This document is a cost benefit approach to the downloading of Java software into onboard Air Traffic Management (ATM) systems via the Aeronautical Telecommunication Network (ATN). It gives insight into the requirements for the downloading of software and develop a base case with reference to the EATCHIP ATM 2000+ strategy. It then shows where additional cost have to be expected and investigates areas of benefit: the reduction of acquisition cost for airborne systems and system components, the shortening of implementation cycles and the reduction of maintenance effort.
COST BENEFIT STUDY :

JAVA ON THE AERONAUTICAL TELECOMMUNICATION NETWORK (ATN)

by

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at the EEC

Summary

This document is a cost benefit approach to the downloading of Java software into onboard Air Traffic Management (ATM) systems via the Aeronautical Telecommunication Network (ATN). It gives insight into the requirements for the downloading of software and develop a base case with reference to the EATCHIP ATM 2000+ strategy. It then shows where additional cost have to be expected and investigates areas of benefit: the reduction of acquisition cost for airborne systems and system components, the shortening of implementation cycles and the reduction of maintenance effort.
Cost Benefit Study: Java on ATN

The Project Manager’s Foreword

I think that Java on the Aeronautical Telecommunication Network (ATN) will be the most beneficial ATN application of the future. It will enable the quick, easy, inexpensive installation of single ATM applications, and even entire ATM systems, into an aircraft. Thus the use of new ATM concepts may be introduced into a high number of aircraft, possibly even overnight.

Future ATM concepts will put a large amount of software into the aircraft and the resultant upgrading of airborne avionics systems, when using traditional methods, would take a long time. As a result, any benefits to be had would only be reached after a significant number of aircraft were upgraded and flying. With Java over ATN, the introduction of new software and the benefits it brings can be immediate.

The cost benefit study is the starting point for the study of the Java over ATN concept and, will be followed by analyses of safety issues and operational concepts. In addition, a technical study has been carried out, in parallel, proving the feasibility of the Java over ATN concept. This technical study will be followed up by a small, pilot implementation.

The presented study starts using the requirements of the ATM 2000+ strategy and develops a picture of airborne avionics equipment in the coming 20 years. Special attention is given to airborne networks. It then gives further insight into the areas of the initial extra cost and the subsequent benefits that Java on ATN has to offer.

Rudi Ehrmanntraut

The Study’s Conclusion

The study has given a deeper insight into areas where cost and benefits will be encountered when utilising downloading of software into onboard CNS/ATM systems. ATN services could lead this process, thus easing the way for other systems to join in. Systems following the downloading technique will benefit from the reduced cost of the technological and other changes required to allow downloading.

Downloading of Java software for onboard CNS/ATM systems offers benefits to all institutions that are affected by the introduction of this new technology. Aircraft and CNS/ATM system manufacturers can gain a competitive advantage when offering their customers more immediate maintenance service at a lower price. At the same time Aircraft operators will profit from the better and cheaper maintenance service. They will also benefit from reduced unit cost for CNS/ATM systems especially for system upgrades, but also, for the implementation of whole systems, if they well exploit Java’s downloadability feature. This allows them to easier equip their fleet with the required avionics, needed to implement and gain the benefits of the different changes in ATM. With faster implementation cycles, aircraft operators can earn these benefits even earlier. In addition, ATM and civil aviation authorities can benefit from the fast spread of new and upgraded CNS/ATM systems, for this supports the implementation of their strategies, designed to meet the increasing demand for safe and affordable air traffic.
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Introduction

Today's avionics equipment is developed, built, sold and implemented mainly as black boxes. The equipment is expensive and takes up precious space in the cockpit. In addition, the installation of new equipment into an already operating aircraft often necessitates expensive retrofitting of the cockpit architecture. Due to high cost, innovation is slow.

Today's operating aircraft are up to 25 years old and some have not changed or have changed only little. This is especially not acceptable for future development as planned in the Air Traffic Management Strategy for 2000+ by the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP).

With the rapid increase of airspace demand new technologies become necessary to safely handle the growing number of aircraft. This is especially true for the crowded areas of central Europe. Still, the increase in capacity without lowering safety standards can only be gained, if a considerable number of aircraft operate new and enhanced systems for Communication, Surveillance and Navigation in Air Traffic Management (CNS/ATM).

