System Dynamics Analysis of Incentives for Automatic Dependent Surveillance Broadcast (ADS-B) Equipage

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ABSTRACT

The demand for air transportation is anticipated to continue to grow in the future. In order to accommodate future demands, the U.S. Joint Planning and Development Office (JPDO) proposed the Next Generation Air Transportation System (NextGen). One of the NextGen technologies currently under development is Automatic Dependent Surveillance – Broadcast (ADS-B), which is a new satellite-based surveillance technology.

In order to achieve the adoption of ADS-B, equipage by aircraft operators is essential. However, it is sometimes difficult to achieve the transition from a current technology to a new technology. Therefore, encouraging the individual user's adoption is a key factor of the successful technology transition.

This thesis develops the system dynamics model to represent how individual users adopt a new technology, and analyzes how the adoption of new technologies can be encouraged using the system dynamics model. The effects of the following four incentive policies are examined: (1) Acceleration of operational benefits, (2) Preferred access, (3) Financial incentive, and (4) Mandate equipage.

The result of the policy analysis shows the each incentive policy is effective to encourage the early adoption of ADS-B. Especially, achieving early benefits is important to accelerate equipage. Moving forward the mandate date of ADS-B equipage also can be effective to increase total benefits.

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Acronyms and Abbreviations

ADOC:	Aircraft Direct Operating Cost
ADS-B:	Automatic Dependent Surveillance - Broadcast
ARC:	ADS-B Aviation Rulemaking Committee
ATC:	Air Traffic Control
CDA:	Continuous Descent Approach
CTDI:	Cockpit Display of Traffic Information
FAA:	Federal Aviation Administration
FIS-B:	Flight Information Service - Broadcast
GBT:	Ground Based Transceiver
GPS:	Global Positioning System
JPDO:	Joint Planning and Development Office
M&S:	Merging and Spacing
NAS:	National Airspace System
NextGen:	Next Generation Air Transportation System
NPRM:	Notice of Proposed Rulemaking
NPV:	Net Present Value
PSR:	Primary Surveillance Radar
PV:	Present Value
PVT:	Passenger Value of Time
RNAV:	area Navigation
SSR:	Secondary Surveillance Radar
TIS-B:	Traffic Information Service - Broadcast
TMA:	Traffic Management Advisor

Chapter 1 Introduction

1.1 Motivation

The demand for air transportation has been increased and is anticipated to continue to grow in the future. According to the forecast by the Federal Aviation Administration (FAA), air transport passengers in the U.S. are projected to double by 2025. It is believed that the current air transportation system cannot accommodate future demands. In response to the future increased demand, the U.S. Joint Planning and Development Office (JPDO) proposes the Next Generation Air Transportation System (NextGen), which includes a set of new technologies to increase capacity as well as to enhance safety and security. The implementation of NextGen has already begun. One of the NextGen technologies currently under development is Automatic Dependent Surveillance Broadcast (ADS-B), which is a new satellite-based surveillance technology (Joint Planning and Development Office, 2007).

Technology transitions are essential to solve complex problems in many cases. However, it is sometimes difficult to achieve a smooth transition from a current technology to a new technology. Some technologies require individual user's adoption to achieve the technology transition. Even though a new technology is developed, if individual users do not adopt it, the benefit of the technology cannot be achieved. Therefore, encouraging the individual user's adoption is a key factor of the successful technology transition.

This thesis develops the model for how individual users adopt a new technology and analyzes how the adoption of the new technology can be encouraged. The motivation of this thesis is to contribute to the FAA's policy making to achieve the successful adoption of ADS-B.

1.2 Problem Statement

This thesis analyzes the effect of incentive policies for encouraging user adoption. There are several approaches for this encouragement. The effects of the following four policies on equipage are examined in this thesis: (1) Acceleration of Operational Benefits, (2) Preferred Access, (3) Financial Incentives, and (4) Mandate Equipage.

1.2.1 Acceleration of Operational Benefits

The first policy to be analyzed is to accelerate operational benefits, which can be derived from applications of a new technology. The operational benefit can be increased by developing new applications or accelerating the implementation of applications. For example, the operational benefit of car navigation systems increased when the new application providing real-time traffic information to drivers was developed (Sugawara, 2007).

1.2.2 Preferred Access

The second policy is to provide preferred access to adopters of new technologies. Only users who adopt the technology can access additional capacity, new services, and so on. The benefit from preferred access decreases as adopters increase. When the number of adopters is small, they can receive a large benefit from preferred access. However, when many users adopt the technology, the benefit of preferred access should be shared and the benefit per user decreases. When all users adopt it, the benefit of the preferred access becomes zero. Therefore, preferred access can be an incentive for early adoption. An example of preferred access is that aircraft equipped with the equipment for the area Navigation (RNAV) can have priority access to Haneda airport in Tokyo, Japan during night time (Japanese Ministry of

Land, Infrastructure and Transport, 2005).

1.2.3 Financial Incentive

The third policy is financial incentive. When financial incentive is given only to early adopters, it can be an incentive for early adoption. While users can receive the operational benefit and the benefit from preferred access every year after adoption, the financial incentive can usually be received only once. Therefore, the financial incentive has the same effect as reducing initial cost of adoption.

1.2.4 Mandate Equipage

The last policy to increase adopters of new technologies is mandate equipage, which is usually required after a certain preparation period. When the mandate date is moved forward, the benefit of the new technology increases because adoption can be achieved early. On the other hand, the cost that users pay also increases. Therefore, this thesis analyzes the optimal timing of mandate equipage.

1.3 Methodology

The methodology that is used for policy analysis in this thesis is a system dynamics modeling, which can be used to analyze the dynamic change of many factors that relate with each other in the complex system.

First, to understand how individual users adopt new technologies, the system dynamics model of the adoption of a new technology is developed. Then, to analyze the effect of each incentive policy described in section 1.2, each incentive is added to the model and the change of adoption behavior is observed.

Chapter 2 Technology Transition

A lot of technologies have been developed to solve various challenges that current society faces. While some technologies have been adopted successfully, some technologies have failed to be adopted even though the technology itself was innovative and valuable. This chapter describes the barriers to technology transition and the incentives for encouraging it.

2.1 Barriers to Technology Transition

There are several barriers to achieving a successful technology transition. The first is the mismatch of the distribution of costs and benefits among stakeholders. Figure 2-1 shows the framework for analysis of cost-benefit distribution (Marais and Weigel, 2006). When the stakeholder who receives benefits and the stakeholder who bears costs are the same, it is easy to achieve a transition as long as the benefits are larger than the costs. However, when the stakeholder who can receive benefits is different from the stakeholder who bears costs, it is difficult to incentivize the adoption. For example, in Figure 2-1, while the first stakeholder (stk_1) can receive benefits without paying any costs, the n^{th} stakeholder (stk_n) cannot receive any benefits in spite of paying costs. There is, therefore, no incentive for stk_n to pay the costs.

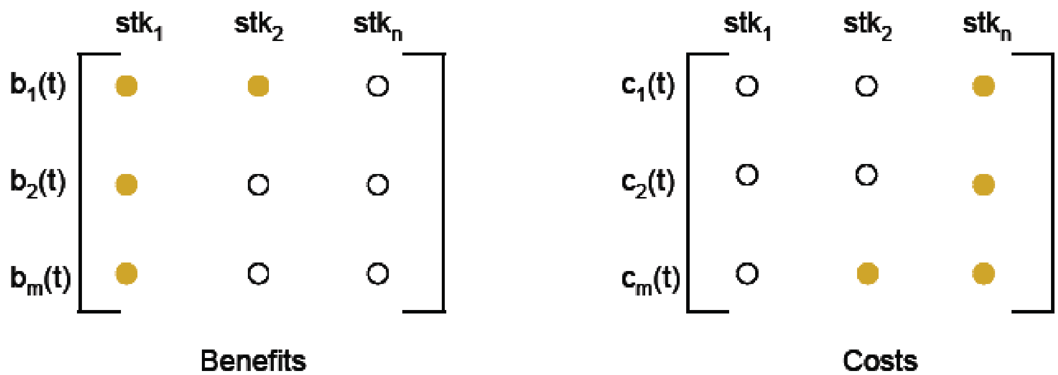


Figure 2-1: Cost-Benefit Distribution across Stakeholders (Marais and Weigel, 2006)

Even within the same stakeholder group, a problem of a group behavior paradox may occur (Olson, 1984). When members of a stakeholder group are large and the benefit should be shared, the incentive to pay a cost is limited. When one member in a group pays a cost and a benefit becomes available, the member who bears the cost can receive only small part of the benefit. On the other hand, other members in the same stakeholder group can receive the benefit without paying any costs. This is a free-rider problem. As the size of group increases, the incentive to pay costs decreases.

The second barrier is a time lag between costs and benefits. Investors prefer immediate benefits. However, the benefit sometimes becomes available only in the future. The present value of future benefits is less than immediate benefits because of the time value of money.

The third barrier is an uncertainty of future benefits. When the future benefit is uncertain, the value of the future benefit is reduced. Figure 2-2 shows this uncertainty (Mozdzanowska et al., 2007). There are two types of uncertainty. One is the uncertainty of the level of the future benefit. And the other is the uncertainty of the timing of the future benefit.

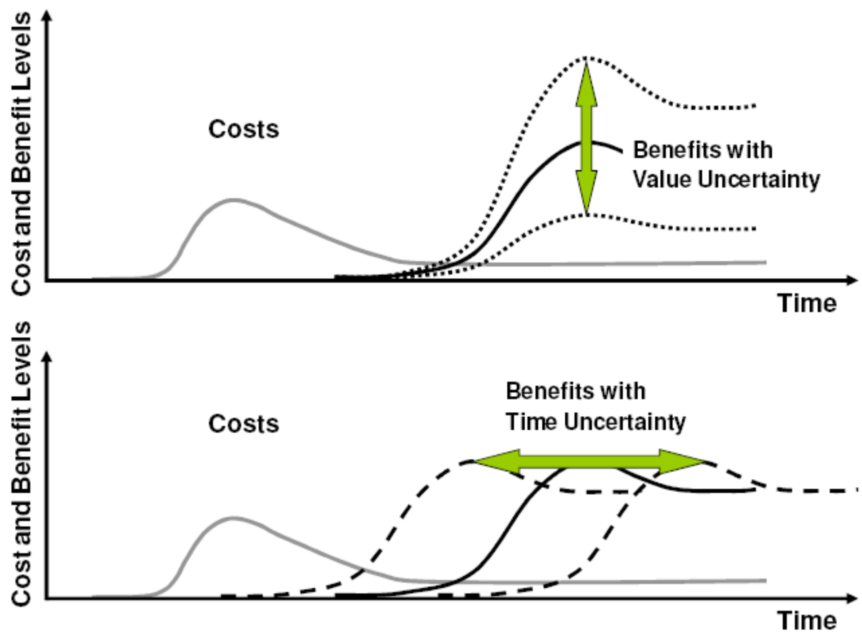


Figure 2-2: Uncertainty of Future Benefits (Mozdzanowska et al., 2007)

2.2 Incentives for Technology Transition

In order to encourage early adoption of new technologies, there are several policy options of incentives for equipage. According to Marais and Weigel, there are four general approaches to encourage adoption of a new technology: (1) Infrastructure and Development Support, (2) Technology value, (3) Positive incentives, and (4) Mandates and punitive measures (Marais and Weigel, 2006).

First, ground infrastructure should be deployed to achieve the benefit of new technologies such as ADS-B. In order to encourage the adoption, the government has to convince users that the benefit of a new technology will be available. When the implementation schedule of ground infrastructure is unclear, the value of the future benefit is reduced because of the uncertainty. Therefore, the government has to show a clear schedule of implementation.

The second approach is to increase the value of a technology itself, which is derived from the development of applications. For example, the technology value of ADS-B is the operational benefit from applications. The FAA may increase the technology value by accelerating the development of applications or developing new applications.

Thirdly, when the technology value itself is not enough to encourage adoption, positive incentives may be used. In this thesis, two types of positive incentives are examined. The first is to give preferred access. The other is to give financial incentive.

The last approach increasing adoption is mandate, which is an effective way to increase adopters. However, when mandate is introduced rapidly without consensus of stakeholders, strong resistance may be raised. In addition, when the mandate requires hurried adoption, the total cost of adoption may increase.

Chapter 3 Automatic Dependent Surveillance – Broadcast

3.1 ADS-B System

ADS-B is a new surveillance technology for the Next Generation Air Transportation System (NextGen). Figure 3-1 shows the ADS-B system architecture. The system is composed of satellite positioning services, aircraft avionics and ground infrastructure. The equipped aircraft broadcasts the position information automatically. Aircraft use the position information from a satellite positioning service, such as Global Positioning System (GPS). This position information is transmitted to ground infrastructure (air-to-ground data link) and other equipped aircraft (air-to-air data link). This capability is called *ADS-B Out*. The information received by ground infrastructure is transmitted to air traffic control (ATC) facilities to be used for air traffic surveillance. The equipped aircraft that receive the information from other aircraft or ATC can display the data on a display unit such as Cockpit Display of Traffic Information (CDTI). This capability is called *ADS-B In*.

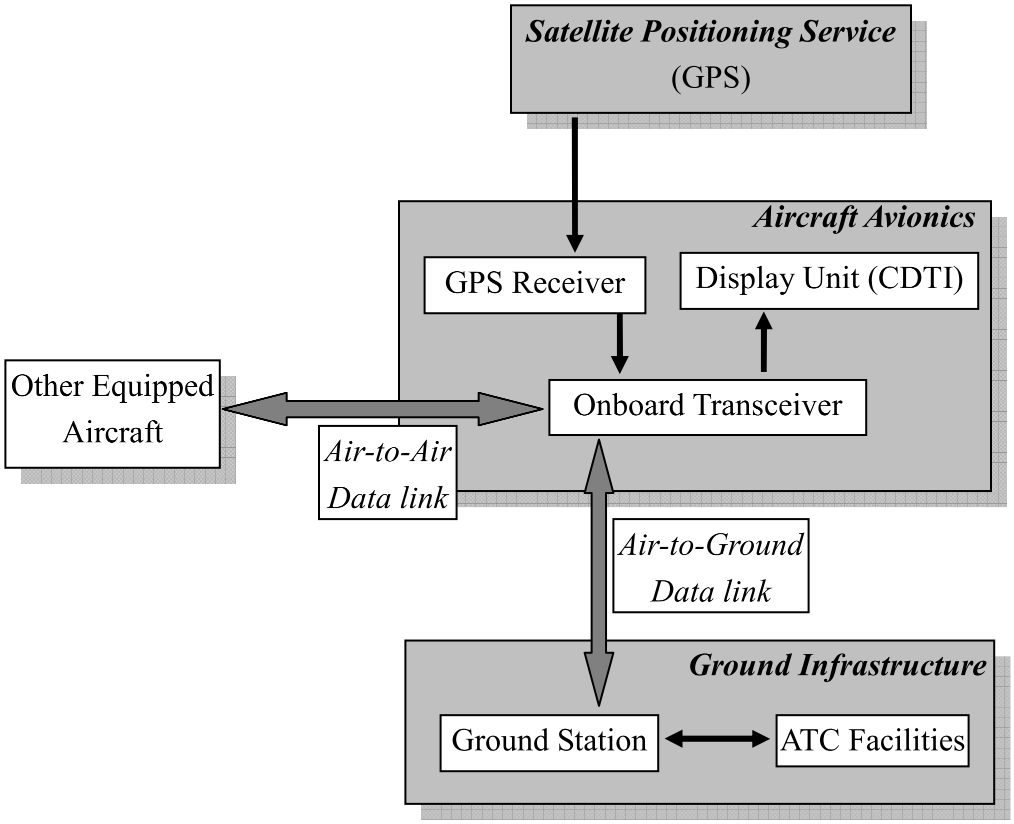


Figure 3-1: ADS-B System Architecture

ADS-B is “automatic” because aircraft transmit position information without any external interrogations unlike TCAS and SSR, which send data in response to interrogations. ADS-B is “dependent” because it relies on position sources and onboard transmission system. The accuracy of the ADS-B system depends on the satellite position sources.

3.2 Current Surveillance Technology

Current surveillance service in the National Airspace System (NAS) is based on the radar information. The radar system consists of primary and secondary surveillance radars. The primary surveillance radar (PSR) recognizes the position of aircraft by receiving the radio wave reflected from the surface of aircraft. PSR requires no special equipment aboard the aircraft. PSR sometimes cannot distinguish aircraft because it receives the reflected wave from objects other than aircraft, for example birds, mountains, clouds, and so on. PSR calculates the distance by measuring the time from sending wave to receiving reflected wave.

A secondary surveillance radar (SSR) transmits interrogation pulse to aircraft. When a transponder aboard the aircraft receives interrogation, it replies the aircraft information. Therefore, aircraft must be equipped with transponder so that SSR system works. Unlike PSR, SSR can identify aircraft because transponder on board aircraft sends the unique code assigned to aircraft.

