Assessing SATNAV Performance Using the Navigation Tool Kit

John W. Lavrakas, *Overlook Systems Technologies, Inc.*
Ted Driver, *Analytical Graphics, Inc.*
Rob Conley, *Overlook Systems Technologies, Inc.*
Seth A. Hieronymus, *Overlook Systems Technologies, Inc.*
D. Knezha, *Overlook Systems Technologies, Inc.*

BIOGRAPHY

John W. Lavrakas is a senior staff engineer for Overlook Systems Technologies, Inc. and Overlook project lead for Navigation Tool Kit. He also provides technical support to various GPS interagency initiatives, including the Integrity Failure Modes and Effects Analysis and Global Dual Monitoring Service projects. He has previously served as director of Operations Support for the GPS Support Center. Mr. Lavrakas has spent 24 years in GPS, supporting the development of the GPS Control Segment, GPS user equipment for military range applications, development of GPS performance analysis capabilities, and developing and marketing GPS-based commercial asset location systems. He is a graduate of Harvey Mudd College and the Claremont Graduate University with BS and MA degrees in mathematics.

Ted Driver is the senior navigation engineer at Analytical Graphics, Inc. (AGI). He has worked on Navigation Tool Kit for two years, having previously been the technical lead for Navigation Tool Kit at Overlook Systems Technologies, Inc. He was formerly a senior GPS Support Center operations analyst within the 2nd Space Operations Squadron (2 SOPS) at Schriever Air Force Base. He has worked in the GPS field for eight years, and designed the environment and navigation models for the GPS High Fidelity Simulator currently in use at Schriever Air Force Base. Mr. Driver received his BS in physics from the University of California at San Diego and his MS in physics from the University of Colorado. He is past Chair of the ION Rocky Mountain Section.

Rob Conley is chief engineer for Overlook Systems Technologies, Inc. He has worked in various aspects of the GPS program for over 23 years. He began his career in GPS in the GPS Joint Program Office (JPO), and has supported the development of operational requirements for Air Force Space Command and development of the Standard Positioning Service Performance Specification. He is a graduate of the U.S. Air Force Academy.

Seth Hieronymus is a staff engineer at Overlook Systems Technologies, Inc., where he has worked on several GPS analysis and development projects, including software development and software testing. Mr. Hieronymus has a BS in physics and math and a BA in history and business administration from Principia College, IL, and an MS in aerospace engineering from the University of Colorado.

Daniel Knezha is a senior operations analyst and the product manager for Navigation Tool Kit at Overlook Systems Technologies, Inc. Prior to leading the effort to create Navigation Tool Kit, Mr. Knezha served as the first director of operations for the GPS Support Center; as a senior analyst in the preparation of quarterly GPS SPS performance reports for the FAA, and supported Air Force Space Command HQ on various constellation sustainment issues. Mr. Knezha is the former Air Force chief of navigation analysis for the GPS constellation. He is a graduate of the University of South Alabama and Colorado State University, holding a BS in finance and a Masters of business administration.

ABSTRACT

As increasing numbers of users depend on satellite navigation services, it is critical that service organizations have visibility into satellite navigation performance. To date, a number of companies have developed capabilities including monitoring networks, analytical tools, and service centers. These capabilities, however, are often limited in scope, proprietary, expensive, or inadequate for overall system assessment and monitoring. Capitalizing on experience gained from assessing precise positioning service (PPS) and standard positioning service (SPS) performance for the DoD´s GPS Support Center and the Federal Aviation Administration (FAA), respectively, the authors have supported the development of an integrated tool that formalizes this understanding and meets the broader needs of the user community. This tool is called Navigation Tool Kit™.

This paper describes the tool's applications and benefits. It was developed to meet the following objectives:

- Assess past satellite navigation performance
- Assess and monitor current satellite navigation performance
- Predict short and long-term satellite navigation performance
- Assess time transfer performance
- Apply assessments to sites, regions, and positions along navigational routes for air, land, and sea operations
- Incorporate the effects of electromagnetic threats or electromagnetic interference to facilitate mitigation and remediation of GPS interference
- Provide assessments of how satellite navigation supports a wide range of user applications
- Provide visualization of spatial and time-based performance data using overlays onto map data and imagery

The Navigation Tool Kit can be used by: satellite navigation users to assess current performance, satellite operators to support management of the service, military mission planners to predict and assess satellite navigation service in a variety of threat environments, commercial aviation operations to predict and assess satellite navigation performance, and satellite acquisition and engineering organizations to experiment with various constellation configurations and user equipment capabilities.