Altogether the need for innovation in CNS/ATM systems in connection with the high cost of new onboard equipment gives a negative outlook for the future of safe and affordable air-traffic. Java on ATN presents itself as a contribution to the solving of these difficulties.

Java on the Aeronautical Telecommunication Network (ATN) is the synthesis of two innovative technologies. The ATN is a data communications internetwork that allows digital data connections between aircraft and ATM ground segments. It will comprise existing communication networks and infrastructures where possible. On the other hand Java has become famous in the area of another internet, often called the Internet with its well known application, the World Wide Web. Java is a programming language that is adapted to the heterogeneity of a network because it allows the execution of Java programs on the different types of machines belonging to the network. Java programs can be transported or downloaded via an internet and be executed by the receiving computer. With Java on ATN software for CNS/ATM systems can be downloaded into airborne computing systems.

Reduce Unit Cost

With downloading of software the unit that is acquired is no longer a dedicated black box. Instead, the unit can now be divided into its software, comprising the system's main functionalities, and its hardware, that can be reduced to standard processing resources only possibly required specialised input and output media.

When adding a new functionality or upgrading an existing system the required hardware might already be onboard the aircraft and the acquisition of a new black box would not be required. Together with the easier installation by downloading this should reduce acquisition and acquisition related cost for CNS/ATM components, system upgrades and eventually for whole new systems.

Shorten Implementation Cycles

The ATN and its services will be ready for implementation in 2002. However, the ATN has the capacity to also implement further services. If the airborne ATN unit is designed to handle downloadable software, new services can be integrated without effort.
New ATM functionalities, that are implemented as ATN services, then, are available to all ATN participants right after certification. Also any other onboard system utilising downloadable software can easily implement new or enhanced components. Safety and other benefits they offer can immediately be realised.

When involving all Communication Navigation and Surveillance / Air Traffic Management (CNS/ATM) systems in a software based architecture, it will be possible to implement whole new systems by downloading.

**Reduce Maintenance Cost**

Decisions on acquisition are not only based on the item's price and installation cost. Maintainability, with focus on flexibility for future upgrades, is a major aspect for every airline aiming at modern, up to date equipment. With the increasing amount of software for CNS/ATM systems software-maintenance will become more important.
Studies

Affected Institutions
For new technologies to find their way into operation, they need to convince
• aircraft operators of their efficiency or extraordinary benefits
• manufacturers of their competitive advantages
• ATM and Civil Aviation Authorities of their contribution to safe operation

Aircraft Operators
New CNS/ATM systems and system applications will have to offer benefits that exceed cost for their acquisition, implementation and operation. If they replace existing systems, they need to offer more efficiency or an extraordinary increase in benefits. Most new system will combine both aspects.

Current drivers of innovation are:
• achieving more efficiency
• achieving maximal product quality
Also mandates of aviation authorities can accelerate innovation.

1. Achieving more efficiency by reduction of Direct Operational Cost (DOC)

Typical split for DOC\(^1\)

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<table>
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<tr>
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<tbody>
<tr>
<td>crew</td>
<td>23%</td>
</tr>
<tr>
<td>fuel &amp; oil</td>
<td>28%</td>
</tr>
<tr>
<td>maintenance</td>
<td>22%</td>
</tr>
<tr>
<td>depreciation / rentals</td>
<td>27%</td>
</tr>
</tbody>
</table>

Reduced delays and new organisation of airspace and airspace operation will reduced DOC. More generally, competing CNS/ATM systems will be evaluated according to their effect on DOC. It is expected, that future CNS/ATM systems will have to offer benefits in DOC.

2. Achieving maximal product quality

Capacity growth as one of the benefits of the ATM 2000+ strategy, helps airlines to improve product quality by:
• reduced delays
• diversification of offered products: more city pairs at more occasions

Manufacturers
System and aircraft manufacturers want to offer modern, safe and efficient technology to their customers. Products should offer a better benefit cost relation than those of competitors.

ATM and Civil Aviation Authorities
This study does not further investigate on certification and safety issues. A follow up study will concentrate on this.