There are some gaps of radar coverage of the continental U.S. at low altitude. The reasons of the gaps of radar coverage is the geographically restriction, such as mountain area, or cost-effective manner, such as remote area. Outside radar coverage, the separation between aircraft should be large.

3.3 ADS-B History

There have been some trials of ADS-B technology in the U.S. One of the trails was conducted at UPS's hub airport in Louisville, KY. The FAA and UPS have been working together to develop ADS-B for a decade. The ADS-B operation at Louisville airport was approved by the FAA in January 2008. This is the first satellite-guided merging and spacing during approaches in the U.S. In addition, the approval enables the CTDI assisted visual separation, which allows aircraft to continue visual approach even when visibility drops below requirement, and Surface Area Movement Management (Hughes, 2008).

Another trial is Capstone program in Alaska. Alaska Capstone program was an early demonstration of ADS-B capability. The reasons why Alaska was chosen as a demonstration of the new technology were lack of radar coverage, harsh weather, and so on. According to the information published by the National Institute for Occupational Safety and Health, accident rates in Alaska were up to 400 percent above the national average (Federal Aviation Administration, 2001). Phase I of Capstone program was in Yukon-Kuskokwim (Y-K) Delta. Phase II extended to Southeast Alaska. The Capstone program enabled surveillance outside radar coverage and increased onboard situation awareness. According to FAA accident statistics, the Capstone program reduced the aircraft fatal accident rate by 45% (Federal Aviation Administration, 2007a).

3.4 Future of ADS-B

The FAA breaks down the ADS-B implementation schedule into four segments. The first segment (2006-2010) includes building ground stations as shown in Figure 3-2. These area include TIS-B/FIS-B only coverage. Only Louisville, Philadelphia, the Gulf of Mexico, Ontario will have ADS-B ground based transceivers (GBTs).

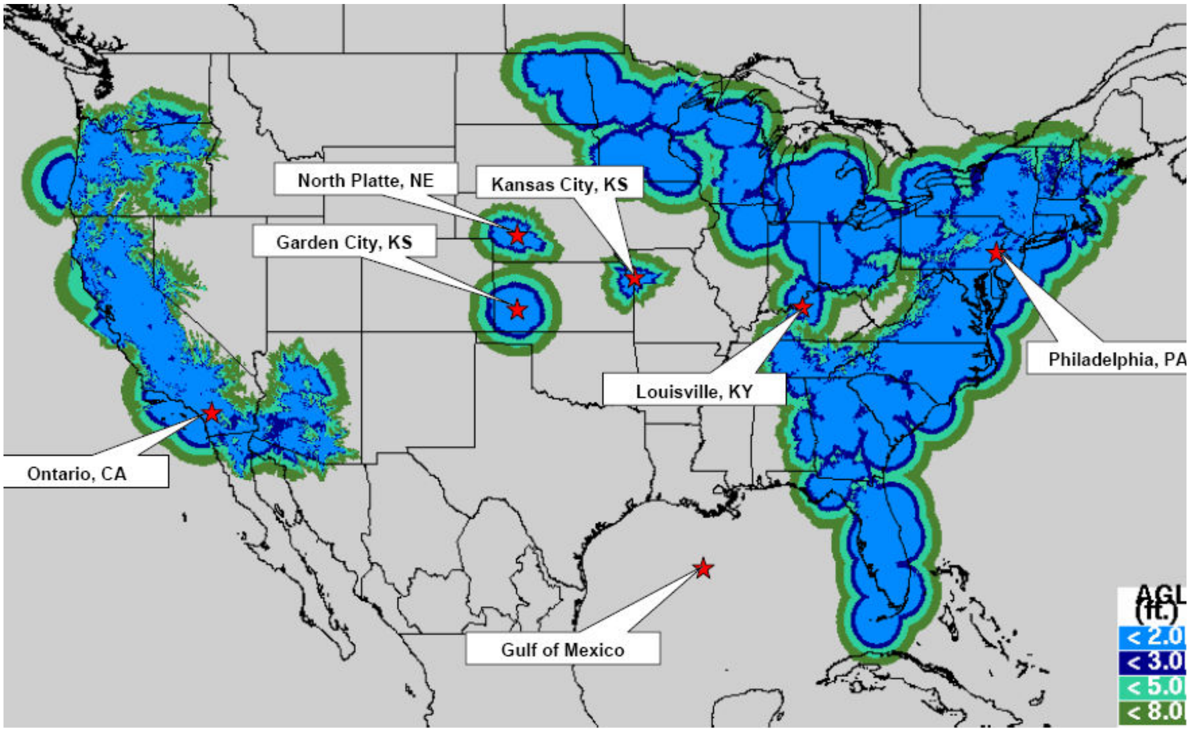


Figure 3-2: Segment 1 Coverage (Federal Aviation Administration, 2006)

Segment 2 (2009-2014) includes completing ground station coverage of the US in existing SSR airspace. Aircraft equipage will increase up to 40%. Segment 2 also includes finalizing the ADS-B Out definition. Segment 3 (2015-2020) includes 100% aircraft equipage of ADS-B Out. The definition of ADS-B In will be finalized in Segment 3. Segment 4 includes that legacy surveillance equipment such as SSR will be decommissioned. Applications of ADS-B will be fully implemented (Federal Aviation Administration, 2006).

The FAA issued the notice of proposed rulemaking (NPRM) about ADS-B Out on October 5, 2007 (Federal Aviation Administration, 2007a) and accepted public comments until March 3, 2008. The NPRM proposed the performance requirement for avionics equipment. In the NPRM, the FAA also proposed the mandate equipage of ADS-B Out by January 1, 2020.

3.5 Ground Infrastructure

To achieve the benefit of ADS-B, the deployment of ground infrastructure is essential. In August 2007, FAA awarded a performance-based contract to a consortium led by ITT Corporation. The contractor will install and maintain the ground equipment necessary to provide ADS-B uplink and downlink to ATC. According to the FAA's schedule, all ground infrastructures will be placed where current surveillance exists by end of fiscal year 2013.

3.6 Benefit

There are two types of operational benefit of ADS-B: the independent benefit that is independent of other aircraft's equipage, $B_i\ (t)$, and the dependent benefit that depends on other aircraft's equipage, $B_d\ (t)$. The benefit per aircraft per year can be described as follows:

$$Benefit/Aircraft\ (t) = B_i\ (t) + B_d\ (t)$$

3.6.1 Independent Benefits

The independent benefit, $B_i(t)$ increases over time because more applications will be developed. The following five applications are the applications of the independent benefit type. These applications are based on the assumptions of ADS-B Out application by the FAA (Federal Aviation Administration, 2007b). However, these applications do not include all applications that the FAA is planning to implement.

<u>a) More efficient en route conflict resolution</u>

Improved accuracy and update rate of surveillance allows reduction in potential conflict warning (8nm to 7nm). The benefit from the reduced conflict warnings is calculated as a product of the number of prevented warning, the percentage of warnings that are acted upon, and the average cost of a prevented vector maneuver. The average cost of prevented vector maneuver is estimated from the distance of maneuver, and average speed.

b) More efficient ATC-based merging and spacing due to improved surveillance

Increased ability of merging and spacing (M&S) enables Continuous Descent Approach (CDA) in higher demand area. The benefit of CDA is calculated from average fuel saving.

c) More efficient en route metering to the arrival fix

The improved accuracy and update rate increases the capability of controller automation called Traffic Management Advisor (TMA), which optimizes arrival flows into busy airports. ADS-B can reduce the uncertainty of the meter fix arrival time. The reduced meter fix uncertainty can lead to the increase of runway throughput.

d) More efficient ATC management of surface movement

The FAA is upgrading ASDE-3 to ASDE-X. ASDE-X can increase some surface efficiency: 1) improved identification of aircraft within a queue, 2) improved ability to perform conformance monitoring, 3) improved surface surveillance during heavy precipitation, and 4) improved ATC confidence in surface surveillance date.

e) Optimal routing

ADS-B can provide radar-like separation in non-Radar Airspace. The radar-like separation permits the flights of additional more efficient routes. As a result, the aircraft can reduce the flight distance and flight hour.

3.6.2 Dependent Benefits

The second type of benefit is the benefit depending on %Equipage. The dependent benefit can be described as the function of % equipage as follows:

$$Benefit/Aircraft\ (t) = B_i\ (t) + B_d\ (t) = B_i\ (t) + B_{dmax} \times \%Equipage(t)$$

The following two applications are the applications of dependent benefit type. These applications are also based on the assumption by the FAA (FAA, 2007b), but do not include all applications that the FAA is planning to implement.

<u>a) More efficient separation en route</u>

The radar-like separation in non-radar area can reduce the separation and increase sector capacity. The FAA announces that the initial separation will be limited to selected altitudes, but widens to most altitudes above 24000 feet after ADS-B Out equipage increases. Therefore, the benefit from the more efficient separation depends on % equipage.

<u>b) Optimal routing</u>

The optimal routing can lead to the increased capacity. The benefit from increased capacity depends on other aircraft's equipage. The capacity will not increase when only small number of aircraft adopt. When more aircraft adopt, the capacity increases more. Therefore, this application depends on % equipage.

3.6.3 Assumption for Value of Benefit

The FAA calculated the benefits of each application of ADS-B and the result is published on the FAA's website (Federal Aviation Administration, 2007b). The methodology that the FAA used to estimate the benefits is based on the "Economic Value for Evaluation of Federal Aviation Administration Investment and Regulatory Programs". Economic value is derived from reduced flight hours. The economic value of reduced flight hours is quantified in terms of the aircraft direct operating cost (ADOC) and the Passenger Value of Time (PVT). Direct operating cost is fuel, crew and maintenance. PVT per aircraft type is based on average number of seats and average load factors. The average economic value of ADOC and PVT is shown in Table 3-1.

Table 3-1: Assumption of Economic Value (Federal Aviation Administration, 2007b)

ADOC –airborne (per hour)	$2814
ADOC –ground (per hour)	$1411
ADOC –block(per hour)	$2596
ADOC –Average(per hour)	$2274
PVT (per hour)	$28.60
PVT (per aircraft-hour)	$1966

Figure 3-3 shows the equipage curve that FAA and ARC used as the assumption for the benefit estimation.

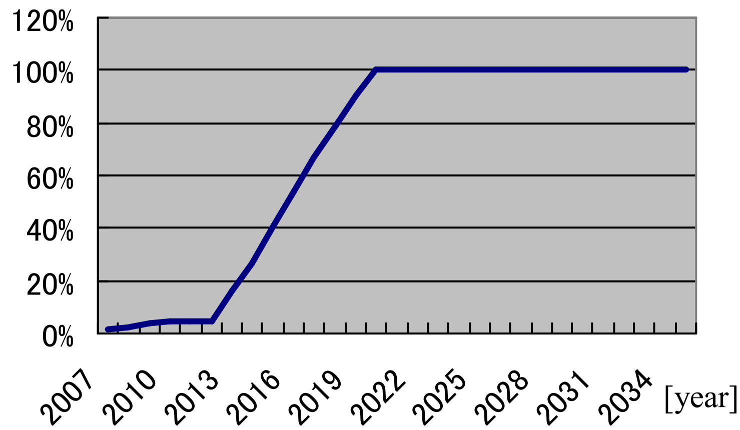


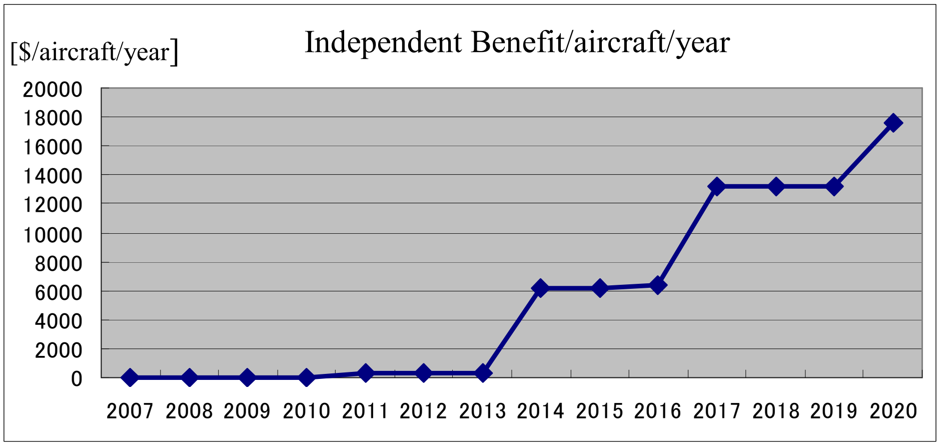
Figure 3-3: Assumption of Equipage Curve (Federal Aviation Administration, 2007b)

The FAA calculated the present value as of 2007 of the benefit of each application from 2007 through 2035. This benefit includes ADOC, which is the benefit for aircraft operators, and PVT, which is the benefit for passengers. The present value of the benefit for airlines is estimated by subtracting PVT. Table 3-2 also shows the first year when the benefit will be realized.

Table 3-2: Assumption of Benefit and First Year Benefit Realized (ADS-B Aviation Rulemaking Committee, 2007)

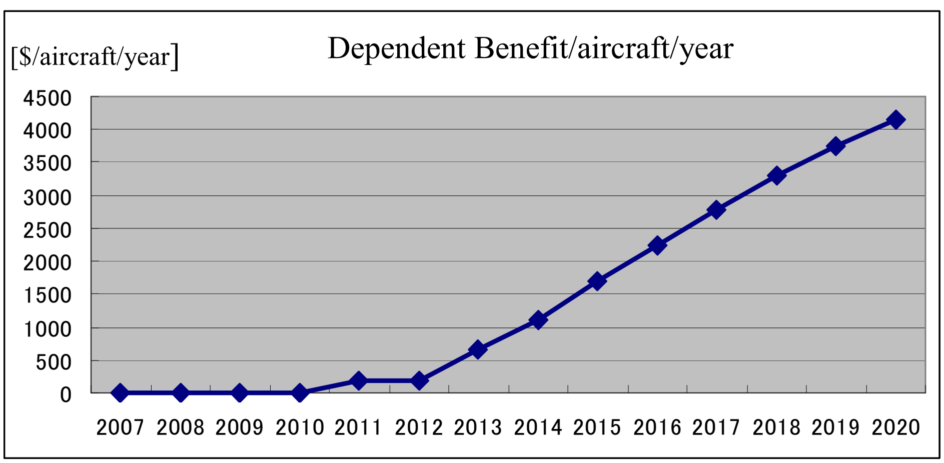
Application	Benefit for airlines (PV $Million)	First Year benefit realized
More efficient en route conflict resolution	$433.0	2017
Increased ability to allow CDAs	$429.8	2014
More efficient en route metering to the arrival fix	$225.2	2020
More efficient ATC management of surface movement	$14.5	2016
Increased capacity	$247.9	2011
Optimal routing	$46.7	2011

Using the above information, the independent benefit per aircraft per year and the dependent benefit per aircraft per year can be calculated. Figure 3-4 and Figure 3-5 shows the Independent Benefit per aircraft per year and Dependent Benefit per aircraft per year respectively.



(note) Estimated from the FAA assumption for the benefit of ADS-B Out

Figure 3-4: Independent Benefit per Aircraft per Year



(note) Estimated from the FAA assumption for the benefit of ADS-B Out

Figure 3-5: Dependent Benefit per Aircraft per Year

3.7 Cost

For an aircraft operator, the unit cost of acquisition of ADS-B Out is mainly composed of GPS, augmentation, and transponder. Because older aircraft are not equipped with GPS, the acquisition cost of ADS-B is high. On the other hand, because new aircraft are already equipped with GPS, the acquisition cost is less expensive. Furthermore, when aircraft are already equipped with upgradable transponder, the cost is much less expensive.

Therefore, the cost of adoption of ADS-B Out varies based on aircraft age. Aircraft can be divided into 3 types based on aircraft age. This categorization is estimated from the assumption used by the FAA (Federal Aviation Administration, 2008). Type A is the oldest aircraft group, which does not have GPS or Transponder. Type B is the middle age aircraft group, which has GPS and upgradable transponder. Type C is the newest aircraft type. The unit cost of Type A includes the GPS with augmentation and transponder. The unit cost of Type B includes the augmentation and transponder upgrade. The unit cost of Type C includes the augmentation upgrade. Aircraft of Type A was delivered between 1983 and 1998. Aircraft of Type B was delivered between 1998 and 2008. Aircraft of Type C will be delivered after 2008.

Table 3-3: Aircraft Type by Aircraft Age (Federal Aviation Administration, 2008)

	Type A	Type B	Type C
GPS	×	○	○
Augmentation	×	×	×
Transponder(DO-260A)	×	△(upgradable)	○
Deliveries	1983-1998	1998-2008	2008-
Unit cost	$150,000	$70,000	$32,000

The cost of acquisition of ADS-B Out also depends on the regular maintenance cycle. There are several types of maintenance checks of aircraft. The light maintenance is done every month or every a few months, and usually finished overnight. The heavy maintenance is done every 4 or 5 years. Because the heavy maintenance check requires a lot of space and time, the aircraft have to be out of service during the maintenance.

