EXECUTIVE SUMMARY

SADC Regional Satellite Based Air Traffic Control TA
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The Southern African Transport and Communications Commission (SATCC) has initiated a project to identify the Southern African Development Community's (SADC's) satellite based air traffic control requirements. The goal of this project is to provide managerial guidelines and a technical roadmap for a regional implementation of satellite navigation.

This study is aimed to address the following project objectives:

- Recommend architecture to support future CNS/ATM services for both aviation and non-aviation users.

Develop program plan to satisfy current and future operational demands of all potential, local, regional and international users.

Minimize schedule risk and impact to guarantee an accurate, safe, and reliable system.

Chart a path to compatibility and inter-operability with other satellite based augmentation systems.

Develop evolutionary implementation of plan to satisfy operational benefits at lowest cost.

Develop documentation for decision-makers in SATCC nations and potential investors/financiers.

- Assist SATCC to inform members of program plan and to gain regional support for that plan.

  Design an implementation plan for the SATCC region that can be expanded to all of Africa.

EVALUATION OF CURRENT SYSTEM

The assessment of the current SATCC regional infrastructure is used to establish a baseline from which the region but also individual countries can determine the need for progression to a CNS/ATM system based on regional capabilities and requirements. The assessment was conducted through Airport/Airspace Questionnaires, Site Visits, National CAA inputs, Airline Questionnaires and different methods of Data Analysis.

The purpose of the data survey was to determine the aviation requirements on a regional basis and not to isolate the conditions of any single nation's aviation infrastructure. While a few nations were not able to respond to the survey and other surveys were incomplete, the data provided was still used to provide the basis for an assessment of regional capabilities and requirements.

The conclusions and observations presented in this report are based on the data collected using this methodology and are predicated on the assumption that the CAA's visited and the data provided are representative for the region.

All of the countries in the SATCC group have at least one international airport, from which several local operators conduct operations into outlying national airports and into neighboring countries.

The en-route structures are managed primarily by procedural separation. Radar was found mainly in the terminal areas. With the exception of only a few busy crossing points, traffic moves within the region with little restriction. The greatest problem associated with traffic flow, voiced by both service users and providers, was communications. These communications problems included both air-to ground and ground-to-ground. En-route navigation facilities appeared to be adequate; however, user concerns were considerable when availability was discussed. Users generally said they relied heavily on GPS and inertial reference systems to operate in the en-route environment. According to information available two SATCC member states have approved GPS for supplemental use.

Terminal operations, as with en-route operations, are managed primarily procedurally. Traffic density and prevailing weather in most parts of the region preclude the need for radar. Communications problems associated with en-route operations appeared to have less impact on terminal operations. Terminal navigation aids were adequate to service existing capacity but as with the enroute strata, users indicated that there were some difficulties associated with availability and calibration.

Air traffic control service across the region can be characterized as adequate, however, depending on the specific nation, the ability of the current system to accept future increases of safety was questionable. Discussions with several users indicated similar concerns that current capabilities would not be able to cope with any future capacity increases. In many cases, controllers received little or no follow-on or simulator training once certified, although the development and expansion of in-country training institutions shows the development of a promising trend. However, in many areas, proficiency is maintained mainly by traffic worked on shift, which may not be sufficient to prepare air traffic controllers to handle more demanding scenarios in the future. These issues will require the further development of training requirements and institutions.

The current regional aircraft mix includes a large variety of both modern, well equipped aircraft and older aircraft equipped with only basic avionics. Most of the major national airlines operating internationally carry FMS, inertial reference systems, and/or GPS. Discussions 'with the users indicated that most planned to upgrade their aircraft to some level of GNSS capability as avionics became available and retrofit funds appropriated. Smaller aircraft servicing local regional airports, (e.g., B-737, ATR-42) were well equipped with traditional navaids as well as GPS in many cases. General aviation aircraft and smaller commuter aircraft across the region still depend heavily on NDB and VOR facilities.

NATIONAL AND REGIONAL REQUIREMENTS AND GOALS

As Southern Africa makes an incremental transition to reliance on satellite-based guidance, the system architecture will be matched to requirements throughout the region. This will ensure that safety and service standards will be at least equivalent to those provided by traditional aids.