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\(^1\) Aviation Systems Analysis Capability of NASA, data from 93, for B737, B747, B 757, B767. The table shows the mean DOC for these aircraft.
**Technological Background**

The key technological requirements to enable a system to download software are

- the status as an ATN End-System (ES) and
- dynamic storing of software
- availability of a language that fulfils the systems performance requirements

The purpose of this chapter is to provide knowledge about current technology in

- Networking (2.2.1)
- Static and dynamic storing of software (2.2.2)
- Java (2.2.3)

**Networking**

For explanatory purposes the following types of diagrams are used

... for focus on topology & function:  
... for focus on layers and their protocols according to the OSI reference model:

- abbreviations

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<table>
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<tbody>
<tr>
<td>ES</td>
<td>End System</td>
<td>e.g. ATN services in aircraft and on the ground</td>
</tr>
<tr>
<td>IS</td>
<td>Intermediate System</td>
<td>e.g. ATN router</td>
</tr>
<tr>
<td>BIS</td>
<td>Boundary Intermediate System</td>
<td>e.g. ATN-router</td>
</tr>
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</table>

When focusing on the layers of the Open Systems Interconnection (OSI) protocols the network and transport layers will be Connectionless Network Protocol (CLNP) and Transport Protocol Layer 4 (TP4) respectively.

Please note, that the pictures do not necessarily comply with the architecture of actual ATN implementations.

**ATN Architecture**

The ATN, as planed for implementation in the year 2002, will for the first time link the aircraft to the ground via a modern datalink network. In the aircraft the ATN router and the ATN Service Unit (SU), carrying the ATN datalink services, will be installed. On the ground side the corresponding Air Traffic Control Centre (ATCC) also need the ATN-router and applications.

Airborne ATN applications communicate with their peer applications on the ground side while the data is transparently routed through the ATN. The picture below shows this interaction using Controller Pilot Data-Link Communication (CPDLC) and Automatic Dependent Surveillance (ADS) as examples.
The ATN SU as the First Airborne ATN ES

Airlines participate in the ATN using the ATN Aircraft Operator Communication (AOC). Thus, airlines have access to all airborne ATN ES using the ATN addressing and routing mechanisms.

For purposes of downloading software airlines can use ATN AOC. Instead of the usual messages software will be send and the onboard ATN router will distribute the software to its destination ES’s. Downloading will take place when the aircraft is on the ground, not operating. Downloading will not interfere with regular AOC.

AOC communication during the flight: Downloading of software via ATN AOC while not operating:
Therefore, every systems with the status of an ATN ES meets the networking requirements for downloading software. Currently, the ATN SU is the only onboard system that will meet the networking requirements for downloading software.

**Onboard Implementation of CNS / ATM Systems**

For the interconnection of onboard CNS/ATM systems most aircraft operate the ARINC 429 bus that provides a connection oriented data transfer service. On top of this a general-purpose file transfer protocol (GPFT) operates. The ATN OSI stacked is mapped on the GPFT protocol.

The following paragraph will look at the current state of interconnection between onboard CNS / ATM systems.

**Inner Aircraft System Interconnection without Networking**

There are several functionalities that require the interconnection of and data exchange between the ATN SU and the Flight Management System (FMS). E.g.

- ADS: for data exchange
- future 4D Trajectory Negotiation (TN): for data exchange
- Multipurpose Control and Display Unit (MCDU): Shared display and control unit for ATN SU and the FMS

The ADS application is designed to give automatic reports about the aircraft to the controller. While every report comprises the aircraft’s 3D position, timestamp and figure of merit, other information are optional: e.g. air vector, short term intent, projected profile, extended projected profile². Therefore, data has to be obtained from the FMS.

Current implementations use a reduced stack for the communication between onboard CNS/ATM systems, consisting only of protocols for the Physical and Data Link Layer. The Network and above layers are omitted. The interconnection of the ATN SU and the MCDU follows the same principle.

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² ATN Upper Layers and Applications, 21.9.95, p. 14
This architecture limits data exchange to the formats of messages implemented in the application itself. Addressing and other network features are not available. Nevertheless, future ATN applications to support 4D TN will require an even increased co-operation of ATN SU and the FMS and the shared display and control unit.

**Change to Networking**

To allow a network connection between the FMS and the ATN SU only the completion of the rudimental stacks is required. The implementation of the complete ATN stack allows all physically connected systems to interact as ATN ES.

