Airlines, Sabena (former), Belize – Maya Island Air, Benin – Druk Air, Bolivia – Lloyd Aéreo Boliviano, Botswana – Air Botswana, Brazil – TAM, Varig, Brunei Darussalam – Royal Brunei Airlines, Bulgaria – Balkan Air Tour, Burkina Faso – Air Burkina, Cameroon – Cameroon Airlines (Camair), Canada – Air Canada (former), Cape Verde – Transportes Aéreos de Cabo Verde, Cayman Islands – Cayman Airways, Chile – Lan Chile, China, People's Republic of – Air China, China, Republic of (Taiwan) – China Airlines, Colombia – Avianca, Congo-Kinshasa – Congo Airlines, Costa Rica – Lacsa, Côte d'Ivoire – Air Ivoire, Croatia – Croatia Airlines, Cuba – Cubana de Aviación, Cyprus – Cyprus Airways, Czech Republic – Czech Airlines, Denmark – Scandinavian Airlines System (SAS) (regional), Dominican Republic – Air Santo Domingo, Dominicana de Aviación (former), Egypt – EgyptAir, El Salvador – Taca International Airlines, Estonia – Estonian Air, Ethiopia – Ethiopian Airlines, Fiji – Air Fiji (domestic), Air Pacific (international), Finland – Finnair, France – Air France, Gabon – Air Gabon, The Gambia – Gambia International Airlines, Georgia – Airzena Georgian Airlines, Germany – Lufthansa, Ghana – Ghana Airways, Greece – Olympic Airways, Greenland – Greenlandair, Guadeloupe – Air Caraïbes (regional), Guinea-Bissau – Transportes Aéreos da Guiné-Bissau, Hungary – Malév, Iceland – Icelandair, India – Indian Airlines (Domestic & Regional), Air India (International), Air India Express (International - Low Cost), Indonesia – Garuda Indonesia, Merpati Nusantara Airlines (domestic), Iran – Iran Air, Iraq – Iraqi Airways, Ireland – Aer Lingus, Israel – El Al, Italy – Alitalia, Jamaica – Air Jamaica, Japan – All Nippon Airways, Japan Airlines, Jordan – Royal Jordanian Airlines, Kazakhstan – Air Kazakhstan, Kenya – Kenya Airways, Kiribati – Air Kiribati, North Korea – Air Koryo, South Korea – Korean Air, Kuwait – Kuwait Airways, Kyrgyzstan – Lao Aviation, Latvia – Air Baltic, Lebanon – Middle East Airlines, Libya – Libyan Arab Airlines, Lithuania – Lithuanian Airlines, Air Lithuania, Luxembourg – LuxAir, Macedonia – Macedonian Airlines, Interimpex-Avioimpex, Madagascar – Air Madagascar, Malawi – Air Malawi, Malaysia – Malaysia Airlines, Maldives – Air Maldives (former), Malta – Air Malta, Marshall Islands – Air Marshall Islands, Martinique – Air Caraïbes (regional), Mauritania – Air Mauritanie, Mauritius – Air Mauritius, México – Aeroméxico, Mexicana de Aviación, Moldova – Air Moldova, Monaco – Heli Air Monaco, Mongolia – MIAT Mongolian Airlines, Montenegro – Montenegro Airlines, Morocco – Royal Air Maroc, Mozambique – Linhas Aéreas de Moçambique, Myanmar (Burma) – Myanma Airways, Namibia – Air Namibia, Nauru – Air Nauru, Nepal – Royal Nepal Airlines, Netherlands – KLM, New Caledonia – Aircalin (international), Air Calédonie (domestic), New Zealand – Air New Zealand, Nigeria – Nigeria Airways, Norway – Scandinavian Airlines System (SAS) (regional), Oman – Gulf Air (regional), Oman Air, Qatar – Qatar Airways, Pakistan – Pakistan International Airlines, Panama – Copa, Papua New Guinea – Air Niugini, Paraguay – Transportes Aéreos del Mercosur, Peru – Aeroperu, Lan Perú, Philippines – Philippine Airlines, Poland – LOT Polish Airlines, Portugal – Air Portugal (TAP), Qatar – Gulf Air (regional), Qatar Airways, Republika Srpska (Bosnia-Herzegovina) – Air Srpska, Romania – Transporturi Aeriene Române (TAROM), Russia – Aeroflot, Rwanda – Rwandair Express, Samoa – Polynesian Airlines, Saudi Arabia – Saudia, Senegal – Air Sénégal, Serbia and Montenegro – Air Seychelles, Sierra Leone – Sierra National Airlines, Singapore – Singapore Airlines, Silkair, Slovenia – Adria Airways, Solomon Islands – Solomon Airlines, Spain – Iberia Airlines, Sri Lanka – SriLankan Airlines, Sudan – Sudan Airways, Suriname – Surinam Airways, Sweden – Swiss, Swissair (former), Syria – Syrian Arab Airlines, Tajikistan – Air Tanzania, Thailand – Thai Airways, Tonga – Royal Tongan Airlines, Trinidad and Tobago – British West Indian Airways (BWIA), Tunisia – Tunis Air, Turkey – Turkish Airlines, Turkmenistan – Turkmenistan Airlines, United Arab Emirates – Gulf Air (regional), Etihad Airways (national), Emirates (Dubai), United Kingdom – British Airways, Uruguay – Pluna, Uzbekistan – Uzbekistan Airways, Vanuatu – Air Vanuatu, Vanair, Venezuela – Avensa, Viasa, Vietnam – Vietnam Airlines, Yemen – Yemenia Yemen Airways, Zambia – Zambia Airways, Zimbabwe – Air Zimbabwe