Regional estimates provided in the questionnaires project an average of about 19% annual growth in air traffic movements during the periods between 1999 and 2005 and a 12% increase between 2005 and 2010. On site evaluations and analysis of the navaid service life data provided in the questionnaire indicate that a majority of existing ground based navigation infrastructure are approaching the end of their service lives. Consequently, a significant service gap could emerge if no action is taken to preclude it. An initial gap analysis was done comparing current and future service requirements.

As with current requirements, future requirements are characterized in terms of phases of flight throughout the study. Future requirements are expressed as minimum requirements and are categorized by implementation phases. Minimum requirements are provided because this is a regional study and the attempt is to bring the entire region to a minimum level of service.

To ensure that system implementation is attained in the most effective manner, system implementation has been targeted for three phases:

* Phase 12000-2004 * Phase 112005-2009 * Phase 1112010-2017

These phases have been developed according to the schedules for implementation indicated by system developers. A two-year cushion period has also been allowed for new technologies to become more established. This follows ICAO's three phases of implementation except that for SATCC, Phase I starts in 2000 whereas for ICAO, Phase I ends in 2000. Therefore, SATCC's Phase III starts after ICAO's Phase III has ended.

Phase I essentially is the initiation of a transition from ground-based to space based navigation with improvements in service provided for all phases of flight except surface. Phase 11 builds on these improvements and offers significant improvements in the en-route and approach phases of flight. Phase III implementation will provide precision services to all airports. High precision services will also support more efficient terminal procedures at the busier airports. Category 11/111 approaches and surface navigation will also become standard at international airports in the third phase. These requirements were developed using regional forecasts and data from field reports characterizing NAVAID service life, maintenance issues and user concerns.

This report advises SATCC to adopt the goal of Category I precision approaches in Phases 11 for all international airports and in Phase III for all domestic airports. This counsel is based on safety and traffic flow objectives. Precision approaches are significantly safer than non-precision approaches, documented in reducing error as much as five times better.

The recommended goal for using RNP-2 for en-route navigation was extrapolated from current US test programs involved with future separation reduction criteria. At the current time, the AR region does not have a plan to introduce RNP-2 for en-route navigation as a minimum future requirement. Admittedly, forecasting requirements beyond ten years is a subjective exercise, but necessary from a planning perspective. It is expected that en-route criteria will become reduced in future requirements as aviation traffic in the AR region continues to grow.

The study indicates minimum standards for future requirements. Nevertheless, the minimum is important to establish a basis for standardization and interoperability, so that all common facilities offer a consistent base level of service. This does not establish a limitation on individual aviation organizations that may choose to exceed this standard.

A matrix was developed which indicates the team's recommendation for SATCC's future minimum requirements. Nevertheless, the basic premise of attaining supplemental means service in Phase 1, primary means service in Phase 11 and sole means service in Phase III is the foundation of the team's identification of viable navigation options and in the formation of implementation scenarios.

AVAILABLE TECHNOLOGY AND OPTIONS

The technology is broken down into the different possible elements of satellite navigation; this includes basic GNSS systems, Space Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS).

All basic GNSS systems share certain common characteristics. Each is comprised of three main components: a space segment, consisting of a constellation of satellites responsible for broadcasting positioning information; a ground segment that includes the monitoring and management of the satellite system; and finally, the user segment, consisting of all receivers accessing the system. There are presently three candidate systems for the BASIC GNSS stage of implementation, the Global Positioning System (GPS), the Global Orbiting Navigational Satellite System (GLONASS) and Galileo. SBAS systems improve accuracy and the performance of a Basic GNSS system by monitoring error levels and broadcasting a correction message from a different satellite constellation in space. The first organization to develop an SBAS has been the United States Federal Aviation Administration (FAA) with its Wide Area Augmentation System (WAAS). As its system has proceeded in development, other nations and private corporations have launched the planning of alternative systems. Under ICAO's guidance in the GNSS Panel (GNSSP) and through the Inter-operability Working Group (IWG), the international aviation community is working to ensure that SBAS is designed as a navigational system that allows like systems from other countries to integrate and form a worldwide system. Core participants include the United States FAA representing WAAS, the Japanese Civil Aviation Bureau (JCAB) representing the MTSAT Satellite Augmentation System (MSAS), ESA representing the EGNOS and NAVCANADA representing the Canadian WAAS (CWAAS).