The following picture shows an inner aircraft network comprising the ATN router and SU, the FMS and the MCDU. While the ADS as the example ATN data link service requests and obtains data from the FMS, both the FMS and the ADS application send data to the MCDU for display and receive input from the MCDU’s HMI.
Since the ARINC 429 has strong restrictions for networking a different subnetwork might evolve that supports networking.

With an implementation that follows this architecture, the ATN SU, the FMS and the MCDU are ATN ES. These system fulfil the networking requirements for being targeted to download software.

Conclusion on Inner Aircraft Networking
ATN services will from the start function as addressable ATN ES. Other CNS/ATM systems, especially those, that are already physically interconnected with the ATN router and ATN SU, can become ATN ES by operating a complete OSI stack. Thereby, airborne ATN ES build an aircraft intranet.

Static and Dynamic Storing of Software
On modern avionics computers the application specific software, as distinct from the system-software, is located on so called Onboard Replaceable Modules (OBRM). These modules can be plugged into the front panel of the computer Line Replaceable Unit (LRU).

To change the software, the technical personnel has to perform the following tasks:
- removal of the OBRM
- ev. loading of new software onto the OBRM in shop with a firmware data loader
- insertion of new / changed OBRM
- cross checking of Part Numbers (PN)
- unit and system tests

The safety guidelines for the exchange of OBRM are:
- may be performed only by special technical personal
- cross checking of numbers on LRU and OBRM after exchange
- build in test after exchange

Generally, the process of replacing OBRM’s needs to be in co-ordination with the airworthiness authority, that keeps the register of the affected aircraft.
The modified software needs a certain level of certification, according to the system it belongs to. In the case of user modifiable software no further certification is required.

Reasons for software changes:
They may be manufacturer driven:
• removal of design deficiencies
... or airline driven:
• airline preferences
• random OBRM hardware failures
• limited upgrades

Cost groups affected by software maintenance when utilising OBRM technology:
• personnel: technical, technical management, OBRM content provider
• material: OBRM
• time out of service

When using OBRM technology, downloading of software is not possible. This is due to the static character of OBRM memory.

To allow downloading of software, software has to be dynamically stored, i.e. it must be saveable and erasable, as well as persistent.

Java

Environment
Java software needs a special environment to be executed. To allow downloading of Java software, a system must implement the Java runtime. Java runtimes exist for most Commercial Off The Shelf (COTS) Operating Systems (OS).

Performance
For current ATN application current Java performance is sufficient.

It is assumed in this study, that by the time that downloading software for other avionics will be feasible, a language will be available that satisfies all requirements concerning
• portability
• real-time performance
• standardisation and certification to the required level
• safety.

When targeting systems that require those features, the study will refer to Java as such a language, knowing that it is, thereby, taking future development as guaranteed.
Levels of Exploitation

Development of Avionics According to ATM 2000+ Strategy

According to the ATM 2000+ strategy each transition step requires growth and enhancement of airborne equipment.

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<tr>
<td>concepts</td>
<td>route structure optimisation based on RNAV techniques</td>
<td>Limited transfer of separation responsibility from ground/controller to air/pilot</td>
<td>Further transfer of separation responsibility from ground to air</td>
</tr>
<tr>
<td></td>
<td>Introduction of RVSM</td>
<td>Initial free route airspace and operation</td>
<td>Extended free route airspace and operation</td>
</tr>
<tr>
<td>required avionics</td>
<td>RNAV (RNP 5)</td>
<td>Datalink applications to support free routes and enhanced collaborative planning</td>
<td>4D FMS</td>
</tr>
<tr>
<td></td>
<td>RVSM MASPS</td>
<td>Enhanced FMS capabilities and new HMI</td>
<td>Datalink applications to support 4D trajectory planning and navigation</td>
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<td></td>
<td>ACAS II</td>
<td>ATN</td>
<td>ASAS</td>
</tr>
<tr>
<td></td>
<td>modeS transponder</td>
<td>RNP 1 based on GNSS1</td>
<td>GNSS 2</td>
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</table>

Especially in the third step (2010 - 2015) changes are expected, that can not yet be conceptualised. The main aims are:

- increased productivity: “Re-distribution of tasks between the human and the machine and, where applicable, between air and ground” \(^3\)
- “Optimisation of procedures, processes and improved assistance tool algorithms based on the availability of more accurate data and other technical improvements.”\(^4\)

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\(^3\) ATM 2000+ strategy, executive summary p. X
\(^4\) ATM 2000+ strategy, executive summary p. X
Base Case
According to the steps of the ATM 2000+ strategy the ATN SU and other CNS/ATM systems will develop.