Navigation Tool Kit is a trademark of AGI.

INTRODUCTION

The need exists today for various GPS performance assessment capabilities, all of which tie back to better means and metrics for assessing GPS performance. Improved situational awareness, the renewed focus of satellite operators on effects in the field, military needs for understanding available capability in theater, the ability to predict service availability globally, and the desire to assess U.S. Government commitments to GPS are all needs based on GPS performance. In the early days of GPS, an assessment of dilution of precision values at a site or along a route was the most that could be done. Today, users are interested in actual navigation performance under a variety of threat conditions, including intentional and unintentional jamming, degraded atmospheric conditions, and in rugged terrain.

A number of tools have been developed to improve the insight people have into GPS performance. Some of these include the following:

- GPS Integrated Analysis System (ITAS) is a software tool used to determine the effects of GPS testing on L1 (1575.42 MHz) and L2 (1227.6 MHz) frequencies on civil GPS receivers in the vicinity of a test site;
- Space Battle Management Core System (SBMCS) is a tool that furnishes warfighters with operationally relevant space planning and execution information and tools to support their missions. SBMCS incorporates a GPS Navigation Accuracy function that allows the user to predict GPS constellation navigational accuracy over a target area or site for a specific time period;
- GPS Interference and Navigation Tool (GIANT) models the performance of GPS systems in a jammed or benign environment;
- System Effectiveness Model (SEM) for the Global Positioning System (GPS) provides users with a simple yet precise means of forecasting the availability and accuracy of GPS for any global location and for any date and time;
- Tactical Tool Suite (TTS) is a GPS performance assessment tool that allows an analyst to determine GPS signal-in-space position and time performance in the past and in the future for sites and regions;
- Tactical Automated Mission Planning System (TAMPS) is a computerized method of planning and optimizing mission routes against hostile targets.

Each of these tools has fulfilled its unique mission, but often the tools are asked to go beyond their original intended purpose. What has been needed is a comprehensive tool that merges GPS performance assessment for sites and regions, route planning, threat modeling, terrain and atmosphere modeling, and visualization. Navigation Tool Kit is designed to provide all these capabilities, building on the success of AGI's highly successful Satellite Took Kit ® (STK) software.

OVERVIEW OF THE TOOL

Navigation Tool Kit is an open-architecture, modeling, simulation, operation, and analysis tool that runs on standard PCs and is designed to support the entire GPS satellite navigation (SATNAV) community. Navigation Tool Kit's graphical user interface (GUI) is specifically designed for the SATNAV community with an intuitive workflow that guides users/operators step-by-step through input and customization while ensuring high-fidelity output. Navigation Tool Kit was jointly developed by AGI and Overlook Systems Technologies, Inc. to seamlessly integrate a wide array of data from both civil and military sources.

Navigation Tool Kit incorporates the industry-standard algorithms provided in ICD-GPS-200 for interfacing between the space segment and the navigation user segment of GPS. In addition, it accepts data directly from PLGRs (Precise Lightweight GPS Receivers) and both civilian and military data services. This comprehensive commercial off-the-shelf (COTS) software gives the SATNAV community complete insight into the system's level of service—the past, current, and future performance quality of a GPS location solution—in flexible output formats, including reports, archives, graphs, 2-D map contours, and STK scenarios. Figure 1 shows a picture of the Navigation Tool Kit display.