It takes some time to install ADS-B Out. Therefore, when aircraft adopt ADS-B Out outside the heavy maintenance cycle, the aircraft must be taken out of operation. As a result, the cost for the adoption of ADS-B Out becomes more expensive when aircraft adopt ADS-B Out outside the heavy maintenance cycle. Therefore, the maintenance cycle is an important factor for the decision about when aircraft operators adopt the ADS-B Out.

The other cost of implementation of ADS-B is the cost for FAA to deploy ground infrastructure. On the other hand, maintenance cost for ADS-B will be less expensive than that for the current radar-based surveillance system. ADS-B ground infrastructure does not have moving parts while radar system has rotating antenna and additional system complexity including calibrator.

Chapter 4 Modeling

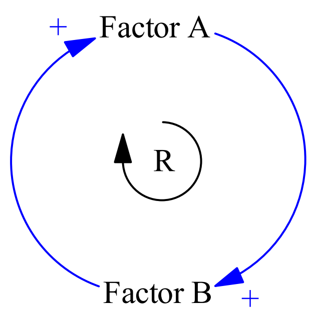
This chapter describes the modeling of how aircraft operators make a decision about the adoption of ADS-B Out and how the benefit of ADS-B Out changes. Aircraft operators adopt ADS-B Out based on the benefits they can receive and the costs they have to pay. On the other hand, the benefits of ADS-B Out depend on how many aircraft are equipped with ADS-B Out. Benefits and equipage relate with each other and change dynamically.

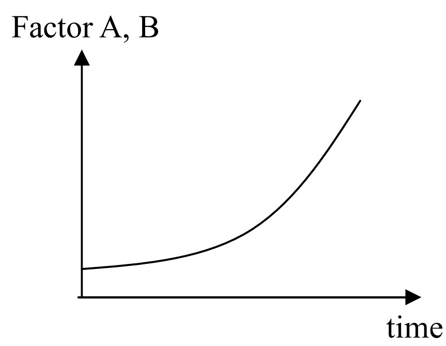
The benefit of ADS-B Out has been calculated by FAA and ADS-B Aviation Rulemaking Committee (ARC). This benefit is calculated based on the assumption of equipage curve. However, the equipage curve changes as the benefit of ADS-B Out changes. Therefore, the system dynamics model can be used to represent these complex dynamic changes.

4.1 System Dynamics Modeling

System dynamics modeling is a tool that enables understanding the structure of complex systems where many factors relate with each other, to build computer simulations model of complex systems, and to design more effective policies. System dynamics can be used for both qualitative and quantitative analysis. (Sterman, 2000)

The feedback loop is a core concept of a system dynamics model. There are two types of feedback loops: reinforcing (positive) loops and balancing (negative) loops. The reinforcing loop is shown in Figure 4-1. When factor A increases, factor B also increases. When factor B increases, factor A increases more. The behavior of each factor in reinforcing loop increases or decreases exponentially. Reinforcing loop works as either virtuous circle or vicious circle.

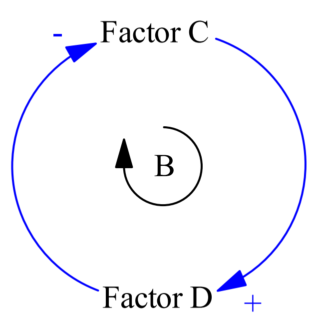


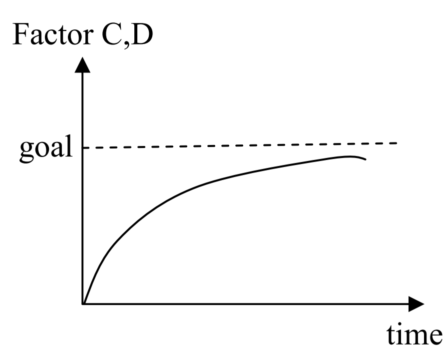


Structure ***Behavior***

Figure 4-1: Reinforcing (Positive) Loop

Another feedback loop is a balancing (negative) loop. The balancing loop is shown in Figure 4-2. When factor C increases, factor D also increases. When factor D increases, factor C decreases. The behavior of each factor in a balancing loop is goal-seeking. Whatever the initial values of the factor C and D are, the factors reach to the equilibrium point.





Structure ***Behavior***

Figure 4-2: Balancing (Negative) Loop

4.2 Basic Model of ADS-B Out Equipage

This section describes the basic model of ADS-B Out equipage. Aircraft operators make a decision about whether or not to adopt ADS-B Out and when to adopt ADS-B Out based on benefits and costs. At the same time, in order to achieve the benefit of ADS-B Out, there are three factors to be satisfied: ground infrastructure, applications, and aircraft equipage. Some applications also require the equipage of other aircraft.

The model is mainly composed of two parts: Adoption Model and Benefit Model. The input of the Benefit Model is the ground infrastructure, applications and % equipage, and the output is the current and estimated future benefits. The input of the Adoption Model is benefits and costs, and the output is % equipage.

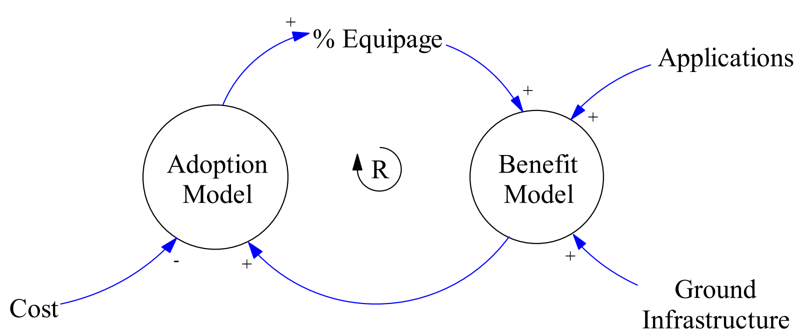


Figure 4-3: General Concept for Model of ADS-B Out Equipage

There is one reinforcing loop. When % equipage increases, benefits of ADS-B Out increase. When benefits increase, more aircraft adopt ADS-B Out and % equipage increases more. This reinforcing loop is the major driver of increase of the adopter of ADS-B Out.

Figure 4-4 shows the basic model of ADS-B adoption. The following section describes the detail of the basic model.

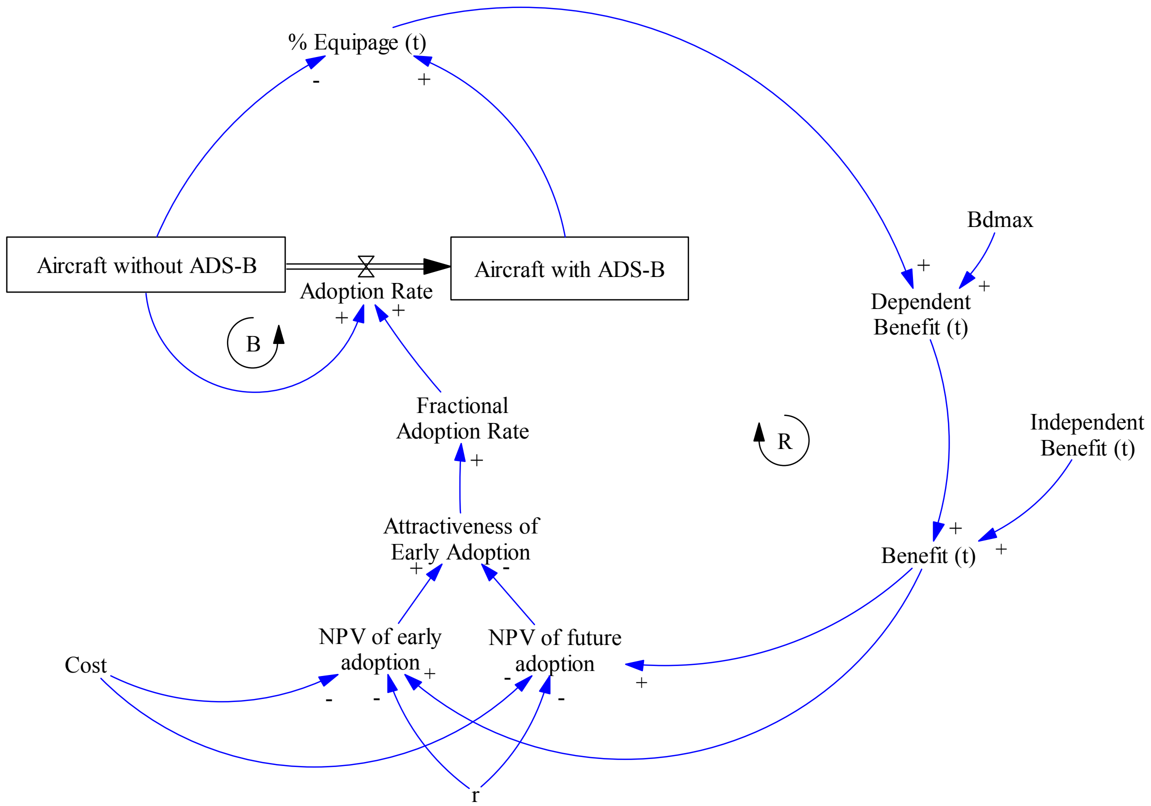


Figure 4-4: Basic Model of ADS-B Out Equipage

4.2.1 Adoption Model

As shown in Figure 4-4, all aircraft are divided into two stocks: Aircraft without ADS-B and Aircraft with ADS-B. The equation for the number of aircraft with ADS-B, the number of aircraft without ADS-B and the adoption rate in year t is:

$$\#\ of\ Aircraft\ with\ ADS\text{-}B = \int Adoption\ rate(t)\ dt;$$

$$\#\ of\ Aircraft\ without\ ADS\text{-}B = Initial\ value - \int Adoption\ rate(t)\ dt;\ and$$

$$Adoption\ Rate = \#\ of\ Aircraft\ without\ ADS\text{-}B \times Fractional\ Adoption\ Rate.$$

The unit of Adoption Rate is aircraft/year, and the unit of Fractional Adoption Rate is 1/year.

The attractiveness of early adoption is based on the differences between Net Present Value (NPV) of early adoption and of future adoption.

NPV is a major criterion for the investment decision. When they make a decision about investment, 75% of firms always or almost always calculate NPV (Franklin et al., 2006). As NPV is the difference between the present value of the future benefits and costs, NPV can be calculated as follows:

$$NPV = \sum_t \frac{CF(t)}{(1+r)^t} = \sum_t \frac{Benefit(t)}{(1+r)^t} - \sum_t \frac{Cost(t)}{(1+r)^t}.$$

Above, *CF(t)* is the cash flow at time *t* and *r* is the discount rate.

In general, when a project has positive NPV, companies are assumed to invest in the project. However, a positive NPV does not mean that it is best undertaken now. It might be even more valuable if undertaken in the future. Therefore, in order to invest a project now, there are two conditions. One is that NPV should be positive, and the other is that NPV of current investment should be larger than NPV of future investment.

However, because equipage of ADS-B Out will be mandate in the future, positive NPV is not necessarily required for the adoption of ADS-B Out. The aircraft have to adopt ADS-B Out sooner or later even if NPV is negative. A question for aircraft operators is when the optimal timing of adoption is.

This System Dynamics model calculates NPV of early adoption and future adoption at each unit time step and compares these NPV so that aircraft operators who have not yet adopted ADS-B Out make a decision whether or not they adopt ADS-B Out at the time step.

When $NPV_k(t)$ is defined as NPV as of year t when aircraft adopt ADS-B Out k years later, that is to say the adoption in year $t+k$, $NPV_k(t)$ can be calculated as follows:

$$NPV_k(t) = -\frac{C}{(1+r)^k} + \frac{B_{t+k+1}}{(1+r)^{k+1}} + \frac{B_{t+k+2}}{(1+r)^{k+2}} + \cdot\ \cdot\ \cdot + \frac{B_R}{(1+r)^{R-t}} = -\frac{C}{(1+r)^k} + \sum_{i=k+1}^{R-t} \frac{B_{t+i}}{(1+r)^i}\ .$$

Above, R is the aircraft retirement year. The aircraft can receive the benefit after adoption ADS-B Out until the aircraft retires. Aircraft have to pay unit acquisition costs when aircraft adopt.

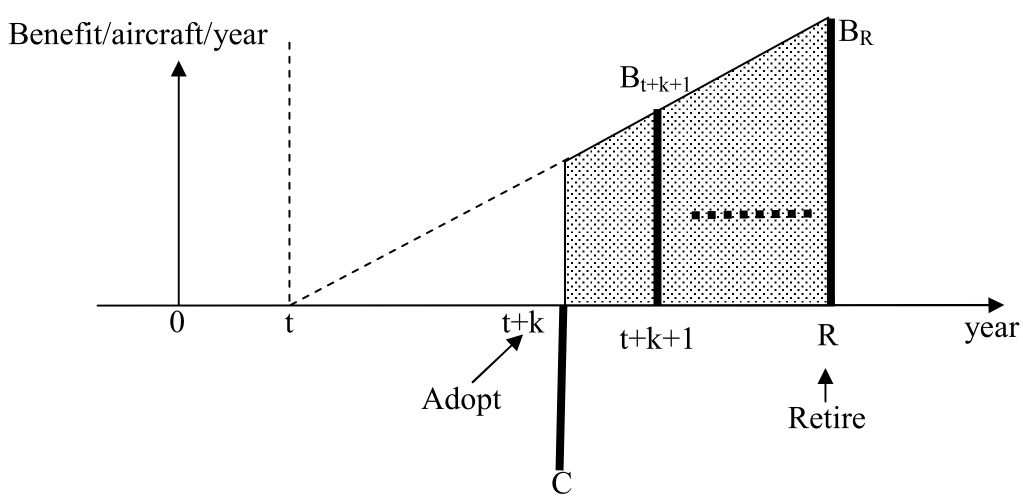


Figure 4-5: Definition of $NPV_k(t)$

In order to adopt in year t, NPV of adoption in year t should be larger than any NPV of future adoption between year t and the mandate date:

$$NPV_0(t) > NPV_k(t),\ (k=1, 2, \cdot\cdot\cdot, T - t).$$

Above, T is the mandate date. Therefore, the difference between NPV of adoption in year t and NPV of future adoption k years later should be positive:

$$NPV_0(t) - NPV_k(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \cdot\cdot\cdot + \frac{B_k}{(1+r)^k} - C + \frac{C}{(1+r)^k} = \sum_{i=1}^{k} \frac{B_i}{(1+r)^i} - \frac{C(1+r)^k - C}{(1+r)^k} > 0.$$

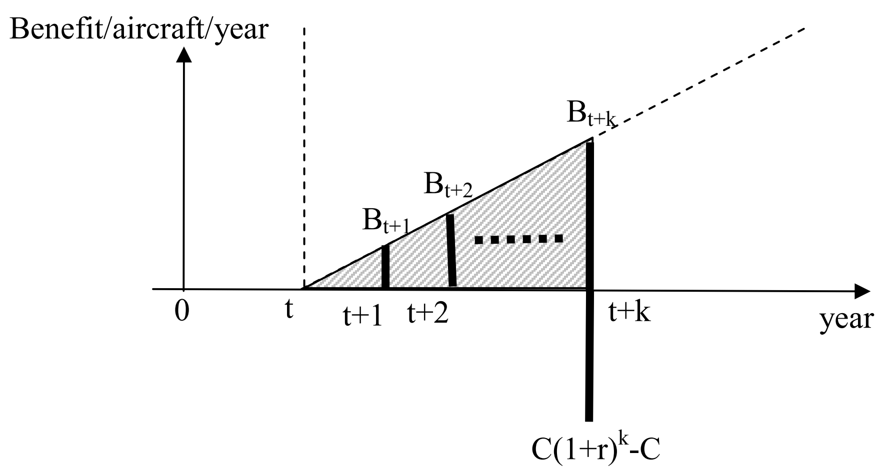


Figure 4-6: $NPV_0(t)$ - $NPV_k(t)$

While the advantage of early adoption in year t, compared to adoption in year t+k, is to receive the benefit between year t and t+k, the advantage to wait for the equipage until year t+k is the differences between C and $C/(1+r)^k$. In other words, if aircraft operators wait for the equipage until year t+k and invest the money (C) in another project or financial product of the same risk until year t+k, the aircraft operator can receive $C(1+r)^k - C$ in year t+k. This is the opportunity cost of early adoption. If the advantage of early adoption is larger than the advantage to wait, the aircraft invest in year t.

For example, the difference between NPV of adoption in year t and adoption 2 years later can be calculated as follows.

Cash flow of Investment in year t

Year	t	t+1	t+2	t+3	・・・	R
Benefit		B_{t+1}	B_{t+2}	B_{t+3}	・・・	B_R
Cost	-C					
$NPV_0(t)$	-C	$+B_{t+1}/(1+r)$	$+B_{t+2}/(1+r)^2$	$+B_{t+3}/(1+r)^3$	・・・	$+B_R/(1+r)^{R-t}$

Cash flow of Investment 2 years later (in year t+2)

Year	t	t+1	t+2	t+3	・・・	R
Benefit				B_{t+3}	・・・	B_R
Cost			-C			
$NPV_2(t)$			$-C/(1+r)^2$	$+B_{t+3}/(1+r)^3$	・・・	$+B_R/(1+r)^{R-t}$

The difference between NPV of adoption in year t and adoption 2 years later is:

$$NPV_0(t) - NPV_2(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} - C + \frac{C}{(1+r)^2}.$$

Attractiveness(t) can be defined as the minimum differences of $NPV_0(t)$ and $NPV_k(t)$ of any future date until the mandate date:

$$Attractiveness(t) = \min\{ NPV_0(t) - NPV_k(t)\},\ (k = 1, 2, \cdots, T - t).$$

Above, T is the mandate date.