In addition to those systems private commercial initiatives from Lockheed Martin and Boeing are underway to launch geo-stationary and/or non-geo-synchronous satellites to supplement SBAS.

The proposed Lockheed Martin Regional Position System (RPS) would consist of a twelve-satellite constellation with two satellites at six different orbital locations. The system will be globally distributed, with three sectors serving the Americas, Europe/Africa and the Asia/Pacific regions. Depending on demand, Lockheed Martin would also broadcast messages in for other SBASs, including Japan's MSAS, Russia's GLONASS and Europe's EGNOS.

Boeing Space and Defense group has also proposed the development of a sixteen (16) satellite Boeing Positioning System (BPS) to provide mobile satellite service and aeronautical radio-navigation services. Unlike the Lockheed Martin system, this system will be based on non-geo-synchronous orbit satellites.

Like RPS, the BPS satellites will be capable of carrying SBAS transponder equipment as payload, making this satellite system another alternative for SBAS transmission. The system is also designed with the intention of being used for a wider array of aviation related Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) services.

These developments are significant, since services may be bundled into more cost-effective packages (than the purchase of SBAS broadcast services alone) when this service becomes commercially available.

GBAS systems also augment Basic GNSS signals, however, they do so through a land-based broadcast. Consequently, coverage areas are smaller, but signals can avoid many of the interferences that degrade signals broadcast from space. This lends a higher level of accuracy within the range of GBAS coverage.

Currently, most nations developing plans for satellite navigation implementation regard GBAS and SBAS as complementary aspects of a comprehensive GNSS program. Much work has already been devoted to harmonizing the systems so a single receiver can work, regardless if the source of augmentation is an SBAS or a GBAS. However, GBAS installations are capable of functioning entirely independent of SBAS, although their functionality is limited to the geographic range of their signals-a range that is generally limited to VHF line of sight and power output.

Because GBAS systems are local systems for a specific airport they can be introduced individually when aging conventional systems need replacement.

The US LAAS CAT I systems will be the first available interoperable GBAS system and is planned to be available at the end of 2001.

LAAS at an earlier or later stage will be the preferred option in areas of reduced SBAS availability, high availability airports and of course at international airports which have a CATII/III requirement. A single SARPS compliant GBAS system will provide service to all runway ends with one single systems on airport property. Properly equipped aircraft may use additional GBAS features (Position, Velocity, Time) in the airport terminal area to make arrival and departure procedures more efficient. In addition, GBAS can also support surface operations by providing guidance for navigation on taxiways and gate areas.

A network of long-range LAAS systems, "Extended LAAS" (ELAAS), can provide coverage over a larger area (such as an entire nation).

Multiple technology options are listed in the study, they serve as an overview of available technology during the recommended phases of implementation. The number of alternatives was reduced to a reasonable yet meaningful set for analysis. Therefore, the strategy in this study is to define the obvious boundary choices. An example of one alternative boundary choice is a baseline alternative that will not include any satellite navigation implementation but continue with only an upgrade of the current ground based navigation systems. In addition, all architecture options and scenarios must satisfy the minimum regional requirements that were developed. Using these guidelines, the alternatives were limited to the following five architecture options for analysis:

Scenario 1 - Improve current ground based systems with no satellite navigation implementations

Scenario 2 - Implement only GBAS when needed at the airports. The future availability of additional basic satellite constellations will improve satellite navigation such that it can provide a sole means system for all phases of flight.

Scenario 3 - Implement only SBAS to satisfy the minimum regional requirements. The only exception to the requirement for Cat 11/111 GBAS in Phase III international airports since SBAS cannot meet this requirement

Scenario 4 - Implement both GBAS and SBAS late in order to learn from the mistakes made by the leaders of any technology

Scenario 5 - Implement both GBAS and SBAS early in order to obtain maximum benefit from the new improvements in technology

The five architecture options all satisfy the minimum regional requirements as defined by the surveys from the SATCC member states. Therefore, in theory each alternative is as good as the next one and the only differential is in the cost benefit analysis, which will be considered later. But to look beyond mere quantitative benefits, the study also presents a qualitative assessment of the different architectural options in order to present SATCC with additional information in order to make an informed decision as to which is best to satisfy the regional requirements of SATCC. For the assessment of additional parameters was defined, these include Technology, Operations, Political and Legal issues, Risks, Control and Non-aviation Users. Without assigning a special weight factor to the parameters, the solution of choice could be just to improve the current ground system, because this causes the least implications for Political, Legal, Risk and Control parameters. Obviously, these parameters alone should not drive the decision for a satellite navigation solution. However, they need to be considered in the implementation of any CNS/ATM infrastructure.