Figure 8-2. List of National Airlines/"Flag Carriers"

Without a global spectrum augmentation, the aerospace industry will face difficult consequences. Pilots and ground personnel will face greater safety risks, aircraft certification costs will increase, and time-to-market will slow. These factors will inevitably be reflected in increased costs per airplane, which will be passed through to the purchasing carriers and, ultimately, to the traveling public. International cooperation will become increasingly important in the future; aerospace companies would benefit from worldwide ATM spectrum allocation.

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[73] "List of National Airlines," Farlex, http://encyclopedia.thefreedictionary.com/List%20of%20national%20airlines.

8.5 Frequency Band Considerations

Section 8.5 conveys important frequency band considerations. The analysis presented in this paper is based on total requirements for spectrum without reference to which spectrum bands would be used. However, specific bands need to be identified. This band identification needs to be based both on the technological characteristics of the bands and on the availability of these bands for use by aeronautical telemetry. Availability depends both on regulatory limitations and on the nature and number of incumbent users. The US has proposed two candidate bands for further study, namely 4400-4940 MHz and 5925-6700 MHz, based on technological and regulatory considerations. There is a French proposal to also consider the 5030-5250 MHz band. The U.S. supports consideration of the 5091-5150 MHz portion of that band.

Because of limitations of spectrum availability in specific locations, we need to identify more than the 650 MHz required spectrum in order to assure world-wide harmonization. Among these bands, only the 5925-6700 MHz band satisfies the 650 MHz requirement by itself. The 5090-5250 MHz is allocated world-wide for aeronautical navigation and satellite use and not for mobile applications such as telemetry. In the US, the 4400-4940 MHz band is allocated to Government fixed and mobile services as well as to very limited non-Government satellite use, while the 5925-6700 MHz band is allocated exclusively to non-Government uses, including fixed satellite uplinks, fixed service, and mobile service in a limited portion of the band. Government users might thus prefer to use the 4400-4940 MHz band. However, this band does not meet the full 650 MHz requirement. Moreover, a survey of band use by the Mid-Atlantic Frequency Coordinator shows that this band is already heavily used in many parts of the country. This survey demonstrates that there is no readily available spectrum in this band at the Western Test Range Complex and limited availability at many other major test ranges. However, there is substantial spectrum available in this band at test ranges on the Gulf Coast and Northern Florida, as well as at Kwajalein and at commercial Mid-West test sites. Therefore, there might be a need to shift some testing to new locations if we are to depend primarily on this band. No survey has been made regarding use of the 5925-6700 MHz band. However, we would expect that use of this band might be greatest near settled areas and less in isolated areas, such as much of the Western Range Complex. Thus, it might be feasible to make major use of this band at ranges that are located in isolated areas and less use at those ranges that are located in settled areas. It might thus be possible, through judicious assignments, to meet spectrum requirements at many locations by use of parts of both bands that are available at each specific location.