Fractional Adoption Rate is a function of *Attractiveness(t)*. Aircraft operators are assumed to adopt ADS-B Out when *Attractiveness(t)* is larger than the minimum requirement of attractiveness for early adoption. However, the minimum requirement of attractiveness for adoption depends on the willingness of early adoption and is different according to aircraft operators because the fleet configuration and operational pattern is different. The minimum requirement of attractiveness for early adoption can be modeled as a normal distribution centered around the average minimum requirement of attractiveness for adoption, A^* with standard deviation σ. Below, A is *Attractiveness(t)*:

$$\textit{Minimum required attractiveness} = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(A-A^*)^2}{2\sigma^2}\right).$$

The fractional adoption rate can be calculated as cumulative distribution function:

$$\textit{Fractional adoption rate} = \int \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(A-A^*)^2}{2\sigma^2}\right)dA\,.$$

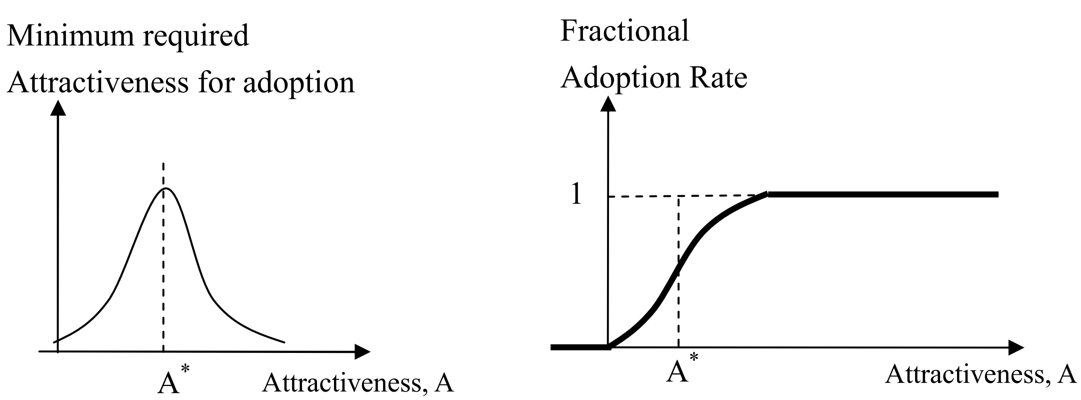


Figure 4-7: Definition of Fractional Adoption Rate

4.2.2 Benefit Model

As mentioned in section 3.6, there are two types of operational benefits: the independent benefit that is independent of other aircraft's equipage, $B_i\ (t)$, and the dependent benefit that depends on other aircraft's equipage, $B_d\ (t)$:

$$Benefit/Aircraft\ (t) = B_i\ (t) + B_d\ (t) = B_i\ (t) + B_{dmax} \times \%Equipage(t).$$

The independent benefit, $B_i\ (t)$ increases over time because more applications will be developed. As described in section 3.6.3, the independent benefit increases as shown in Figure 4-8.

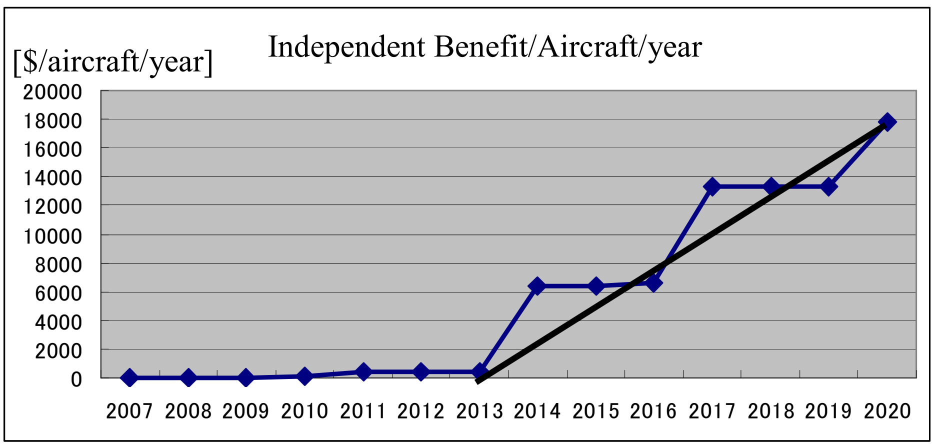


Figure 4-8: Independent Benefit per Aircraft

In this model, $B_i\ (t)$ is assumed to increase linearly over time. The equation of $B_i\ (t)$ is:

$$\begin{cases} B_i(t) = \dfrac{18000}{2020-2013} \times (t-2013) = 2571 \times t - 5175423 & (t \geq 2013) \\ B_i(t) = 0 & (t < 2013). \end{cases}$$

From section 3.6.3, the equation of the benefit depending on other aircraft equipage, $B_d(t)$ is:

$$\begin{cases} B_d(t) = B_{dmax} \times \%Equipage(t) = 4000 \times \%Equipage(t) & (t \geq 2011) \\ B_d(t) = 0 & (t < 2011). \end{cases}$$

The unit of $B_i\ (t)$, $B_d\ (t)$ is dollar per aircraft per year. The aircraft with ADS-B can receive the benefit, $B_i\ (t) + B_d\ (t)$, every year.

In order to calculate NPV in the Adoption Model, future benefits should be estimated. With the above definition equation, $B_i(t)$ can be calculated. Because the $B_d\ (t)$ depends on % equipage, future % equipage should be estimated first. The % equipage in mandate date should be 100%. Therefore, the future % equipage between time t and the mandate date can be estimated by linear interpolation. Then the future benefit between time t and the mandate date can be calculated by using the estimated % equipage.

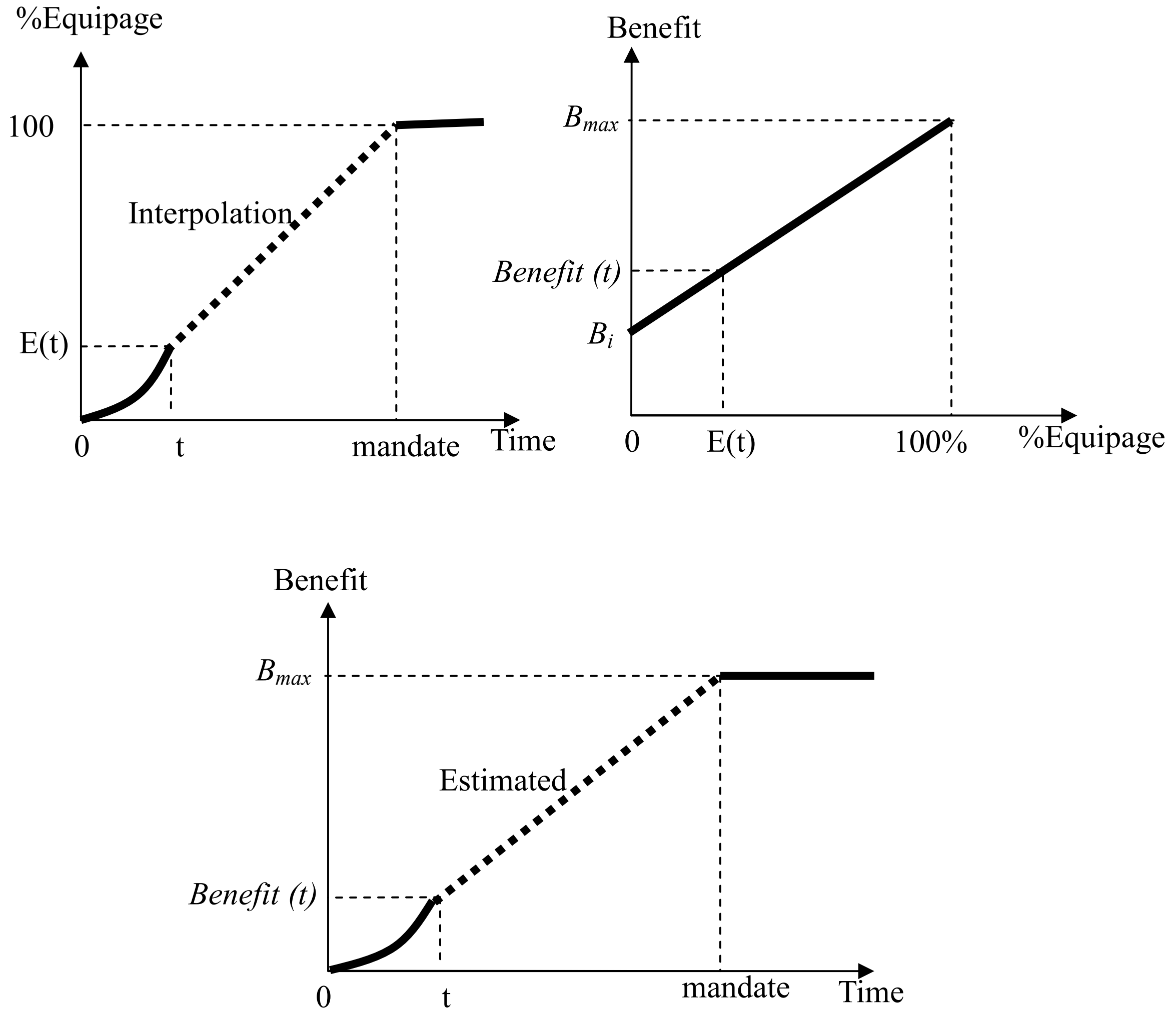


Figure 4-9: Estimation of Future Benefit

4.3 Further Expansion of the Model

The basic model developed in section 4.2 can show the basic idea of the Adoption Model and the Benefit Model. But it is too simple to represent the real ADS-B Out equipage. Three factors should be added to the basic model. The first is the maintenance cycle of aircraft, the second is the aircraft age, and the third is the deployment of ground infrastructure.

4.3.1 Cost and Maintenance Cycle

As mentioned in section 3.7, the acquisition cost of ADS-B Out depends on the regular maintenance cycle. The cost for the adoption of ADS-B Out becomes more expensive when aircraft adopt ADS-B Out outside the heavy maintenance cycle.

As mentioned in 4.2.1, adoption rate is determined by the comparison of the NPV between the early adoption and the future adoption. The NPV varies according to the maintenance cycle. Therefore, the adoption rate should be calculated separately based on the position of aircraft in the maintenance cycle. Figure 4-10 shows the model that takes into account the factor of the maintenance cycle.

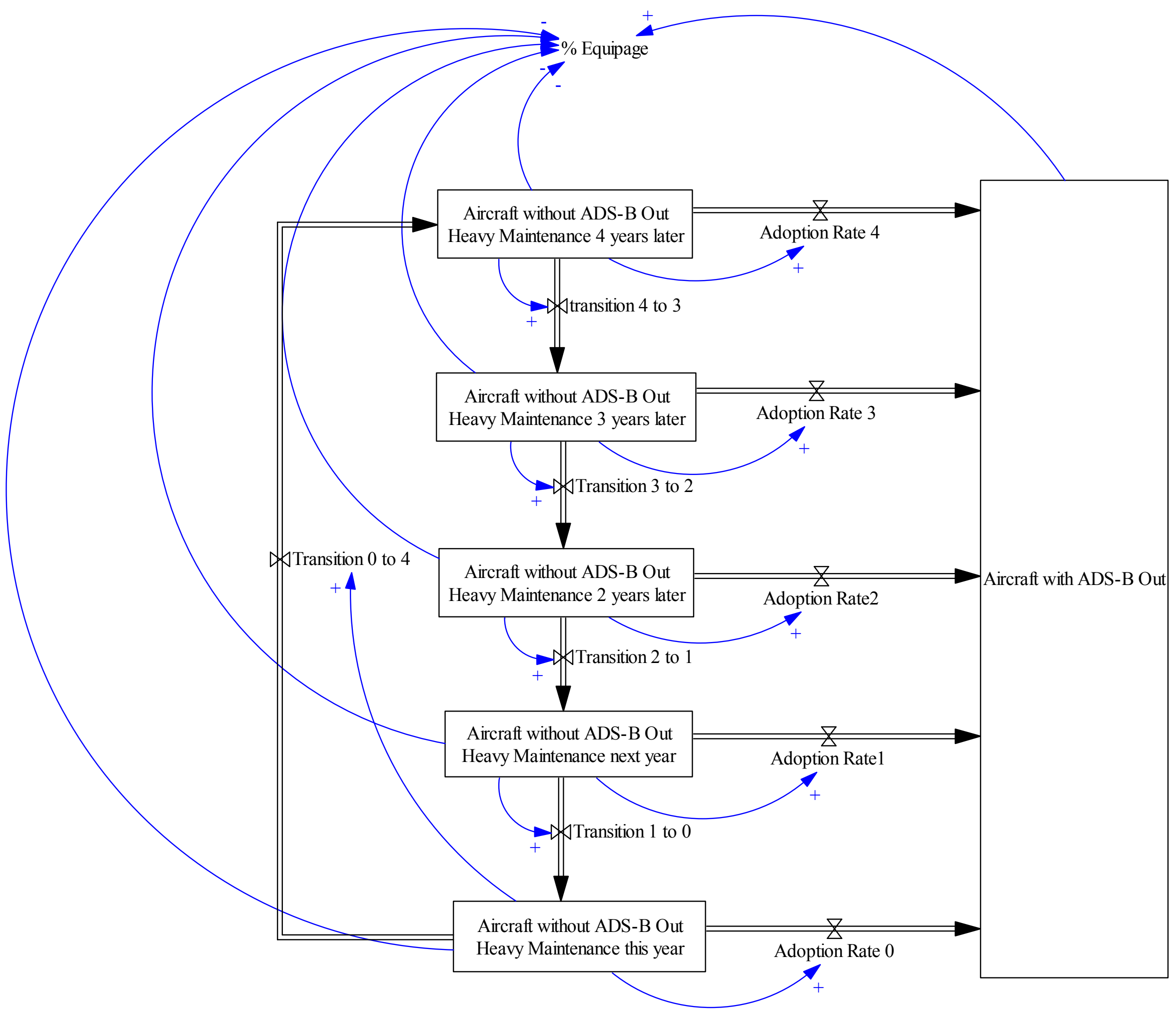


Figure 4-10: Adoption Model by Maintenance Cycle

This model assumes that each aircraft receives a heavy maintenance visit every five years. Therefore, the aircraft without ADS-B Out are divided into five stocks, each of which represents the aircraft group of each position in the maintenance cycle: Aircraft that receive the heavy maintenance this year, 1 year later, 2 years later, 3 years later and 4 years later. Every year, aircraft move stocks from 4 years later to 3 years later, from 3 years later to 2 years later, from 2 years later to 1 year later, from 1 year later to this year, and from this year to 4 years later.