The following table shows assumptions for the development of
• Versions of the ATN Service Unit and their launches
• inner aircraft networking
• storing of airborne software
synchronised with the different phases of the ATM 2000+ strategy.

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<tbody>
<tr>
<td>Versions of ATN SU</td>
<td>ICAO CNS/ATM -1 package included air - ground services: ADS, CPDLC, CM, FIS</td>
<td><strong>assumed:</strong> new air - ground services: e.g. FLIPCY, DYNAV, PPD new air - air services</td>
<td>4D TN supporting datalink services <strong>assumed:</strong> other new air - ground and air - air services</td>
</tr>
<tr>
<td>Assumptions about launch of Versions of ATN SU</td>
<td>2002</td>
<td>2007</td>
<td>2012</td>
</tr>
<tr>
<td>availability of Inner aircraft networking</td>
<td>no inner aircraft networking system intercommunication omits networking by direct mapping on subnetwork</td>
<td>spread of backbone bus technologies for interconnection of CNS/ATM systems</td>
<td>no change <strong>assumed</strong></td>
</tr>
<tr>
<td>Storing of airborne software</td>
<td>static storing on OBRM</td>
<td>no change <strong>assumed</strong></td>
<td>no change <strong>assumed</strong></td>
</tr>
</tbody>
</table>

System upgrades will also be required after the adaptation to conceptual changes in ATM and advances in technology that are expected especially in the third step (2010 - 2015) of the ATM 2000+ strategy.

Further technological development and restructuring of ATM that might be found necessary after the end of the ATM 2000+ strategy in 2015 might also require system upgrades and implementation of new systems. However, this is out of the scope of this study.

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5 You can find a table of acronyms in the back of the document.
Target ATN Services for Downloading Software
The earliest date for launching a system that is enabled to download software via the ATN is assumed to be 2005.

Systems build from 2005 on can initially be downloading enabled. Otherwise, an upgrade is required to enable downloading.

Systems build before 2005 have to be upgraded to enable downloading. Hardware prerequisites for the enhancement can be met at initial implementation.

Target all CNS/ATM Systems for Downloading Software
Avionics system, other than the ATN SU, can also be involved in the utilisation of downloadable software. Only those systems will be targeted that fulfil the networking and software prerequisites.

Again there are different ways to meet the further prerequisites to become downloading enabled.
Cost

Base Case
Cost for the base case are not listed and not known. Alternatives to the base case will list only additional cost.

Target ATN Applications for Downloading Software

Changes in Design and Implementation of the ATN SU
The ATN services will be ATN ES’s and operate the full OSI stack. Therefore they initially fulfil the networking requirements for downloading software. There are no extra costs.

For the implementation of ATN services in the ATN SU airworthy dynamical storing technologies have to be introduced into avionics. Therefore, extra cost have to be accounted.

The Java runtime has to be installed in the ATN SU to allow execution of Java software. It has to be standardised to a certain degree. There will be extra cost for this.

ATN SU’s that are not initially designed and implemented to allow downloading of software have to be upgraded. This concerns ATN SU’s that start service before the estimated launch of downloading technology for avionics in 2005.

Upgrade of the ATN SU
The cost for utilisation of downloadable software for ATN services depend on design and implementation of the ATN SU.

The basic types of implementing the ATN SU are:
1. basic black box, software for ATN-services on OBRM’s, resources optimised for initial requirements
2. Computing Unit (CU) with a COTS OS and dynamic storing facilities
3. CU with COTS OS as in 2. but with expanded resources