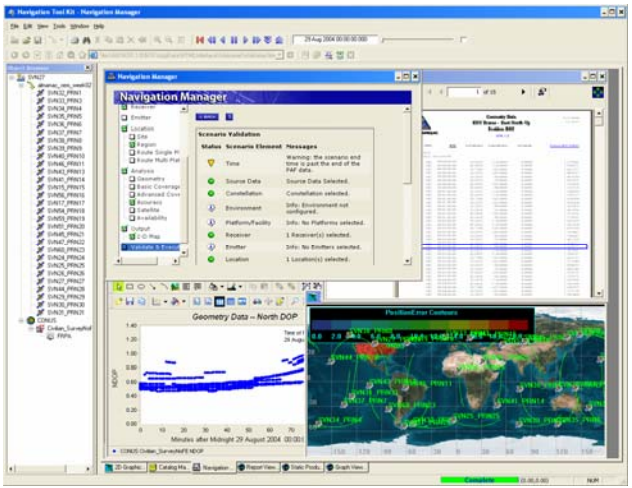


Figure 1. Navigation Tool Kit display

Navigation Tool Kit provides the following categories for defining scenarios to assess GPS performance. These are shown in the white panel on the left-hand side of Figure 2.

- Time – selects the start time and end time of a scenario and the time step used
- Source Data – points to the source data for the analysis: either a Performance Assessment File (PAF) for past, current, and short-term predicted assessments or a Prediction Support File (PSF) for long-term predictions.
- Constellation – points to the GPS almanac for defining the constellation. Also permits a user connected to the Internet to automatically download the latest almanac.
- Environment – points to various environmental features, such as ionospheric delays and digital terrain elevation data (DTED).
- Platform and Facilities – points to predefined platforms and facilities or permits user to create new ones. Platform characteristics include body masking. Examples are F-18 aircraft and U.S. Coast Guard DGPS sites.
- Receivers and Emitters – points to predefined GPS receivers and emitters or permits user to create new ones. Examples are the military PLGR, military aviation receivers, civilian recreational receivers, and civilian surveying receivers.
- Location – points to predefined sites, routes, and regions or permits user to create new ones. Examples are the continental United States and Overlook's Colorado Springs office.
- Analysis – selects analysis data to be collected including dilution of precision values and navigation errors.
- Output – selects data output options, including archiving data for later analysis, graphical reports, and 2-D map overlays.
- Validation and Execution – provides the user a single page assessment of the readiness of the scenario to run. If a category is complete, it is indicated by a green dot to symbolize it is GO. If a category has not been completed, it is indicated by a red mark to symbolize NOGO, further action is needed.

For output, Navigation Tool Kit provides several convenient formats. For regional assessments, there is a 2-D map showing time-based performance. Users can move forward and backward in time to assess GPS performance at specific times. There are also predefined charts and graphs that display summary data for sites and regions.

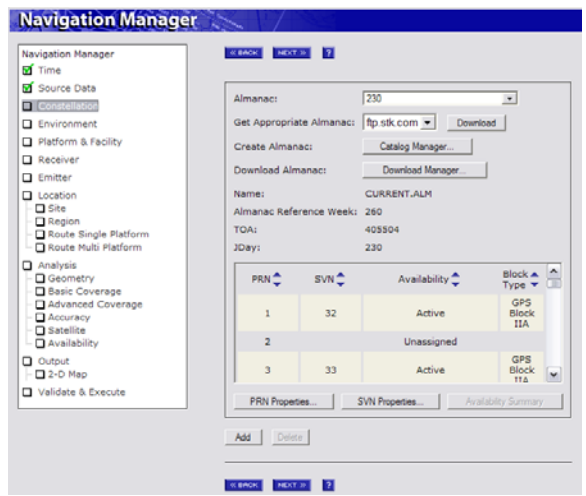


Figure 2. Navigation Manager

GPS receivers are divided into three major groups. Each group has a number of characteristics that can be set to define its functionality:

- Receiver Front End – the Front End models the received signal power and tracking loops (frequency, phase, and code) of the receiver and permits the user to assess the affects of satellite power characteristics and emitter characteristics. The Front End logic can be disabled for faster processing.

- Receiver Processing Logic – the Receiver Processing Logic models the satellite selection algorithms, including mask angles.
- Receiver Antenna – the Receiver Antenna can be set as either fixed radiation pattern antenna (FRPA) or controlled radiation pattern antenna (CRPA).

The tool allows users to perform a wide array of analyses, including outputting key data items in reports and exportable files, performing statistical computations, and creating graphic charts and displays. Reports and charts are built using Crystal Reports, providing a wide range of flexibility in creating unique reports. Some analysis features include:

- Output of key parameters – key parameters that are computed may also be output to reports or exported to data files.
- Statistics – a number of basic statistics can be performed on the key parameters, including mean, standard deviation, root mean square, minimum, and maximum.
- Availability – determine when the availability threshold criteria are met. Multiple conditions for availability can be set.
- Past/present/predicted performance assessments.