Adoption rate for each stock is calculated separately.

a) Heavy maintenance in year t

When aircraft receives regular heavy maintenance in year t, the NPV of adoption in year t is as follows:

$$NPV_0(t) = -C + \frac{B_{t+1}}{1+r} + \frac{B_{t+2}}{(1+r)^2} + \cdot \cdot \cdot + \frac{B_R}{(1+r)^{R-t}}.$$

NPV of future adoption (k years later) is as follows:

Future adoption in the future maintenance cycle

$$NPV_k(t) = -\frac{C}{(1+r)^k} + \frac{B_{t+k+1}}{(1+r)^{k+1}} + \frac{B_{t+k+2}}{(1+r)^{k+2}} + \cdot \cdot \cdot + \frac{B_R}{(1+r)^{R-t}}$$

Future adoption out of the maintenance cycle

$$NPV_k(t) = -\frac{C+AC}{(1+r)^k} + \frac{B_{t+k+1}}{(1+r)^{k+1}} + \frac{B_{t+k+2}}{(1+r)^{k+2}} + \cdot \cdot \cdot + \frac{B_R}{(1+r)^{R-t}}.$$

Above, AC is the additional cost when aircraft adopt ADS-B out of the maintenance cycle. The differences of NPV between adoption in year t and the future adoption k years later are:

Future adoption in the future maintenance cycle

$$NPV_0(t) - NPV_k(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \cdot \cdot \cdot + \frac{B_k}{(1+r)^k} - C + \frac{C}{(1+r)^k}$$

Future adoption k out of the maintenance cycle

$$NPV_0(t) - NPV_k(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \cdot \cdot \cdot + \frac{B_k}{(1+r)^k} - C + \frac{C}{(1+r)^k} + \frac{AC}{(1+r)^k}.$$

The attractiveness of the adoption in year t is the minimum differences between NPV of the adoption in year t and the future adoption k years later. The differences between NPV of the adoption in year t and the future adoption usually become the smallest when aircraft operators compare the adoption in year t and the future adoption in the next maintenance cycle.

b) No heavy maintenance in year t

When aircraft does not receive regular heavy maintenance in year t, the NPV of adoption in year t is as follows:

$$NPV_0(t) = -C - AC + \frac{B_{t+1}}{1+r} + \frac{B_{t+2}}{(1+r)^2} + \cdot\ \cdot\ \cdot + \frac{B_R}{(1+r)^{R-t}}.$$

NPV of future adoption (k years later) is as follows:

Future adoption in the future maintenance cycle

$$NPV_k(t) = -\frac{C}{(1+r)^k} + \frac{B_{t+k+1}}{(1+r)^{k+1}} + \frac{B_{t+k+2}}{(1+r)^{k+2}} + \cdot\ \cdot\ \cdot + \frac{B_R}{(1+r)^{R-t}}$$

Future adoption out of the future maintenance cycle

$$NPV_k(t) = -\frac{C + AC}{(1+r)^k} + \frac{B_{t+k+1}}{(1+r)^{k+1}} + \frac{B_{t+k+2}}{(1+r)^{k+2}} + \cdot\ \cdot\ \cdot + \frac{B_R}{(1+r)^{R-t}}.$$

The differences of NPV between adoption in year t and the future adoption (k years later) is:

Future adoption in the future maintenance cycle

$$NPV_0(t) - NPV_k(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \cdot\ \cdot\ \cdot + \frac{B_k}{(1+r)^k} - C + \frac{C}{(1+r)^k} - AC$$

Future adoption out of the future maintenance cycle

$$NPV_0(t) - NPV_k(t) = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \cdot\ \cdot\ \cdot + \frac{B_k}{(1+r)^k} - C + \frac{C}{(1+r)^k}.$$

Basically, aircraft operators compare the NPV of the adoption in year t and the NPV of the adoption in next maintenance cycle. When the benefit before the next maintenance is larger than the opportunity cost and the additional cost of the adoption outside the maintenance cycle, the aircraft operator adopts ADS-B Out this year with paying the additional cost rather than waiting until the next maintenance cycle.

4.3.2 Cost and Aircraft Age

As mentioned in section 3.7, the cost of adoption of ADS-B Out varies based on aircraft age.

Therefore, the adoption rate should be calculated separately according aircraft age. In this model, aircraft is divided into 3 types based on aircraft age as shown in Table 3-3.

Figure 4-11 shows the adoption model that takes into account the aircraft age and is composed of 3 adoption models: adoption models for Type A, B and C. Type A is the oldest aircraft, which do not have GPS or transponder. Type B is the middle age aircraft, which have GPS and upgradable transponder. Type C is the newest aircraft. The adoption model of each aircraft type represents the adoption model in Figure 4-10. The adoption rate of Type A, B and C is calculated by using the unit cost of the aircraft of Type A, B and C respectively.

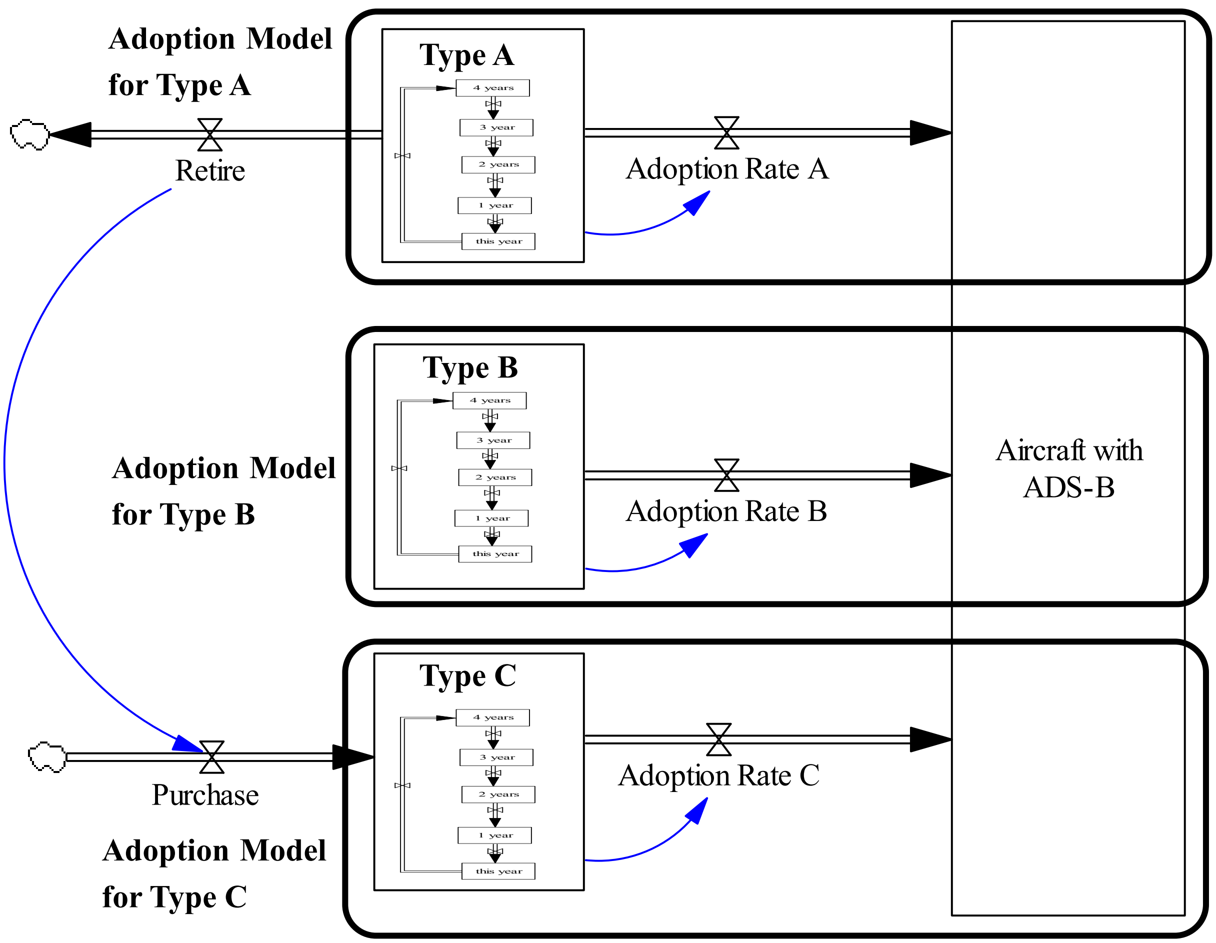


Figure 4-11: Adoption Model by Aircraft Age

This model assumes that all aircraft retire when 25 years old. Because the youngest aircraft of Type A is 10 years old in 2008, all aircraft of Type A will retire in 15 years. Therefore, the retirement rate of Type A is 1/15 of the number of aircraft of Type A. This model assumes that the total number of aircraft does not change. The number of new purchased aircraft of Type C for each year is the same as the number of retired aircraft of Type A.

4.3.3 Deployment of Ground Infrastructure

To achieve the benefit of ADS-B, ground infrastructure is required as well as aircraft equipage. According to the current FAA's schedule, ground Infrastructure will be deployed by the end of fiscal year 2013. Before 2013, ground infrastructure will be deployed by steps geographically. This model assumes that ground infrastructure will be deployed in 4 steps by 2014. The first step of deployment of ground infrastructure is the location included in the segment 1 as shown in Figure 3-2. During the segment 2, the FAA is planning to deploy the ground infrastructure all over the NAS. The current schedule by ITT is shown in Figure 4-13. The ITT plans to deploy the ground infrastructure all over the NAS in 3 steps between 2012 and 2014. According to the deployment schedule of ITT, the ground infrastructure will be deployed from east to west based on the traffic density.

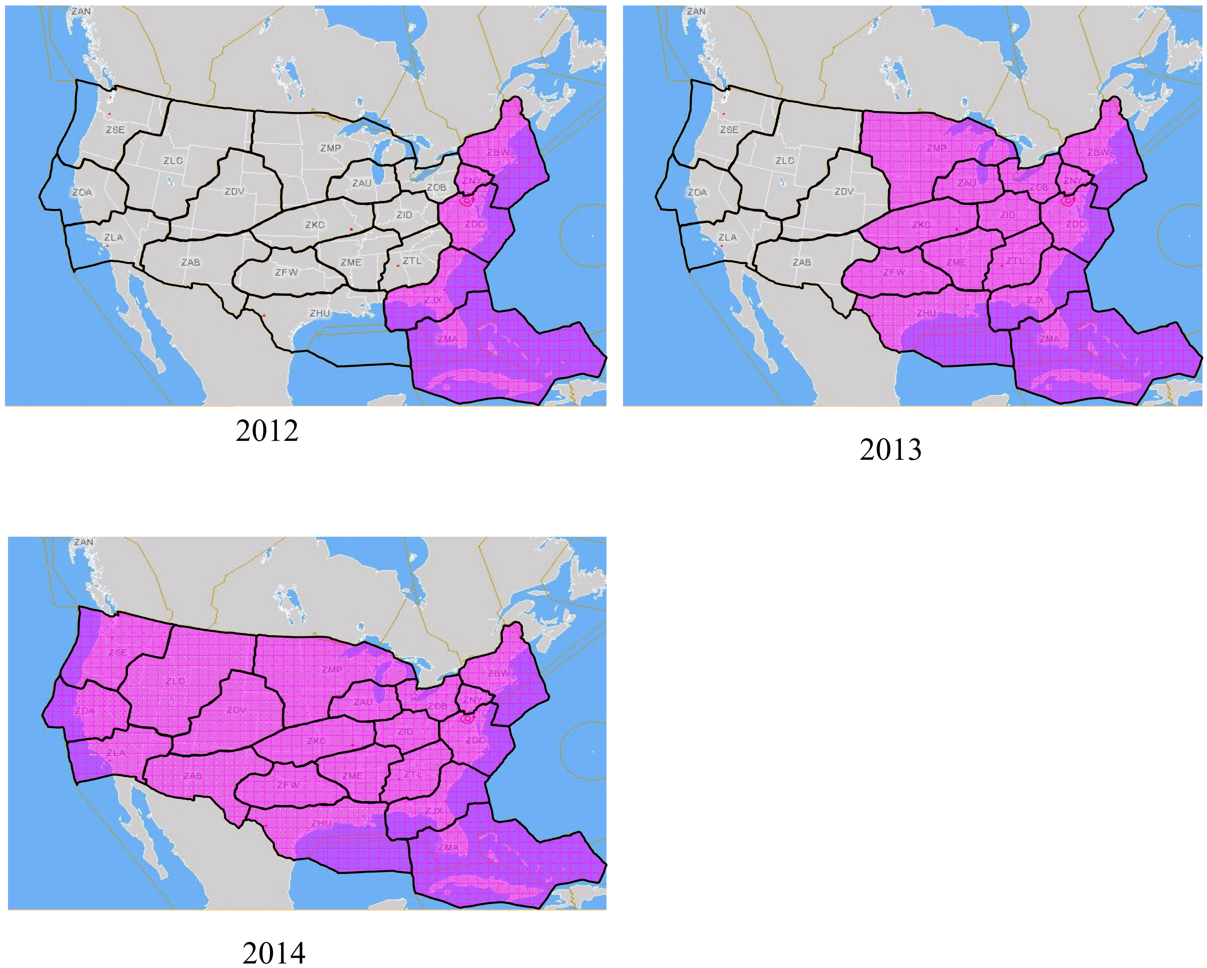


Figure 4-12: Deployment Schedule of ADS-B Ground Infrastructure (Hu, 2008)

When the deployment of ground infrastructure is taken into account, benefit per aircraft can be defined as follows:

$$Benefit(t) = G(t) \times (B_i\ (t) + B_d\ (t)).$$

When *G(t)* is the % operation exposed to ADS-B, Figure 4-13 shows the *G(t)*.

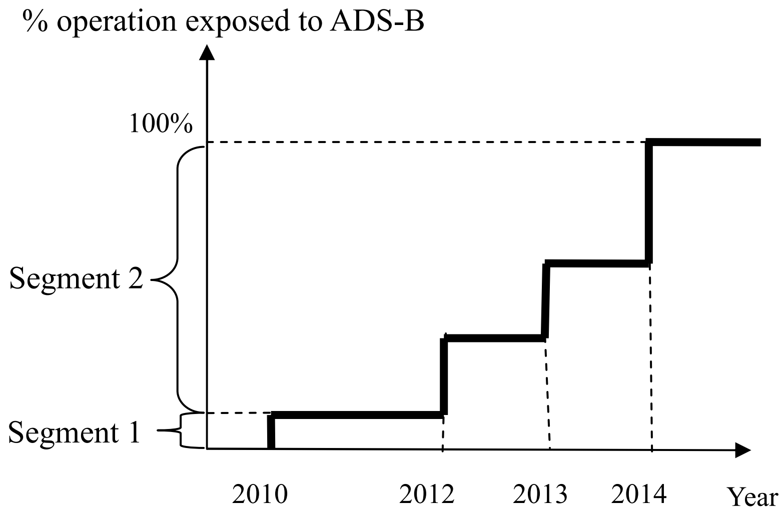


Figure 4-13: Definition of *G(t)*

4.3.4 Summary of Assumptions

The following is the summary of the assumption of this model.

- The mandate date of ADS-B Out is 2020.
- The target of this model is 2008 to 2020.
- $B_i(t)$ increases linearly over time.
- The heavy maintenance cycle is 5 years.
- All aircraft retire when 25 years old.
- Total number of aircraft does not change.
- Discount rate is 7%.

Chapter 5 Policy Analysis

This chapter describes the analysis of incentive policy for encouraging the early adoption of ADS-B Out by using the System Dynamics Model developed in Chapter 4. The following four policies are analyzed in this chapter: (1) Acceleration of Operational Benefit, (2) Preferred Access, (3) Financial Incentives, and (4) Mandate Date.

5.1 Acceleration of Operational Benefits

The first policy for encouraging the early adoption of ADS-B Out is to accelerate the operational benefit. This section focuses on accelerating the implementation of applications, rather than developing new applications. Also, this section does not include the acceleration of the benefits that are currently anticipated to be available after the mandate date. Because most of those benefits require the full equipage of all aircraft, it is difficult to accelerate the implementation of those applications before the mandate date. In this section, the mandate date is fixed in 2020. The effect of moving forward the mandate date will be discussed in section 5.4.

There are two types of operational benefits of ADS-B Out: the independent benefit that is independent of other aircraft's equipage, $B_i\ (t)$ and the dependent benefit that depends on other aircraft's equipage, $B_d\ (t)$:

$$Benefit/Aircraft\ (t) = B_i\ (t) + B_d\ (t) = B_i\ (t) + B_{dmax} \times \%Equipage(t).$$

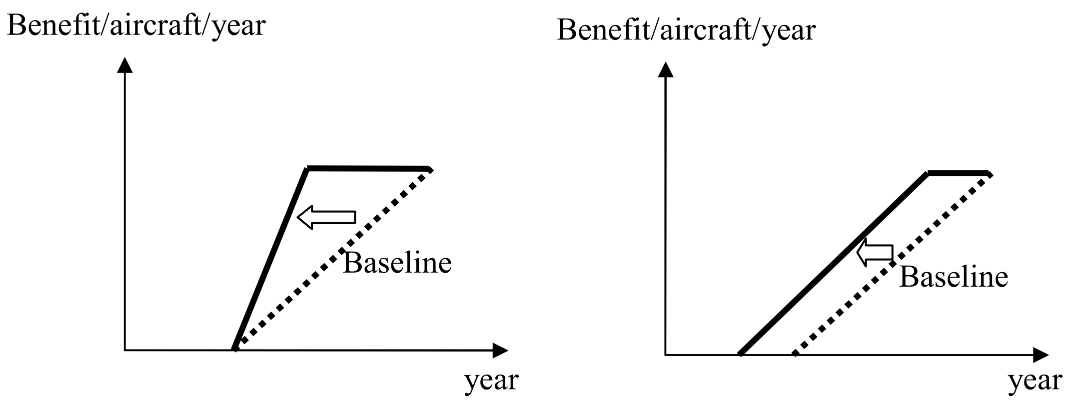
Table 5-1 shows the anticipated accrual date for ADS-B Out benefits.

Table 5-1: Accrual Date for ADS-B Out Application (ADS-B Aviation Rulemaking Committee, 2007)

Application	Type	Accrual date
More efficient en route conflict resolution	Independent	2017
Increased ability to allow CDAs		2014
More efficient en route metering to the arrival fix		2020
More efficient ATC management of surface movement		2016
Optimal routing		2011
Increased capacity	Dependent	2011
Optimal routing		2011

Several applications of the independent benefit type are anticipated to gradually become available between 2011 and 2020. On the other hand, the applications of the dependent benefit type will become available in 2011. Therefore, this section focuses on the acceleration of implementation of the application of the independent benefit type.