The following steps are necessary to advance from the different types of implementation to the utilising of the downloadability feature for an expanding range of ATN services:
<table>
<thead>
<tr>
<th></th>
<th>1. black box approach</th>
<th>2. COTS CU</th>
<th>3. COTS CU expanded resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic ATN</td>
<td>installation of subnetworks</td>
<td>software: ATN stack</td>
<td></td>
</tr>
<tr>
<td>ATN Service Unit (SU)</td>
<td>software: services static storing (OBRM) wrapping: 386 processors or equivalent, avionics custom OS</td>
<td>software: services dynamic storing wrapping: at least 486 processors or equivalent, COTS OS</td>
<td>software: services dynamic storing wrapping: at least 486 processors or equivalent, COTS OS expanded resources: memory and processing power</td>
</tr>
<tr>
<td>update of ATN SU</td>
<td>cannot be updated, must be replaced with a downloading enabled COTS CU</td>
<td>installation of airworthy Java runtime expanding resources: faster processor, more memory</td>
<td>installation of airworthy Java runtime</td>
</tr>
</tbody>
</table>

After this updating of the ATN SU all three types of initial implementation can download updates of their services or new services, as long as their resources allow it.

Note, that the implementation of a COTS CU with expanded resources yields some possible disadvantages.

- **risk:** depending on the knowledge of the size of the final version and the probability of further changes, expanded resources might differ from the actual requirements of the final and finished version. In effect, resources might be too large, and thus suboptimal or to small and requiring further expansion.
- **no return on investment for additional resources until the SU becomes downloading enabled.** However, these problem domains are not new to manufacturers of avionics systems and not introduced by the new technology of downloading software.

### Organisational Changes

Today the aircraft operators organisation to manage onboard software is fit to the OBRM technology. When changing to downloading of software a different organisation of the avionics engineering will be required.

### Additional Tools

New tools have to be developed to accompany the downloading e.g.

- configuration management
- test after installation
Target other CNS/ATM System

Changes in Design and Implementation
In order to become an ATN ES onboard systems have to be physically interconnected with the ATN router and implement the full OSI stack. With evolving bus technologies the physical interconnection with the ATN router will be possible without extra cost. The OSI stack might become commercially available.

Airworthy memory for dynamical storing of airborne software, developed for the ATN SU will be available for other CNS/ATM systems.

For the Java runtime and more generally the Java language enhancements might be required increasing cost.

Miscellaneous
Organisational changes as well as development of tools to accompany the downloading will also be required. However, the basics will already be introduced by the preceding downloading enabled ATN SU. This will reduce cost for both features.

Again, advantages and disadvantages for the different ways to enable a system to download software have to be discussed for every affected system and with respect to the initial implementation. The study omits this.
Benefits
If not stated otherwise, benefits can be accounted for the single aircraft. The realisation of possible benefits does not depend on the number of aircraft equipped.

Downloading of software offers benefits at different stages of a systems lifecycle. These are especially
- introduction
- upgrading to new versions
- maintenance

Avionics have traditionally a long lifespan. Therefore, in addition to a systems lifecycle as expressed in the development of sales, the spread of a system and the systems different versions in operation have to be considered.

Reduce Unit Cost
A unit of an airborne avionics system today is a black box, where software and hardware are designed for each other and heavily depend on each other. With Java and the downloading of software the unit becomes mainly the software with certain hardware requirements, e.g. for special antennas, input and output media for the HMI, and computing resources like memory and processing. However, these hardware requirements will often already be onboard or only need expanding.

The study assumes, that the future will see “user modifiable hardware” that allows expansion of memory or the adding of another processor or exchange for a faster processor without expensive re-certification of the system or aircraft. Cost for Commercial Off The Shelf (COTS) hardware is very low and competition should ensure, that prices stay low when COTS hardware becomes certified as airworthy.

Especially system upgrades will work without acquiring a new black box. The same can be expected for the implementation of wholly new systems. Naively the study assumes, that this will reduce unit cost.

Acquisition related cost as for installation should also be reduced. To install a system or system upgrade by downloading will be easier and cheaper since it does not require time in shop and out of service or retrofitting of the cockpit architecture.

With respect to airline DOC reduced unit cost positively influence depreciation and thereby efficiency. Also, the pay off period is shortened allowing more flexibility.

Shorten Implementation Cycles

Base Case
Today it takes a considerable time to equip a considerable number of aircraft with a new system or the new version of a current system. And even that depends on how cost-effective airlines consider the system or if it is given a mandatory status.