COST-BENEFIT ANALYSIS

Implementing satellite navigation will ultimately enable sole means navigation capability in the Southern Africa region. Because of its extremely large coverage area, significant benefits will accrue if the SATCC member nations join together in implementing a comprehensive satellite navigation system.

The implementation of SBAS and GBAS are expected to be the backbone of whatever broader CNS/ATM upgrades are underway for the SATCC region airspace. This study will look specifically at the operational enhancements SBAS will enable and the benefits from the enhancements-relieving capacity and efficiency constraints in SATCC airspace and its management-are compared with the costs of implementing the system.

ICAO's basic cost-benefit analysis model first evaluates the impact of new technology implementation in terms of the improvements that can be brought about by enhancing precision in navigation and surveillance, as well as by the gradual decommissioning of ground-based NAVAIDs. This results in cost savings and therefore monetary benefit. The precision improvements allow reduced separations and increased airspace capacity and capabilities-as well as more direct routes-all a function of improved air traffic management.

More specifically, benefits are related to the type of airspace considered. For instance, in the continental Europe and the United States, traffic densities are high. Short en-route trajectories are often a function of rigorously controlled flight paths, airport slots and approach control. In the terminal area, benefit can also be associated with shortening the average time and cost of maintaining an aircraft in the air. In the approach phase savings involve more factors, as benefits are associated with cost saved by avoiding delays, cancellations, diversions and over-flights.

Each of the five scenarios was analyzed using a comprehensive cost-benefit model for both WAAS and EGNOS configurations. In this analysis, Scenario 3 (Implement only SBAS starting in phase 11, LAAS/GBAS at international airports in phase 111) had the highest cumulative net present value. It is also significant to note that this scenario also offers the highest value to air traffic control organizations, so it represents the best possibility for future profitability.

There is a marginal benefit associated with using WAAS for this implementation over EGNOS. This is based on current equipment costs and may vary in the future, depending on how vendors actually market their products when SATCC decides to purchase a system.

There are other benefits whose utility are less tangible and cannot be fully assessed in the cost-benefit analysis. These are the more intangible safety and operational benefits that may not be directly quantifiable but they can be assessed in a non-qualitative manner.

RECOMMENDED ARCHITECTURE

Based on the cost benefits, the recommended architecture is a Scenario, where only SBAS is implemented until Phase III, when a Cat 11/111 GBAS has to be implemented to satisfy landing requirements at all international airports. It is important here to repeat that this study only focuses on the minimum regional requirements, so that some nations may want and need additional requirements Ahat is not addressed in this report. To satisfy these minimum regional requirements, the following architecture is recommended:

Phase I -Implement GPS procedures
Implement GPS/Baro NPV procedures
Install free test bed stations if provided by WAAS or EGNOS

Phase 11 - Implement Cat I/NPV SBAS
Implement Cat I GBAS at Mahe and Mauritius
Develop any required procedures

Phase III - Cat 11/111 GBAS at all international airports

It is recommended that in Phase 1, SATCC do not install any operational SBAS or GBAS ground systems. The minimum operational requirements can be satisfied with only the development and implementation of GPS and GPS/Baro NPV oceanic, en route, terminal, and non-precision approach procedures. Since it is not needed to satisfy operational requirements and to save costs, the implementation of any SBAS or GBAS should be deferred until Phase II.

However, in Phase I it is recommended that SATCC solicit offers of free SBAS reference stations for test and educational purposes. SATCC should be involved with the development and testing of the reference stations so as to learn from the test bed and be educated on SBAS and GBAS. In Phases 11, when SATCC is ready to implement, SATCC will be knowledgeable and ready to evaluate the best proposals from all of the SBAS and GBAS service providers, including possible offers from WAAS, EGNOS, Lockheed Martin, Boeing, and maybe a consortium from the GLONASS service providers. By deferring the decision to implement specific SBAS or GBAS options in Phase 1, SATCC will have more opportunities to select and choose from more service providers as the satellite navigation systems mature.