The independent benefit, $B_i\ (t)$ increases over time because more applications will be developed, and is assumed to increase linearly over time. There are two types of acceleration of benefit as shown in Figure 5-1. One is the High Benefit Rate type and the other is the Early Benefit type. The following section examines each type of acceleration of benefit.



(a) High Benefit Rate Type ***(b) Early Benefit Type***

Figure 5-1: Types of Acceleration of Benefit

5.1.1 Acceleration of Operational Benefits of High Benefit Rate Type

The first acceleration of the benefits is to accelerate benefit without changing the first year benefit realized. In the baseline case, the benefits are available after 2014. Because the ground infrastructure will be deployed all over the NAS in 2014, the applications in this section are available only after ground infrastructure is deployed all over the NAS. Figure 5-2 shows the acceleration of the benefit of High Benefit Rate type. In the baseline case, the benefit is zero until 2013 and reaches to the maximum benefit in 2020. In the 2-year acceleration case, the benefit reaches to the maximum benefit in 2018. And in the 4-year acceleration case, the benefit reaches the maximum benefit in 2016. In the 6-year acceleration case, the benefit reaches the maximum benefit in 2016. The benefit never exceeds the maximum benefit because the applications that are anticipated to be available after 2020 are not accelerated.

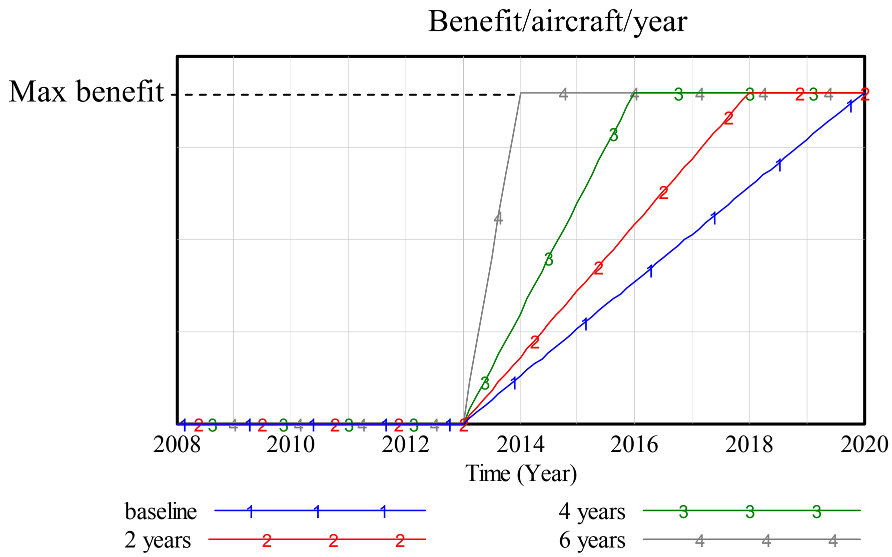


Figure 5-2: Acceleration of Benefit (High Benefit Rate Type)

Figure 5-3 shows the change of the equipage curve. As the benefit is accelerated, the equipage curve is also accelerated. For example, when the benefit is accelerated by 6 years, the % equipage reaches 50% one year earlier than the baseline case.

Figure 5-3 also shows the different equipage curves of different types of aircraft. Type A is the oldest type of aircraft and the acquisition cost is the most expensive. Type C is the youngest and the acquisition cost is the least expensive. The aircraft of type A is affected the most by acceleration of operational benefits. Type A aircraft requires higher benefits to adopt the ADS-B because of the higher acquisition costs. In the baseline case, type A aircraft do not begin adoption until 2015 while type B and type C aircraft begin adoption before 2014. When the benefit is accelerated, Type A aircraft begin adoption earlier than the baseline case.

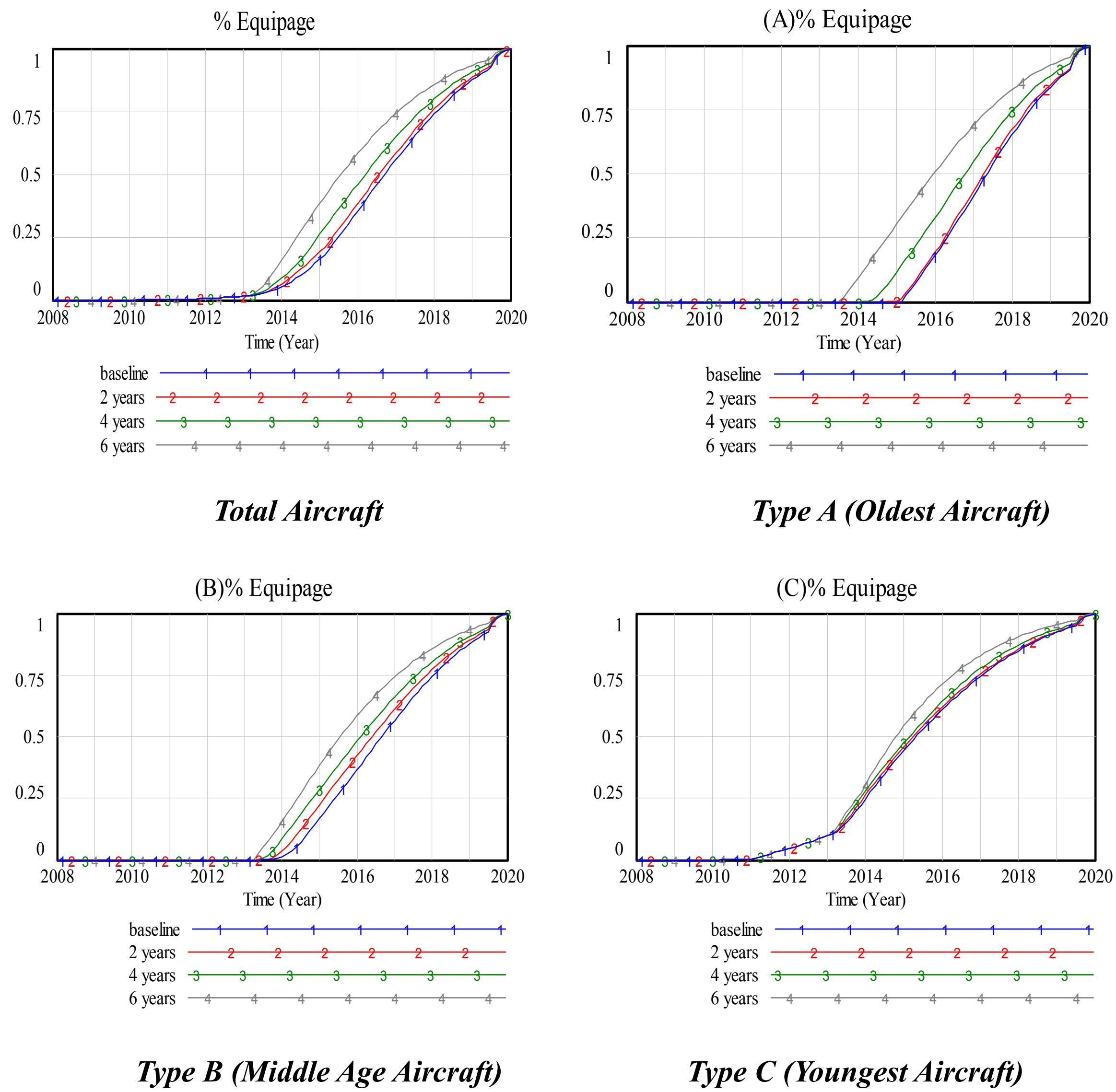


Figure 5-3: Change of Equipage Curve by Acceleration of Benefit (High Benefit Rate Type)

The total benefit per year is calculated as follows:

$$\textit{Total benefit (t) = benefit/aircraft (t)} \times \textit{\# of aircraft equipped (t).}$$

The total benefit per year increases as the operational benefit is accelerated.

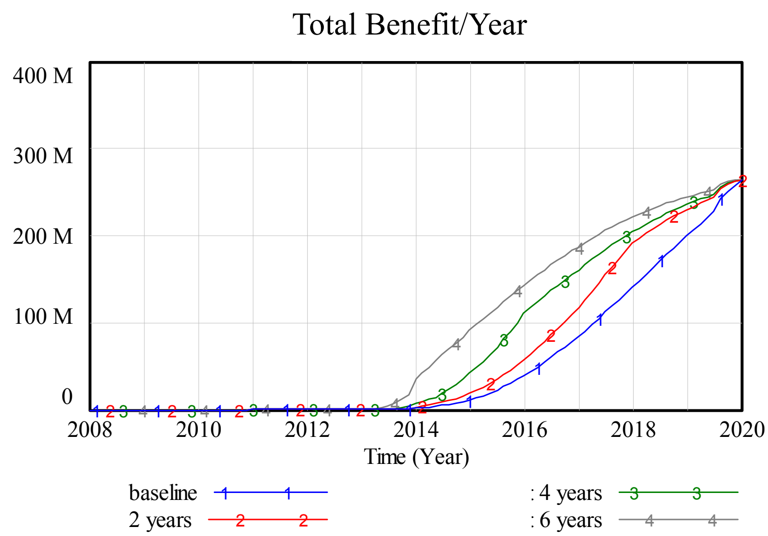


Figure 5-4: Change of Total Benefit by Acceleration of Benefit (High Benefit Rate Type)

The present value (PV) of the total benefit from 2008 to 2020 is the good indicator to show the effect of incentives.

$$PV = \sum_{t=2008}^{2020} \frac{\{\text{total benefit}(t)\}}{(1+r)^{t-2008}}$$

The PV increases by $249 million when the benefit is accelerated by 6 years.

Table 5-2: PV of Total Benefit by Acceleration of Benefit (High Benefit Rate Type)

	Baseline	2year	4year	6year
PV of benefit ($)	293M	368M	447M	542M

5.1.2 Acceleration of Operational Benefits of Early Benefit Type

The second acceleration is to move forward the first year when the benefit is realized by keeping the slope constant. Figure 5-5 shows the acceleration by sliding the slope.

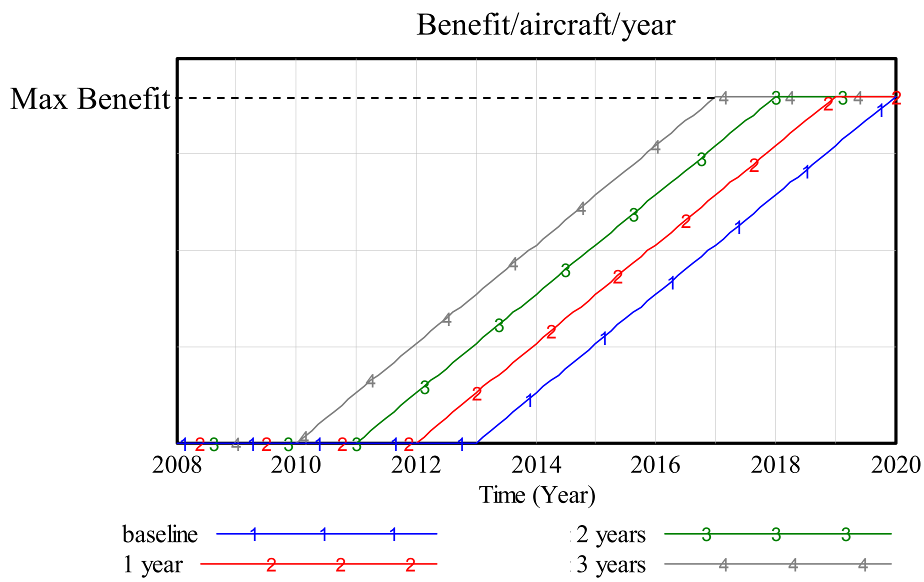
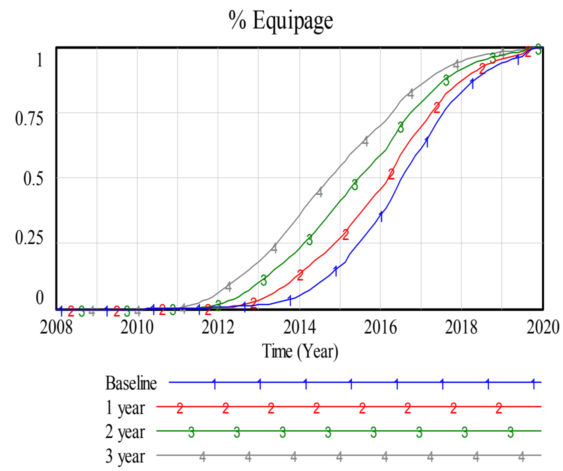


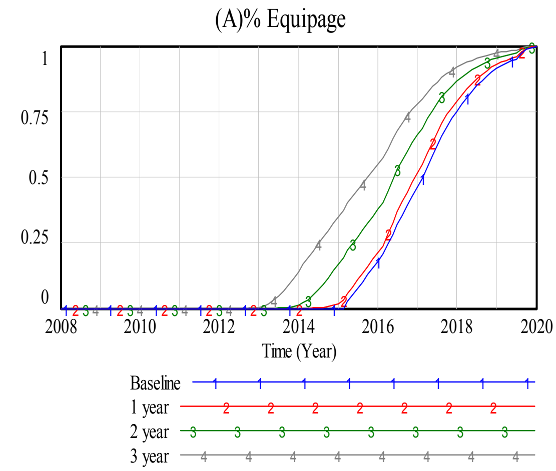
Figure 5-5: Acceleration of Benefit (Early Benefit Type)

According to the current FAA's schedule, the ground infrastructure will be deployed all over the NAS by 2014. When the implementation of applications is accelerated before 2013, it is best to accelerate the deployment of ground infrastructure as well. However, because the schedule of deployment of ground infrastructure is determined by the contract between the FAA and the ITT Corporation, it is difficult to accelerate the schedule. The ground infrastructure will be deployed in steps before 2013. When the applications are accelerated before 2013, the benefit will be partially available only where ground infrastructure is placed.

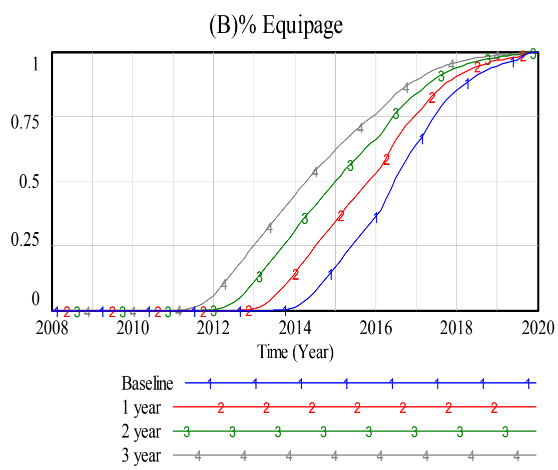
Figure 5-6 shows the change of the Equipage curve when the benefit is accelerated. In contrast to the acceleration of High Benefit Rate in 5.1.1, all types of aircraft are affected almost equally.



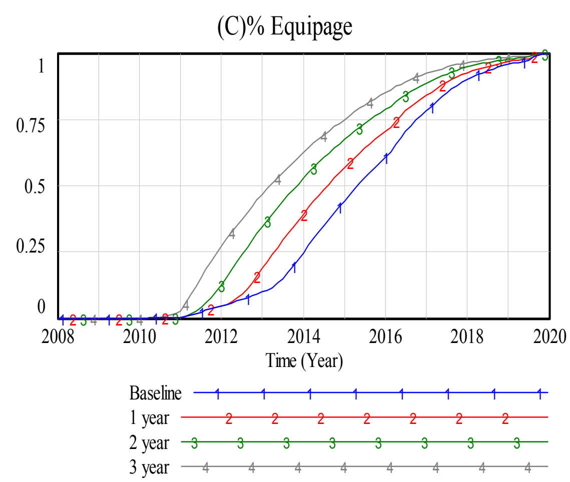
Total Aircraft



Type A (Oldest Aircraft)



Type B (Middle Age Aircraft)



Type C (Youngest Aircraft)

Figure 5-6: Change of Equipage Curve by Acceleration of Benefit (Early Benefit Type)

The total benefit increases as the benefit is accelerated as shown in Figure 5-7.

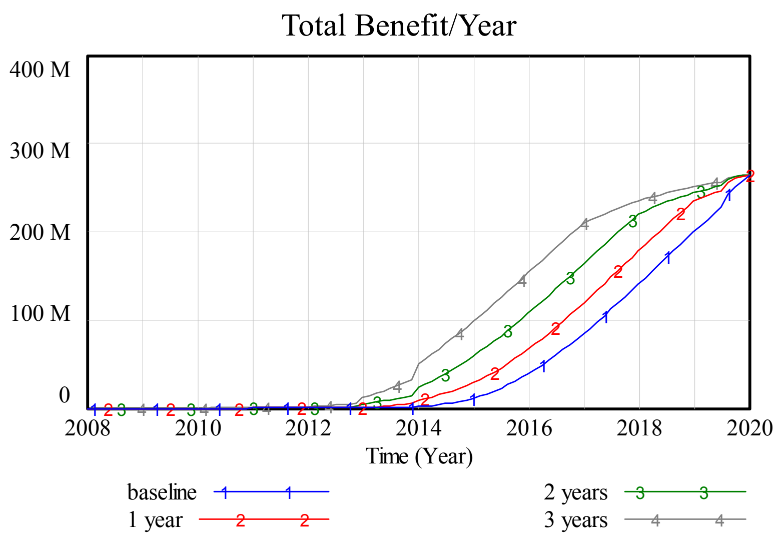


Figure 5-7: Change of Total Benefit by Acceleration of Benefit (Early Benefit Type)

Table 5-3 shows the PV of total benefit from 2008 to 2020 when the application is accelerated by sliding the slope.