The study expects a new version of the ATN SU every five years in synchronicity with the EATCHIP ATM 2000+ strategy. New versions will include an increasing number of services and enhanced functionalities.
The following picture shows the estimated sales of different ATN SU versions for the years 2001 to 2016, comprising 3 new SU releases in 2002, 2007 and 2012. The sales include units for:

- new and initially ATN equipped aircraft
- elder aircraft retrofit to ATN participation
- upgrades for ATN participating aircraft to the next ATN SU version

It is assumed that all new built aircraft will participate in the ATN and carry the ATN SU. It is further assumed, that aircraft build before the ATN introduction will upgrade to participate in the ATN at a rate of 5%. It is also expected that ATN participating aircraft will upgrade to the next version at the same reluctant rate of 5%.

The predicted sales cause the spread of the different versions in the following manner:

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6 numbers for new aircraft obtained from “Global Market Forecast 1997 - 2016 Confirming Very Large Demand” by Airbus Industries
The spread of the current ATN SU version is rather low while on the other hand the diversity in equipage with the different ATN SU versions in operating aircraft is high.

**Target ATN Services for Downloading Software**

When targeting ATN services for downloading lower acquisition cost and eased implementation will allow downloading enabled ATN SU lead to faster upgrade to the next ATN SU version.

Generally, all aircraft participating in the ATN could use the new software component right after certification. However an instant upgrading of all aircraft carrying an ATN SU is not realistic, since upgrading is restricted by the availability of hardware resources of the ATN SU and requirements for other CNS/ATM systems. E.g. the downloading of an ATN datalink service that supports 4D TN is possible, but not sensible when the FMS is not 4D TN enabled.

The following picture shows how the most recent version of the ATN SU will faster be spread over ATN participants.

In effect, more aircraft will be able to implement new ATN applications. The percentage of aircraft that carry the ATN SU to support ATM 2000+ concepts increases.

**Target all CNS/ATM Systems for Downloading Software**

When targeting also other CNS/ATM systems, their spread curves will show a similar behaviour. In addition, the update by downloading could now be sensible for even more aircraft due to synergy effects (see example of ATN SU upgrade restricted by FMS capabilities).

In addition the following effect will occur when enabling all CNS/ATM systems to download software:

A system upgrade enables the aircraft to reduce DOC by 0.5%.

This might be caused by events similar to

- Upgrade to fulfil requirements of second step of the ATM 2000+ strategy (2005 - 2010) allows cost savings in 2 - 3% of fuel cost. This equals a total DOC reduction of 0.7%.

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7 with reference to mean DOC as in airline chapter
• Not yet conceptualised changes in ATM structure, procedures and required avionics in the third phase of the ATM 2000+ strategy (2010 - 2015)
• Changes that go beyond the ATM 2000+ Strategy, that ends in 2015
Scenario:

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aircraft enters service</td>
</tr>
<tr>
<td>5</td>
<td>System upgrade allows cut in DOC in the range of 0.5%</td>
</tr>
<tr>
<td>15</td>
<td>System upgrade allows cut in DOC in the range of 0.5%</td>
</tr>
<tr>
<td>20</td>
<td>Aircraft retires from passenger service</td>
</tr>
</tbody>
</table>

With all CNS/ATM systems downloading enabled and the upgrade as a software upgrade, aircraft operators could upgrade their fleet in one day and cut DOC immediately. Also the required investment for the upgrade will be lower which shortens the pay-off-period. This allows upgrading of aircraft whose lifespan was formerly shorter than the pay-off-period.

In the above mentioned scenario, therefore, aircraft operators can realise the cut of DOC earlier and for a greater proportion of aircraft in their fleet.

Conclusion on Shortening Implementation Cycles
In short, the advantages of downloading software with regard to implementation cycles are:
- immediate availability of new components and functionalities for ATN SU and other CNS/ATM systems to all ATN participants
- reduced pay off period for system upgrades result in
  - increased spread of avionics required for different steps of ATM 2000+ strategy and beyond
  - more flexibility and higher efficiency for aircraft operators

Reduce Maintenance Cost
During each systems lifecycle necessity for maintenance occurs. Generally maintenance is an important group of DOC (22%, see chapter on aircraft operators). Only a small proportion of it will fall on software and software related maintenance. However with the increase of software for CNS/ATM systems the importance of software in maintenance will increase.