APPLICATIONS OF NAVIGATION TOOL KIT

Navigation Tool Kit was built with a rich modeling capability and a flexible graphical user interface(GUI) so that it can be adapted to a wide variety of applications by service providing organizations, system designers, and satellite operators. A detailed list of intended applications along with who will use them is given in Table 1.

Table 1. Applications for Navigation Tool Kit

Organization	Application
Mission planners	• Obtain situational awareness of GPS performance in theater • Assess future GPS performance in threat environment
Satellite operators	• Obtain situational awareness of SATNAV performance to users worldwide • Assess effect of satellite maintenance activities on users
SATNAV acquisition agents and system designers	• Assess performance under a variety of conditions by means of analysis of variations • Investigate performance using new satellite capabilities and constellation configurations
SATNAV service monitors	• Obtain situational awareness of GPS performance worldwide • Assess GPS performance against specifications and commitments

OVERVIEW OF ALGORITHMS

The algorithms implemented by Navigation Tool Kit are intended to give the user a correct modeling of the navigation error seen by a GPS receiver under specified conditions. In some cases they are different from algorithms used to compute the user's navigation state. Although in this paper we do not specifically identify the algorithms used in the Navigation Tool Kit, we do provide an overview of the algorithms incorporated into the tool and some insight into their operation.

Constellation Class

The Constellation Class contains the Satellite and Satellite Antenna Classes. The Satellite Antenna Class models the main lobe of the helix antenna using a 6^{th} order polynomial fit of the actual antenna pattern data, where the coefficients change as a function of the frequency and the satellite model. The earth coverage antenna gain is computed as a function of the GPS off-boresight angle for the earth coverage antenna. The effective transmitted power is computed as the gain times the output of the high power amplifier along the line of sight to each user for each signal transmitted by the satellite at the time of transmission. Spot beam computations have been developed, yet have not be incorporated into the current version of Navigation Tool Kit.

Satellite position is computed using the equations given in Section 20.3.3.4.3 of ICD-GPS-200. Orbital element data is taken from the GPS almanacs issued daily by the 2 SOPS. Navigation Tool Kit is able to compute revised orbital elements based on delta-velocity maneuvers conducted by the 2 SOPS, in which the magnitude of the velocity change and time of the burn for the satellite maneuver are input.

Satellite health is taken from Satellite Outage Files (SOF) obtained from various Navigation Data Services or from user selected settings.

Platform Class

The Platform Class models the antenna orientation, handoff from a primary platform to a secondary platform (each of which contains satellite navigation technology), and the weapons effect. The off-boresight angle is computed for each platform, accounting for the platform roll, pitch, and yaw angles and platform location in 3-dimensional space. The handoff method determines that the primary platform has reached the release point for the secondary platform, initializes the secondary platform error, and sets the tracking loop condition for the SATNAV receiver on the secondary platform.

Receiver Class

The Receiver Class models antenna characteristics, radio frequency (RF) tracking behaviors, and receiver tracking logic. The main steps in antenna and RF processing include computing free space propagation, computation of physical signal masks, computation of antenna efficiency, computation of received signal strength, and computation of relative dynamics.

Both fixed radiation pattern antennas (FRPA) and controlled radiation pattern antennas (CRPA) are modeled. FRPA antenna gain is computed using a 6^{th} order polynomial curve fit to a nominal FRPA gain pattern. The CRPA antenna gain is more complicated, being a function of emitter azimuth and implementing a Howells-Applebaum weighting algorithm to compute the composite gain across all antenna elements.

The Receiver Front End Class determines which signals can be acquired and tracked based on the received power. The main steps of this class are computing the receiver noise floor, computing the signal to noise ratio, computing the frequency, phase, and code tracking error, and generating a list of signals that can be tracked. In some cases the ability of the receiver to track a signal depends on its previous state and on its ability to track relevant codes. For example, if a channel on a military receiver needs to track P(Y) code, then it must first track C/A code before it can acquire the P(Y) code.