Table 5-3: PV of Total Benefit by Acceleration of Benefit (Early Benefit Type)

	Baseline	1year	2year	3year
PV of benefit ($)	293M	380M	484M	592M

5.1.3 Comparison of Two Accelerations

The acceleration of Early Benefit Type is more effective than the acceleration of High Benefit Rate Type. Although area A and B in Figure 5-8 is the same, the PV of total benefit of the acceleration of Early Benefit Type by 3 years is larger than that of the acceleration of High Benefit Type by 6 years.

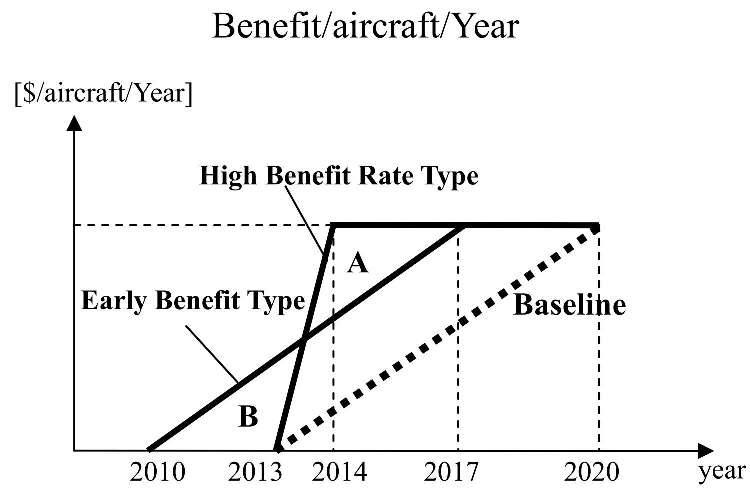


Figure 5-8: Comparison of Two Types of Acceleration of Benefit

The reason why the acceleration of Early Benefit Type is more effective is the delay in adoption. Even though the benefit increases sharply such as High Benefit Rate Type in Figure 5-8, the % equipage cannot increase so sharply because aircraft adopt ADS-B Out in their maintenance cycle. An important thing is to begin adoption early. Therefore, Early Benefit type is more effective than High Benefit Rate type. It is effective in encouraging the early adoption of ADS-B Out to accelerate the implementation of some applications before ground infrastructure will be deployed all over the NAS.

When the maintenance cycle is 3 years and 1 year, the change of the equipage curve is as shown in Figure 5-9. The shorter the maintenance cycle is, the faster the % equipage increases.

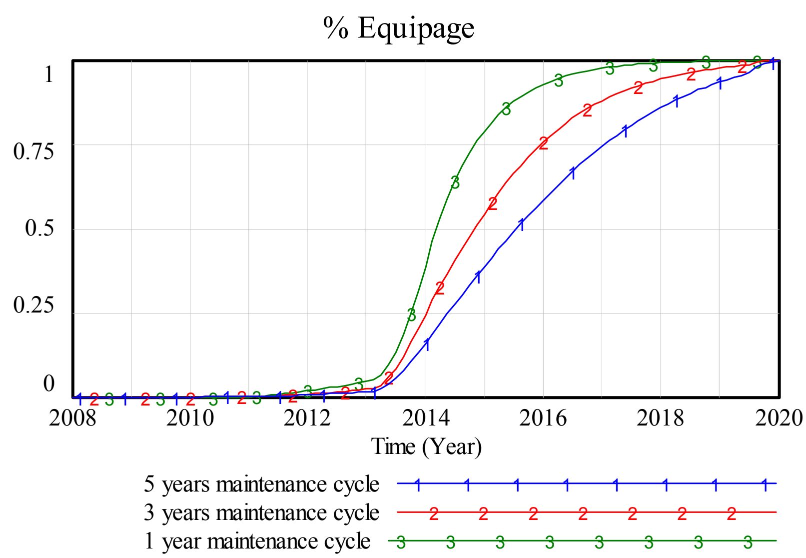


Figure 5-9: Change of Equipage Curve by Shortening Maintenance Cycle

5.2 Preferred Access

The second policy is to give the preferred access to the aircraft equipped with ADS-B Out. The benefit from preferred access decreases as %Equipage increases. The relation between the benefit from preferred access and %Equipage is as shown in Figure 5-10. The early adopter can receive the large benefit. When all aircraft are equipped, the benefit of preferred access is zero.

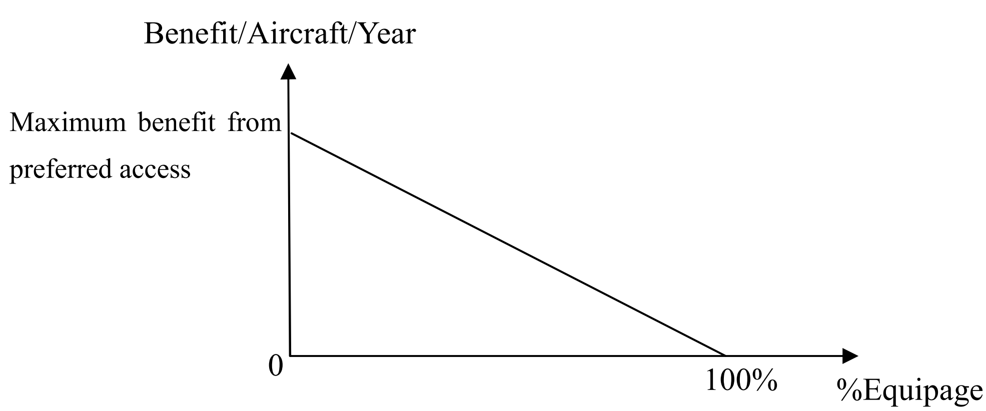


Figure 5-10: Benefit from Preferred Access

In order to analyze the effect of preferred access, the following two type of benefit from preferred access are examined. The first type is the maximum benefit from preferred access is half of the maximum independent benefit and starts from 2012. The other is the maximum benefit is the same as the maximum independent benefit and starts from 2014.

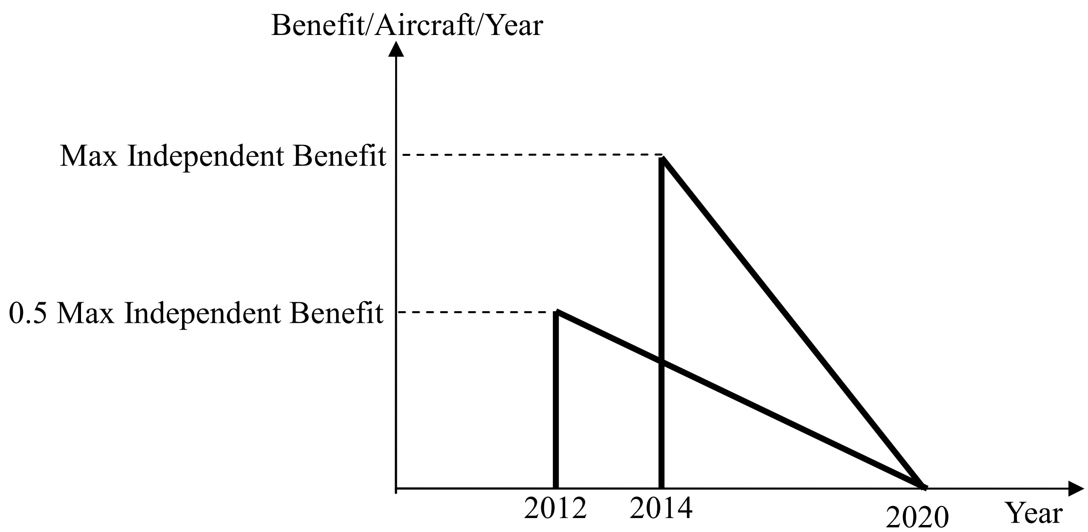
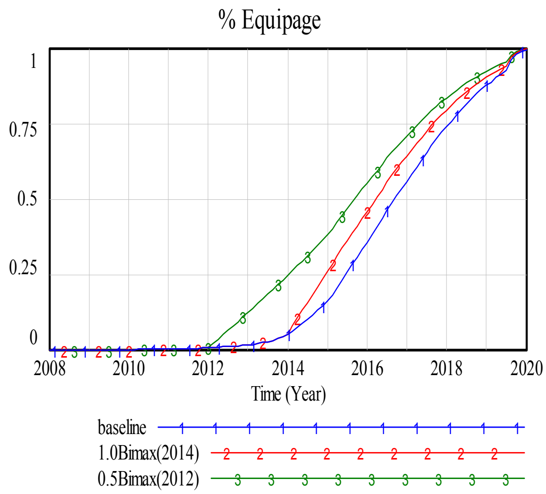
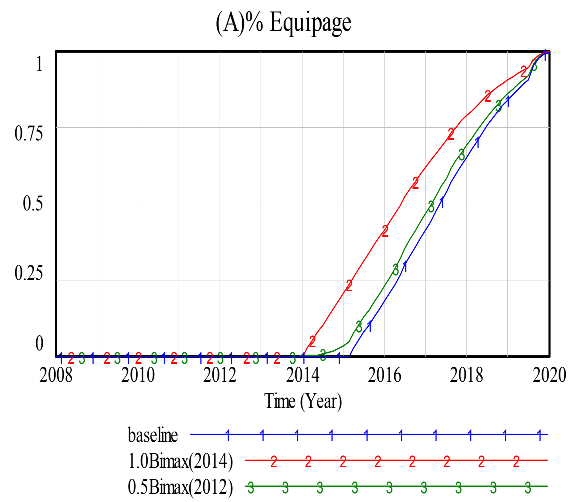


Figure 5-11: Types of Benefit from Preferred Access

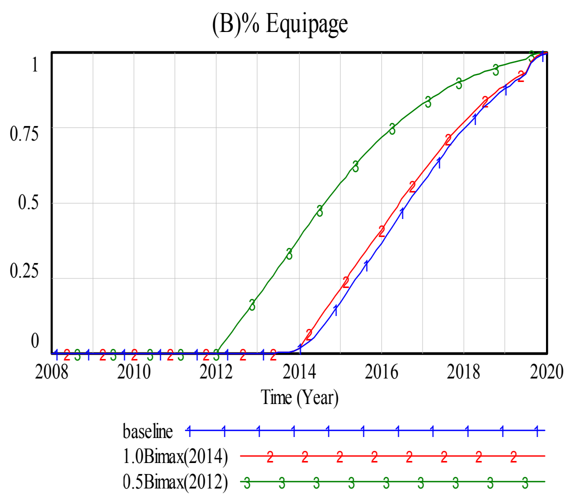
Figure 5-12 shows the change of the equipage curve when the benefit from the preferred access is added to the baseline case. The benefit that starts from 2012 is more effective than the benefit that starts from 2014 except for type A aircraft.



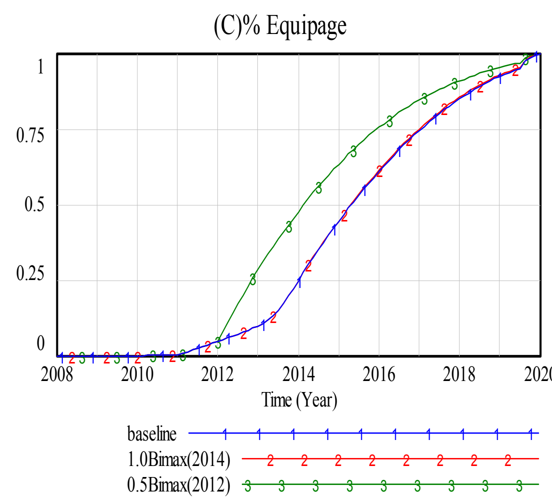
Total Aircraft



Type A (Oldest Aircraft)



Type B (Middle Age Aircraft)



Type C (Youngest Aircraft)

Figure 5-12: Change of Equipage Curve by Preferred Access

The total benefit per year is as shown in Figure 5-13.

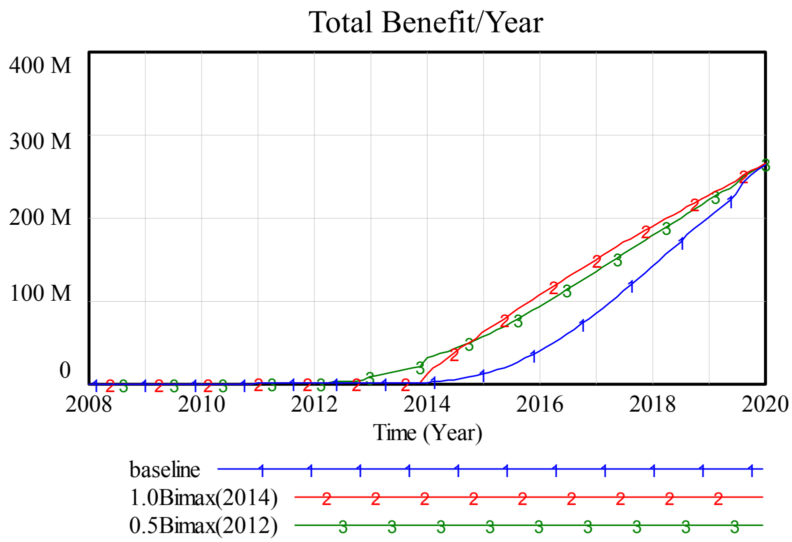


Figure 5-13: Change of Total Benefit by Preferred Access

5.3 Financial Incentives

The third policy is financial incentive. The government should be careful when considering financial incentives because the incentives may distort the market mechanism. The financial incentive makes deadweight loss and decreases the market efficiency. Figure 5-14 shows how financial incentives create deadweight loss. When there are positive or negative externalities that can not be captured by market mechanism, financial incentive by the government can be justified. The examples of externalities are environmental externality, safety externality, security externality, etc. (Viscusi et al., 2005)

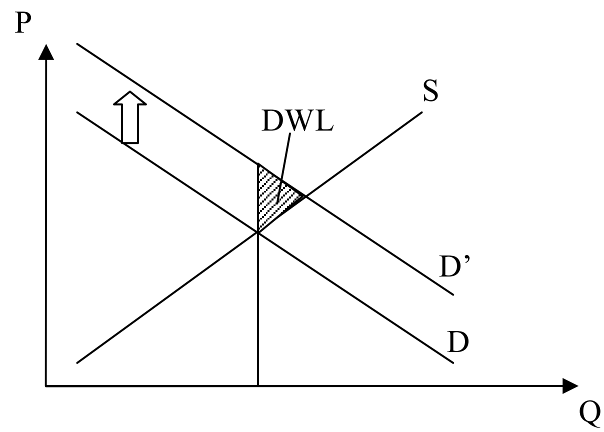


Figure 5-14: Deadweight Loss by Financial Incentive

ADS-B has environmental benefits. ADS-B can reduce the flight hour of aircraft operators and reduce the fuel consumption. While reduced fuel cost is the direct benefit for aircraft operator, it is also an environmental benefit. ADS-B also increases the safety level of operation. However, while increased safety is a benefit for passengers, the benefit from increased safety is sometimes difficult to be captured.

Therefore, the financial incentive for the adoption of ADS-B can be justified by these externalities. The level of financial incentive should be calculated from the value of environmental externality and safety externality. While the estimation of the value for externality is out of the scope of thesis, this section analyzes the effect of the financial incentives on the equipage.

Three types of financial incentive in Figure 5-15 are examined. Aircraft receive the financial incentive once when aircraft adopt ADS-B. *Long&Low* type incentive means that aircraft that adopt before 2018 can receive the financial incentive as much as half of the acquisition cost for type C aircraft, which is the youngest aircraft group. *Short&Middle* type incentive means that aircraft that adopt before 2013 can receive the financial incentive as much as the acquisition cost for type C aircraft. *Short&High* type incentive means that aircraft that adopt before 2013 can receive the financial incentive as much as the acquisition cost for type B aircraft, which is the middle age aircraft group.