Cost for maintenance falls on the guilty party. I.e. in case of design deficiencies it is the manufacturers service to the aircraft operator to remove the deficiency. However, the operators organisational effort is still required. This case will be referred to as manufacturer driven modifications. In case of changes due to aircraft operators preferences and random hardware failures, the cost is solely on the operator. These cases will be referred to as operator driven modification.

Base Case
Cost split for manufacturer driven software modifications:
Manufacturers’ cost for:
- modifying the software
- loading the modified software on OBRM’s
- sending OBRM’s to aircraft operators
- ev. material cost for OBRM’s
- technical personnel for physical OBRM exchange
aircraft operators’ cost:
- time out of service
- administrative co-ordination
- managerial: organising effort is put on concurrent upgrading of the whole fleet, to allow an unified interface for the crew.

One maintenance turn in the software lifecycle comprises manufacturers and operators actions. It consists of different steps for each party:

For example, an OBRM exchange for a fleet of 6 aircraft can be done in 3 months, with an extra downtime for replacement of 0.5 h per aircraft. The 3 months include the co-ordination and administration.

With Downloadable Software
When Software can be downloaded, the maintenance turn can be reduced. Organising the distribution of the modified software becomes obsolete. On the aircraft operators side effort to organise the implementation of the modified software can be reduced to minimum. Also the implementation itself can be finished in one day and does not require time in shop and out of service.
For the implementation of a system's new version the same effect will occur. In a software-based system, the new version of a CNS/ATM system will be software. Therefore, the implementation cycle for the new version now equals the described maintenance action.

**Conclusion on Reducing Maintenance Cost**

In short, the advantages of downloading software for maintenance purposes are:

- shop independence
- no time out of service required
- reduced organisational effort
- when a fleet is affected: immediately for all affected aircraft
- effort for system upgrade reduced to reduced effort for general software modification
Conclusion

The study has given a deeper insight into areas where cost and benefits will be encountered when utilising downloading of software into onboard CNS/ATM systems. ATN services could lead this process, thus easing the way for other systems to join in. Systems following the downloading technique will benefit from the reduced cost of the technological and other changes required to allow downloading.

Downloading of Java software for onboard CNS/ATM systems offers benefits to all institutions that are affected by the introduction of this new technology. Aircraft and CNS/ATM system manufacturers can gain a competitive advantage when offering their customers more immediate maintenance service at a lower price. At the same time Aircraft operators will profit from the better and cheaper maintenance service. They will also benefit from reduced unit cost for CNS/ATM systems especially for system upgrades, but also, for the implementation of whole systems, if they well exploit Java’s downloadability feature. This allows them to easier equip their fleet with the required avionics, needed to implement and gain the benefits of the different changes in ATM. With faster implementation cycles, aircraft operators can earn these benefits even earlier. In addition, ATM and civil aviation authorities can benefit from the fast spread of new and upgraded CNS/ATM systems, for this supports the implementation of their strategies, designed to meet the increasing demand for safe and affordable air traffic.
Acronyms

4D TN 4D Trajectory Negotiation
ADS Automatic Dependent Surveillance
ASK Available Service Kilometre: an airlines transport service of 1 seat or 1 ton of freight for 1 kilometre
ASAS Airborne Separation Assurance System
ATM Air Traffic Management
ATN Aeronautical Telecommunication Network
BIS Boundary Intermediate System
COTS Commercial Off The Shelf
CPDLC Controller Pilot Data-Link Communication
CM Context Management
CNS Communication, Navigation and Surveillance
DOC Direct Operational Cost (for an aircraft)
DYNAV DYNamic route AVailability
EATCHIP European Air Traffic Control Harmonisation and Integration Programme
ES End System
FIS Flight Information Service
FLIPCY FLIght Plan ConsistencY
FMS Flight Management System
GNSS Global Navigation Satellite System
HMI Human Machine Interface
ICAO International Civil Aviation Organisation
IS Intermediate System
LRU Line Replaceable Unit
   The smallest element of a system normally removed and replaced on the aircraft while in operational status by the line maintenance crew.
OBRM On Board Replaceable Module
OS Operating System
PPD Pilot Preferences Downlink
SU Service Unit
   Abstract description of the avionics unit that holds the software to implement the data link services. Not referring to a special technology or physical architecture.