The recommended Cat I /NPV SBAS will be implemented in Phase 11 in two steps. In step one it is recommended that only four reference stations be installed, at Luanda, Mahe, Cape Town, and Mauritius. These four reference stations should provide an Integrity/Partial NPV SBAS, with the coverage as described in the section on the service volume model (page 80). In the second step, it is recommended that the SBAS expand to include an additional 16 stations to satisfy the requirements for a Cat I/NPV SBAS. The additional 16 stations are at Lubango, Saurimo, Kimberly, Durban, Beira, Maputo, Dar es Salaam, Lilongwe, Livingstone, Harare, Kinshasa, Kisangani, Lumbumbashi, Gaborone, Mwanza, and Windhoek.

Based on the success of the VSAT program within SATCC, and the reasonable costs associated with its use, it is recommended that all communications between reference stations, concentrators, and master stations use the VSAT network. It is also recommended that only reference stations are installed within the member states of SATCC. Due to the significant increase in implementation, operations, and maintenance costs for independent SBAS master stations, independent SBAS ground uplink antenna stations, and independent SBAS satellites, it is recommended that SATCCs SBAS only include reference stations that are connected to a full SBAS service provider situated outside SATCC. However, the critical requirement is that the service provider has enough resources to provide adequate coverage for all the airspace that is controlled by the SATCC member states.
If the service provider has a master station that is installed in an ASECNA member state, then it may be possible to connect to that master station. But it will be the option of the service provider. The costs and benefits of using the master station in ASECNA should be no different than a master station anywhere in the rest of the world.

It is recommended that Cat 11/111 GBAS be installed at all international airports within SATCC in Phase 111. Since it is not needed for the minimum operational requirements, only a minimum of GBAS will be required. By deferring until Phase III to implement GBAS, the costs and risk involved with any installations is significantly reduced.

As part of this study there is a need to compare WAAS and EGNOS so that SATCC can make an informed decision as to which is best for the region. ISI has been involved with both WAAS and EGNOS. ISI led the development of the WAAS test bed, the WAAS specifications and is currently supporting the FAA in the development of the operational WAAS. In the past, ISI has also helped ESA develop the specifications for EGNOS, which is very similar and based on the WAAS. A direct comparison between the WAAS specifications and the EGNOS specifications is presented in Appendix C. Both system can provide a Cat I/NPV SBAS, the only difference is the dates when those actual performance levels can be reached. EGNOS will achieve that capability in 2005, while WAAS will achieve that capability sometime after 2001, when it will have a full year of operational experience.
Both systems have designs that will eventually provide the same capabilities. Therefore, it is very difficult for SATCC to make an informed decision at this time, other than costs. In addition, the minimum operational requirements for the SATCC region does not require a decision at this time since only the development of operational procedures are needed at this time in Phase 1. In Phase 11, it is anticipated that SATCC can make an informed decision mainly because more information and operational data will be available.

TRANSITION PLAN

Satellite navigation offers significant benefits, both in terms of safety and future profitability to the SATCC regions. To do this, SATCC will need to plan its transition to all stages of system implementation. This will bring the best benefit to both aviation organizations and the greater user community.

The suggested transition plan is divided into three focus areas: institutional, technical and operational. Institutional activities focus on the process supporting developing satellite navigation. Key institutional elements include developing a program organization, establishing a legal framework and government coordination, familiarizing decision-makers with the technology and related concerns, developing an acquisition strategy and financing the project. Technical issues are concerned with activities directly associated with the installation of technologies. Key technical elements include identifying add-on requirements, establishing a test bed, refining and finalizing the technical design for architecture and decommissioning traditional navigation systems. Operational activities focus on the process of implementing the new system and setting up the systems required to make it fully functional. Operational activities include airspace management, procedure development, training staff on system usage and maintenance, full utilization of basic GNSS, avionics installation and certification, operations and maintenance and final systems evaluation and commissioning.