9.0 Conclusion

The flight test community faces a spectrum shortfall. The amount of spectrum allocated for ATM is not sufficient to meet needs and requirements are growing exponentially. ATM spectrum is vital to both commercial and military flight testing. Economic considerations are important to the proposal currently before the ITU, as Agenda Item 1.5 of the 2007 WRC, which calls for the allocation of additional spectrum for wideband ATM in the 3-30 GHz band.

The analysis and economic model developed by The MITRE Corporation and documented in this report projects the economic impact of inadequate ATM spectrum access. The analysis and resulting model relies heavily upon the knowledge, data and judgment of industry and government experts in the test community, and factored in a wide range of technical, operational and cost considerations. Cost impacts of inadequate ATM spectrum access include technology investments, test delays, test infrastructure enhancements, and inadequate testing. Spectrum augmentation is critical to minimizing these costs. The economic model estimates that cost impacts of inadequate telemetry spectrum at a test range complex over a twenty year period will range from almost $23 billion in the worst case scenario to over $1 billion in the best case. Projected costs of other scenarios fall within this range. In twenty years, the worst case – continue technology investments but no spectrum augmentation, test infrastructure enhancements, or implementation of iNET – shows an annual cost of almost $3 billion and a spectrum shortfall of 977 MHz. The best case – WRC spectrum augmentation of 650 MHz with iNET – shows an annual cost of under $58 million and a zero spectrum shortfall. The best case would provide an annual benefit of $2.6 billion and is the only scenario in which requirements are met in the base case over the next twenty years.

The future use of spectrum must be carefully planned so it can adequately support commercial and government flight test missions. The WRC decision on allocation of additional spectrum for wideband ATM is critical and will determine the nature of flight testing in the future. Agenda Item 1.5 is important to efficient development of innovative aerospace products, and this is important to all of us.

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Appendix A: Projection of Future Spectrum Requirements for Aeronautical Telemetry

Analysis of data going back over 30 years demonstrates that requirements for spectrum to support aeronautical flight test telemetry has been, and continues to expand exponentially. Regression analysis demonstrates that the spectrum per platform that is needed to support the most demanding new programs as they come on-line doubles every 3.9 years and that the underlying spectrum requirements for all programs increase exponentially at a lower rate. Various measures, such as more-efficient modulation and improved spectrum management, are being undertaken to mitigate the need for more spectrum and other measures are under investigation or proposed. However, as long as the requirement for spectrum increases exponentially, measures to decrease the requirement need to be able to continually decrease the need for new spectrum at, at least, the rate that the underlying demand is expanding. Otherwise, the need for new spectrum is only delayed for a few years.

Obviously, this situation cannot continue indefinitely, since useable radio frequency spectrum has some limits and this spectrum also supports many other services. Consequently, the growth of future spectrum requirements will eventually be limited either by growth of underlying demand, the use of test and evaluation methods that do not require expansion in the use of radio spectrum, or, failing these, a decrease in the quality of testing and thus of evaluation. This appendix identifies and briefly discusses possible developments that could lead to decrease in the growth of underlying demand and possible changes in test and evaluation methodology that might mitigate the need for more radio spectrum to support telemetry data transfer requirements.

A. 1 Projection of the Growth in Demand for Telemetry Spectrum

This section describes considerations that could reduce the growth of telemetry spectrum.

A.1.1 Growth in the Capability of the Underlying Technology

The growth in the requirement for telemetry spectrum results from the growth in the capability of the underlying technological capabilities that must be tested. This growth of technological capability is related to the exponential growth in the capacity of the underlying silicon-based electronic technology. According to Moore's Law, the number of devices on a silicon chip grows exponentially, doubling every 1.5 years. Moore's Law has been valid over a number of decades. However, the size of devices on a silicon chip is now in the 90 nanometer range. If device size decreases at the current rate, device size will shrink to atomic dimensions in 27 years. It is unlikely that devices of single atom size or less could be designed to provide needed capabilities. Consequently, the exponential growth of underlying capability would cease unless some other means were found to support such growth.