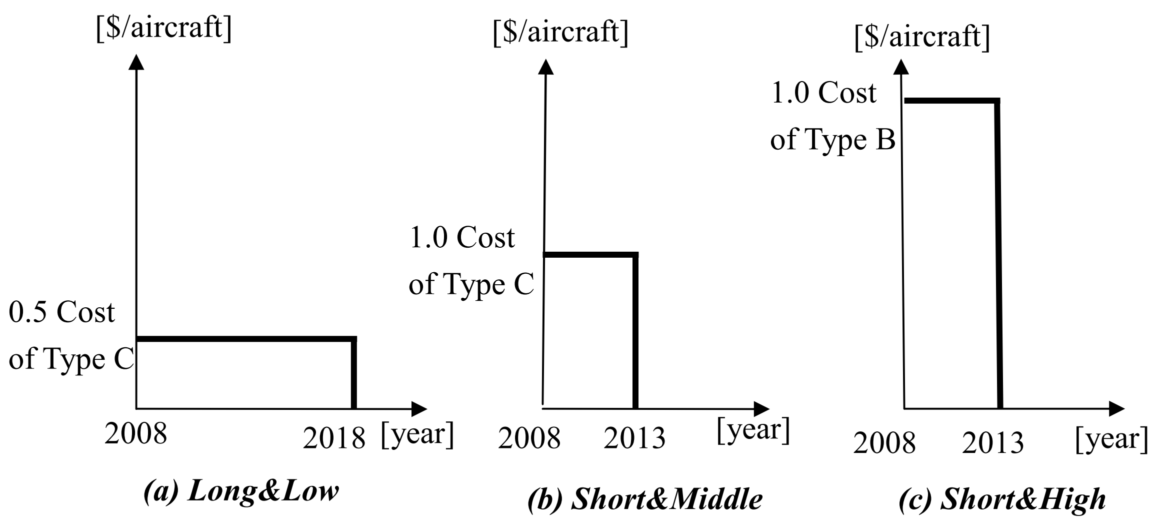
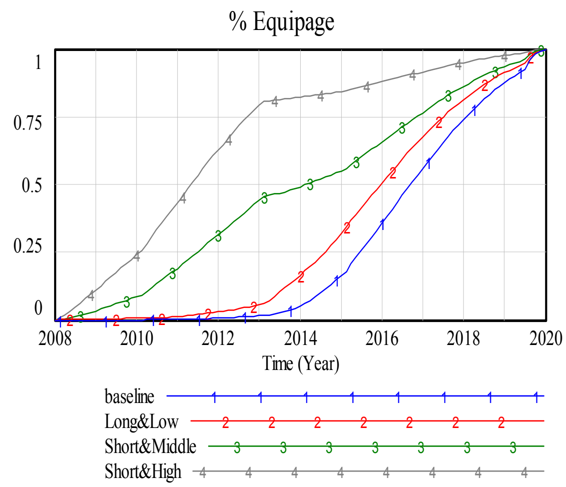
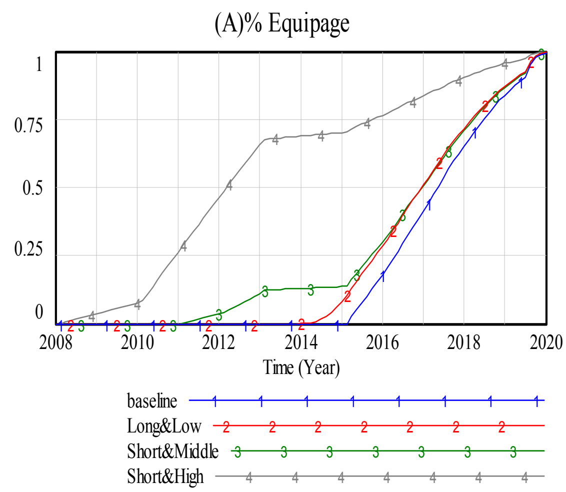


Figure 5-15: Types of Financial Incentives

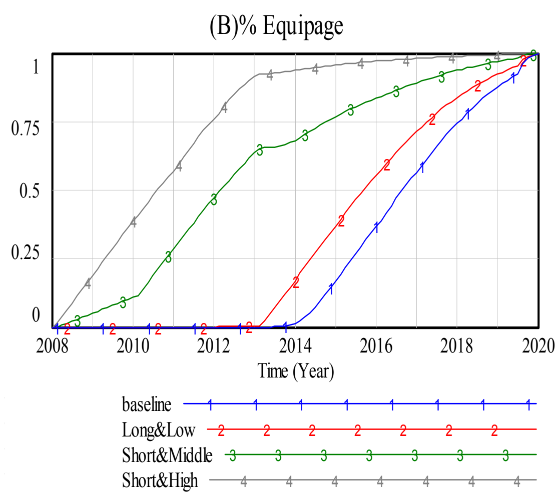
Figure 5-16 shows the change of the Equipage curve. The financial incentives of *Short&Middle* type are more effective in encouraging early adoption than that of *Long&Low* type. When the period of financial incentives is the same, *Short&High* type is more effective than *Short&Middle* type.



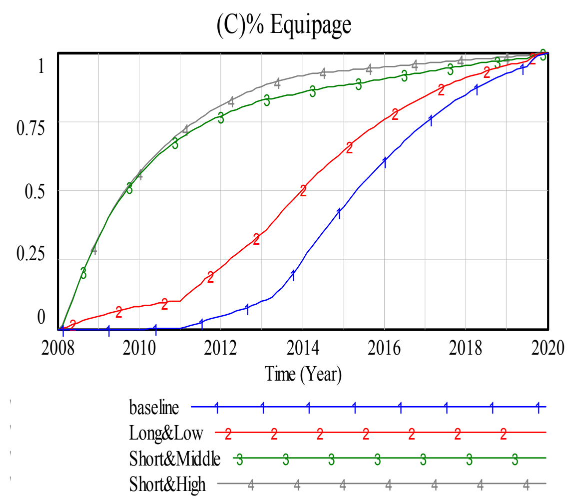
Total Aircraft



Type A (Oldest Aircraft)



Type B (Middle Age Aircraft)



Type C (Youngest Aircraft)

Figure 5-16: Change of Equipage Curve by Financial Incentive

Figure 5-16 also shows the effects of financial incentive of each type aircraft. Type A is the oldest and acquisition cost of ADS-B is the most expenses. Type C is the newest type of aircraft and the acquisition cost is the least expensive. Type C is affected the most by the financial incentive. For aircraft of Type C, the effect of *Short&High* type incentive is almost same as *Short&Middle* type. On the other hand, aircraft of Type A are affected only by the *Short&High* type incentive, not by *Long&Low* type and *Short&Middle* type. While the financial incentive of *Short&Middle* type is only 20% of the acquisition cost for Type A aircraft, the *Short&High* type incentive is almost half of acquisition cost for Type A aircraft.

Therefore, the most effective way of financial incentive is to give *Short&High* type incentive to type A aircraft, and *Short&Middle* type incentive to type C aircraft. However, if the government gives different financial incentive to different aircraft based on aircraft age, this approach may raise an equity issue.

The PV of total expense of FAA for financial incentives is shown in Table 5-4.

Table 5-4: Total Expense of FAA for Financial Incentive

	Long&Low	*Short&Middle*	*Short&High*
PV of total expense of FAA	\$98M	\$144M	\$569M

5.4 Mandate Equipage

The last policy is mandate. Mandate is an efficient and assured way to increase the equipage. The FAA announces that the current plan of mandate is 2020. This section analyzes the effect of the changing mandate date.

When the mandate date is moved forward, the equipage curve changes as shown in Figure 5-17. When the mandate date is from 2014 to 2018, the equipage curves are almost parallel.

Aircraft adopt ADS-B Out in the maintenance cycle just before the mandate date. Because the maintenance cycle is 5 years in this model, aircraft begin to adopt ADS-B Out 5 years before the mandate date. And about 20% of aircraft adopt each year. When the mandate date is moved forward before 2013, aircraft have to adopt out of the maintenance cycle and equipage curve increase more rapidly.

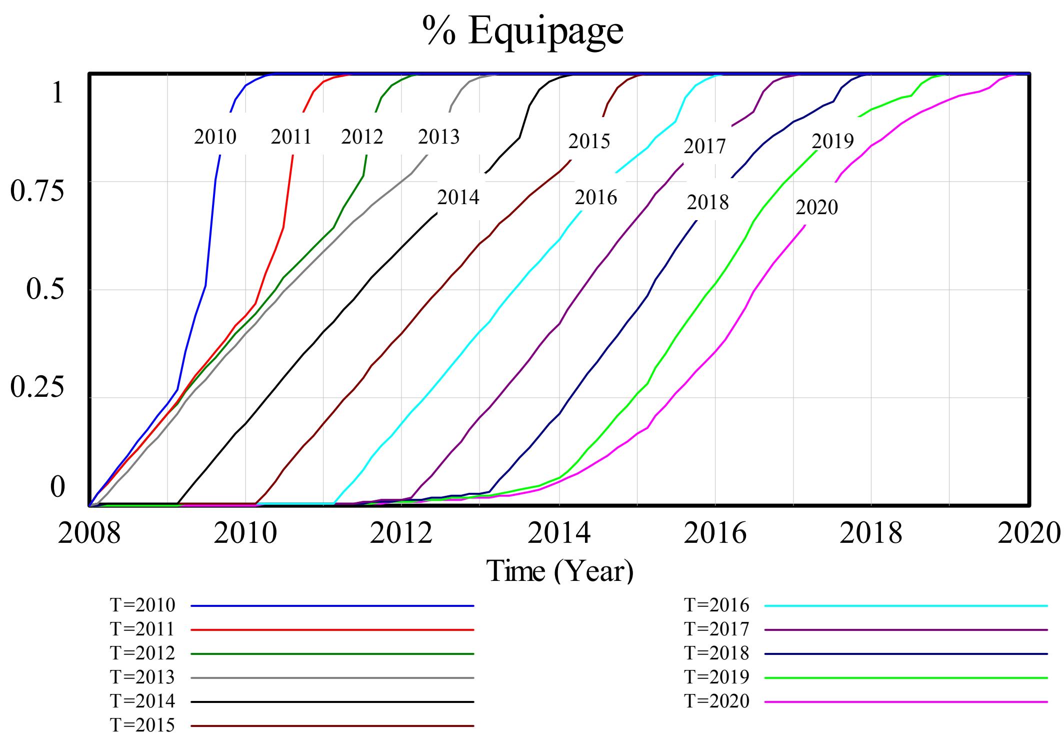


Figure 5-17: Change of Equipage Curve by Changing Mandate Date

Figure 5-18 shows the relation between the mandate date and the NPV from 2008 through 2035. As the mandate date is moved forward, the PV of both cost and benefit increase. There are several reasons for the increase of cost. The first reason is that the PV of cost for early adoption is larger than that for late adoption because of time value of the cost. The second reason is that when the mandate date is before 2013, aircraft have to adopt out of the maintenance cycle and acquisition cost increases. This is the reason why the cost increases more rapidly when the mandate is before 2013. The last reason is that old aircraft have to retrofit. When the mandate date is late, old aircraft will decrease because of retirement and new aircraft increase. The unit cost of ADS-B for old aircraft is more expensive.

PV of total benefit also increases as the mandate date is moved forward. There are two reasons. The first reason is that many aircraft adopt before the benefit is available. Therefore, more aircraft can receive the benefit just after the benefit is realized. The other reason is that the benefit depending on other aircraft's equipage increases because %Equipage increases early.

When the mandate date is moved forward before 2013, the benefit becomes almost steady. Because the independent benefit is available only after 2013, the benefit does not increase even if mandate date is moved forward before 2013. On the other hand, the cost increases rapidly when the mandate date is moved forward before 2013. Therefore, the NPV decreases sharply when the mandate date is before 2013.

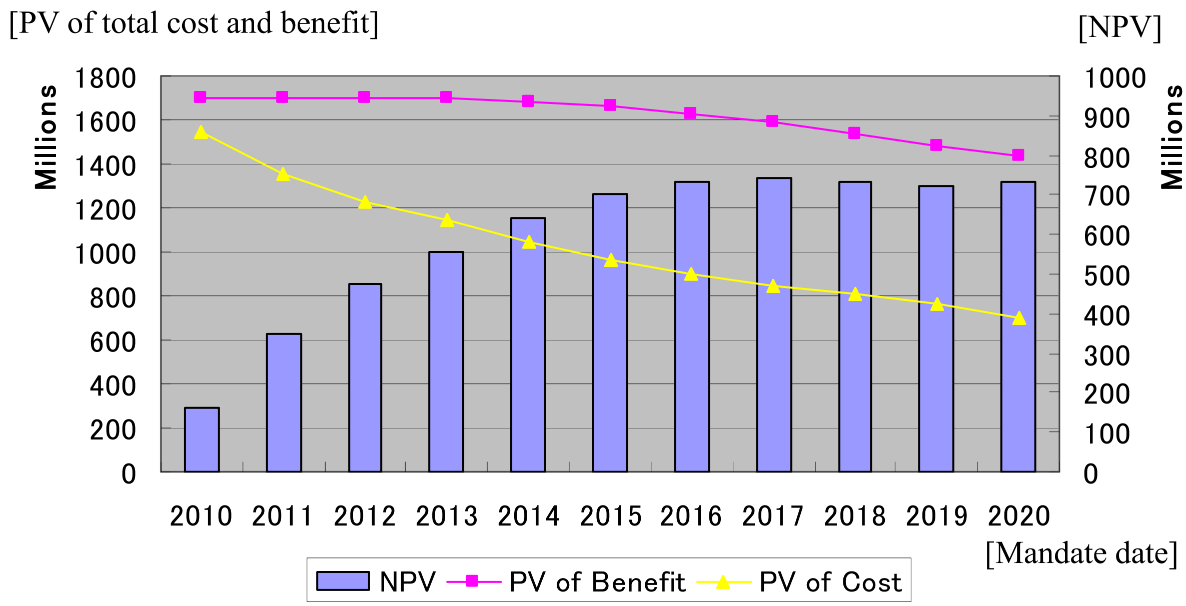


Figure 5-18: NPV and Mandate Date

However, this optimal timing of the mandate equipage in Figure 5-18 is just an example because this model is based on many assumptions. The first assumption is all aircraft take the regular heavy maintenance every five years. When the regular heavy maintenance cycle is three years, the optimal timing of the mandate equipage will change. The optimal timing of the mandate equipage also depends on the assumption of the distribution of aircraft age.

This model includes the benefits and costs only for aircraft operators, and does not include the benefits and costs for passengers and the FAA. When the benefits and costs for passengers and the FAA are taken into consideration, the optimal timing of the mandate equipage will change.

Furthermore, Figure 5-18 shows the change of the NPV when the mandate date is moved forward and other conditions do not change. When the other incentive policies descried in this thesis, such as acceleration of operational benefit, financial incentive, etc. is introduced, the optimal timing will also change.

Chapter 6 Conclusion

There are several barriers to achieve successful transition from a current technology to a new technology. This thesis analyzed how adoption of ADS-B can be encouraged by incentive policies.

First, to understand how individual users adopt ADS-B Out, this thesis developed a system dynamics model, which is mainly composed of two parts: Adoption Model and Benefit Model. Each part relates to the other. Adoption of ADS-B depends on benefits, and the benefits of ADS-B depend on how many aircraft are equipped with it.

Furthermore, the acquisition cost of ADS-B is different according to its position in the maintenance cycle. When aircraft operators adopt ADS-B outside the regular maintenance cycle, the cost becomes higher. Therefore, aircraft without ADS-B are divided into 5 stocks based on position in the maintenance cycle, and the adoption rate is calculated separately.

The acquisition cost is also different according to aircraft age. Because old aircraft are not equipped with GPS receivers, the acquisition cost becomes higher than the new aircraft that is equipped with GPS receiver. Therefore, the aircraft without ADS-B are also divided into 3 stocks based on aircraft age.

Next, using this system dynamics model, this thesis analyzed the effects of the following four incentive policies on adoption of ADS-B: (1) Acceleration of Operational Benefits, (2) Preferred Access, (3) Financial Incentive, and (4) Mandate Equipage.

First, the result of policy analysis shows the acceleration of operational benefit is effective to encourage the early adoption of ADS-B. Two types of acceleration of operational benefits were examined: High Benefit Rate type and Early Benefit type. The acceleration of Early Benefit type is more effective to encourage the early adoption than that of High Benefit Rate type.

Second, preferred access is also effective as an incentive for early adoption because only early adopters can receive the benefit of preferred access. As the adopters increase, the benefits from preferred access decrease. Therefore, the preferred access is an effective policy to encourage early adoption.

Third, the government has to be careful when financial incentives are introduced because financial incentives create the dead-weight loss. Financial incentives can be justified by the externalities such as environmental externality, safety externality, and so on. When the financial incentives can be justified, financial incentives can encourage early adoption. When financial incentives are given only to early adopters, the financial incentive becomes more efficient. When the financial incentives are given to late adopter as well, the financial incentive cannot be an incentive for early adoption.

Last, the mandate equipage is an effective way to increase adopters of ADS-B. Because some benefits of ADS-B require the equipage of all aircraft, mandate equipage in the future is reasonable. When the mandate date is moved forward, the present value of the benefit of

ADS-B increases as well as the cost increases. This thesis showed how the optimal timing of mandate equipage is figured out.

Finally, it should be noted that the numbers used in this thesis, such as the value of benefits and costs of ADS-B, optimal timing of the mandate equipage are just examples. The actual costs and benefits are likely to be different. So care must be used in interpretation of the result and further analysis should be conducted when more accurate cost and benefit estimates are available.

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