A.1.2 Growth in Demand for Weapon System Capability

The historical growth of telemetry spectrum requirements followed from the need to test growing weapon system capability that was being acquired to maintain weapons superiority over the Soviet Bloc during the Cold War. Despite the end of the Cold War, we have continued the process of developing weapons systems with ever increasing capability. However, it is not clear whether there will be prospective opponents against whom such weapons systems, particularly advanced tactical systems, would be required in order to maintain weapons superiority. Clearly, there will no longer be armed conflict between advanced industrial nations and most other advanced nations have been reducing their military capabilities. Possible future opponents then would be limited to some large developing nations, some underdeveloped nations, insurgents against occupation or peace keeping operations, and terrorist organizations. Some large developing nations could possibly develop advanced weapons systems that need to be countered by further development of advanced weapons systems, although it is not clear whether they would, in practice, be able to approach matching our capabilities. However, the development of most highly-advanced systems, particularly tactical systems, would not serve to counter threats posed by the other prospective opponents. Such opponents would make up for technological and organizational deficiencies through guerilla warfare and terrorist tactics and the use, particularly by nations, of weapons of mass destruction. There would be no point in developing a large range of ever advanced capability weapons systems, particularly tactical systems, against such threats. As a result, the demand for more data, hence, more telemetry spectrum, to test increasingly capable systems, could abate.

A.1.3 Introduction of Net-Centric Warfare

Projections on the exponential growth of spectrum requirements for aeronautical flight test telemetry have been based on historical data on the growth of telemetry data transfer requirements that have been needed to support the testing of single weapons platforms. Historically, the types, quantity, and quality of technological capabilities aboard individual platforms have steadily been increasing. Consequently, ever increasing spectrum has been required in order to telemeter increasing test data about these capabilities and their interactions. Current operational concepts include the networking of limited numbers of such high-capability platforms. As a result, telemetry systems need the capacity to transmit test data both on the individual platforms and on their interactions. However, under the concept of net-centric warfare, many individual platforms will have a limited suite of on-board capabilities and will depend on information received through the network to fully support their missions. It is not clear, under this concept, how much test data would be transmitted by telemetry systems. It is possible then, that the implementation of this concept could slow the growth of telemetry spectrum requirements.

A.2 New Test and Evaluation Methodologies

As noted in the previous section, as long as the requirement for spectrum increases exponentially, measures to decrease the requirement need to be able to continually decrease the need for new spectrum at, at least, the rate that the underlying demand is expanding. Otherwise, the need for new spectrum is only delayed for a few years. There are no clear technological methods for countering the projected growth of telemetry spectrum. Hence, if the exponential growth in demand does not abate, new methodologies would be needed to adequately support test and evaluation. This section identifies and discusses some possible methodologies.

A.2.1 Use of Alternative Means of Test Data Transmission

The growth of spectrum requirements might be mitigated by transmitting data at frequencies that are outside the standard radio spectrum. One possible method would be to transmit data using lasers. Another approach would be to transmit data in the Extremely High Frequency (EHF) band, above, preferably well above, 30 Gigahertz (GHz), where large bandwidths are available and there are few competing users. We would encounter many difficulties in attempting to implement such solutions. The beams would be very narrow in both cases, so that it would be difficult and probably costly to initiate and maintain a link. A laser that is powerful enough to maintain a link over a reasonable distance must be employed in a manner such that it does not pose a hazard to vision. Because of high atmospheric absorption at EHF, we would need to operate telemetry in some novel manner in that band, such as by using satellite communications or high altitude relay or data processing platforms.

A.2.2 Alternate Test Data Transmission Methods for Net-Centric Networks of Systems

It is not clear, at this point, how we would test the performance of networks of systems. However, if such networks are appropriately designed, it might be feasible to download a substantial portion of needed test data at ground-based nodes of the network under test and thus minimize the amount of data that needs to be telemetered from mobile platforms. There is an issue as to how appropriate it is to send independent test data over operational data links. However, if the network can be designed in a manner that supports this methodology, then the requirements for telemetry spectrum could be minimized.

A.2.3 Use of Modeling and Simulation (M&S) to Support Evaluation

Telemetry data transmission requirements might also be substantially reduced through the use of M&S to support evaluation. Under this methodology, minimal test data would be used to validate the M&S representation of the system under test and that M&S representation would then be used to evaluate system performance. In order to utilize this methodology, we must be assured that we can construct a M&S representation that replicates the system under test with sufficient accuracy and fidelity. It is not clear at this point how feasible it is to adequately represent large systems, particularly those that implement novel technologies, in M&S. This issue needs to be resolved before we can dispense with the need to transmit large amounts of actual test data.

A.3 Conclusions

As matters stand, decades of available data indicate that spectrum requirements for aeronautical flight test telemetry are increasing exponentially. Clearly, this process cannot proceed indefinitely. On the other hand, this need for increasingly more spectrum cannot be reversed by one time solutions such as more efficient modulation techniques. Such solutions only postpone the required growth. Some combination of a decrease in the growth of underlying test data transmission requirements and in the use of test and evaluation methodologies that mitigate the need for telemetering of test data is needed in order to terminate the need for more spectrum. This appendix identifies a few considerations that could slow or terminate the underlying growth of test data transmission requirements and some alternative test methodologies that could reduce the need for telemetry spectrum. However, unless the exponential growth in the requirement for more telemetry can be terminated or at least substantially reduced by these means, or by other means not yet identified, we will be confronted by the consequences of inadequate or reduced quality of testing that are discussed in the economic analysis.

Glossary

4V4	4 Aircraft, 4 Targets, and 8 Missiles
ACAT	Acquisition Category
AF	Air Force
ARTM	Advanced Range Telemetry
ATL	Acquisition, Technology, and Logistics
ATM	Aeronautical Telemetry
BDM	Bandwidth Demand Model
BMD	Ballistic Missile Defense
bps	Bits Per Second
BW	Bandwidth
BY	Base Year
C2	Command and Control
C2BMC	Command and Control, Battle Management and Communications
CBO	Congressional Budget Office
CCSDS	Consultative Committee on Space Data Systems
CPM	Continuous Phase Modulation
CTEIP	Central Test and Evaluation Investment Program
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DoD	Department of Defense
DOJ	Department of Justice
DOT&E	Director, Operational Test and Evaluation
DSB	Defense Science Board
DT	Developmental Testing
EHF	Extremely High Frequency

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FFRDC	Federally Funded Research and Development Center
FOG	Future On-Going
GAO	Government Accountability Office
GDP	Gross Domestic Product
GEMSIS	Global Electromagnetic Spectrum Information System
GHz	Gigahertz
GMD	Ground-Based Midcourse Defense
GPS	Global Positioning System
HP	Hewlett-Packard
Hz	Hertz
IDA	Institute for Defense Analyses
IFDS	Integrated Frequency Deconfliction System
iNET	Integrated Network Enhanced Telemetry
IRIG	Inter-Range Interchange Group
ITU	International Telecommunication Union
JCAD	Joint Chemical Agent Detector
JROC	Joint Requirements Oversight Council
K	Thousand
Mbps	Megabits Per Second
MDA	Missile Defense Agency
MHz	Megahertz
MIMO	Multiple-Input-Multiple-Output (MIMO)
MNM	Mobile Network MIMO
MRTFB	Major Range and Test Facility Base
M&S	Modeling and Simulation
MUP	Maximum User Program

NASA	National Aeronautics and Space Administration
NAWCWD	Naval Air Warfare Center Weapons Division
NDIA	National Defense Industrial Association
NMU	New Maximum User
NRE	Nonrecurring Engineering
NSF	National Science Foundation
Ops	Operations
OSD	Office of the Secretary of Defense
OT	Operational Testing
PCM	Pulse Code Modulation
PCM/FM	Pulse Code Modulation/Frequency Modulation
PRV	Plant Replacement Value
R&D	Research and Development
RDT&E	Research, Development, Testing, and Evaluation
RF	Radio Frequency
RTF	Return to Flight
SCPS	Space Communications Protocol Standards
SFTE	Society of Flight Test Engineers
SoS	System of Systems
S&T	Science and Technology
TCP/IP	Transmission Control Protocol/Internet Protocol
T&E	Test and Evaluation
TEMP	Test and Evaluation Master Plan
TRMC	Test Resource Management Center
UAV	Unmanned Aerial Vehicle
WRC	World Radio Conference

XG	NeXt Generation