The Receiver Processor Class models the satellite selection logic for a wide variety of receiver types. It includes both an all-in-view algorithm and a best-N selection type. In addition to fixed mask angles, the Class supports adaptive masking depending on the number of satellites visible.

The Receiver Processor Class computes position and time errors based on a variety of error sources, including satellite clock and position errors, atmospheric errors (ionosphere), and computed receiver measurement noise. Satellite error data is taken from Performance Assessment Files (PAF) and Prediction Support Files (PSF) which are obtained from any of several Navigation Data Services. Dilution of precision values are computed using industry standard algorithms. Position errors are computed by taking the satellite position component of the range error along the line of sight from the satellite to the user and combining this with clock and other errors to obtain a composite positioning error. Short-term predictions are performed by extrapolating satellite errors in the PAFs by using the position error rate terms provided. Long-term position error predictions are computed using satellite error statistics contained in the PSFs.

The Receiver Class allows an engineer operating Navigation Tool Kit to modify or create receiver functional units with access to over 40 parameters, including number of channels, mask angle, cabling and low noise amplifier gains, pre-detection integration time, loop noise filter bandwidths for frequency, phase, and code lock loops.

Emitter Class

The purpose of the Emitter Class is to represent in-band interference signals to support analyses of their effect on SATNAV performance. The Class receives requests from the Receiver Class for emitter signal characteristics and transmitted power along the vector between the phase centers of the Receiver and Emitter antennas. The Emitter Class interacts with the Platform class to determine dynamic location and Emitter Antenna orientation.

Physical and Propagation Environment Classes

The Physical Environment Class handles the environmental effects due to physical phenomenon. These include digital terrain elevation data (DTED) based on DTED database information and local obscura as set by the user. The Propagation Environment Class models ionospheric delay. The ionospheric delay model uses the International Reference Ionosphere - 1995.

OPERATION OF THE TOOL

Navigation Manager

Navigation Tool Kit is a scenario driven tool—the user creates scenarios and then executes the scenarios to view the results. A scenario in Navigation Tool Kit consists of the information required to run the scenario multiple times, even on a different computer. This way a user can create a complicated scenario and give it to another Navigation Tool Kit user to run.

The user creates a scenario by pressing the New Scenario button on the toolbar. Once pressed, the Navigation Manager and the 2D map appear. The user interface is laid out so that the user can describe the scenario in a convenient way; first starting with the scenario time, then moving through the different Navigation Tool Kit required data. Each scenario is built up from predefined objects and from information unique to each individual scenario.

Once the user specifies the time, the constellation (defined by GPS almanacs using the SEM format) and the receiver and location specifics, the user specifies what type of analysis to perform with the receivers chosen.

Several types of analysis are available in Navigation Tool Kit, including:

- Geometry
- Coverage (Basic and Advanced)
- Accuracy
- Satellite
- Availability

Geometry coverage provides the user with all Dilution of Precision (DOP) values, while Coverage allows the user to look at the Receiver specific parameters and Asset availability. The user can select Accuracy Analysis to determine the navigation accuracy a specific receiver will achieve as well as gaining insight into the accuracy a satellite is delivering at any given time for a given location. The Satellite Analysis panel allows the user to analyze satellite specific performance without regard to locations—this provides information on specific satellite's behavior independent of receiver limitations and location induced errors. The Availability Analysis is a feature unlike any other in GPS analysis tools. Once the user has specified any of the above analysis types, the user can then select the Availability Analysis and specify threshold criteria that meet his individual navigation availability definitions for each of the analysis types. Then, when the scenario is run, Navigation Tool Kit will respond with a yea or nay; indicating the availability criteria specified are met or they are not. As an example, suppose the user has specified that position DOP, number of Assets, and vertical accuracy are to be output as analysis types. The user can then specify the following availability criteria:
1. PDOP < 3
2. Number of Assets > 6
3. Vertical Accuracy < 3 m

These criteria are then put together in a logical 'AND' statement and the resultant availability is either
A) yes, PDOP <3 AND Number of Assets > 6 AND Vertical Accuracy is < 3 m, or
B) No, it does not meet the criteria.

This availability can be calculated over regions and plotted over time to show animations of user-defined availability as well as being output to reports and graphs.

Scenario Validation

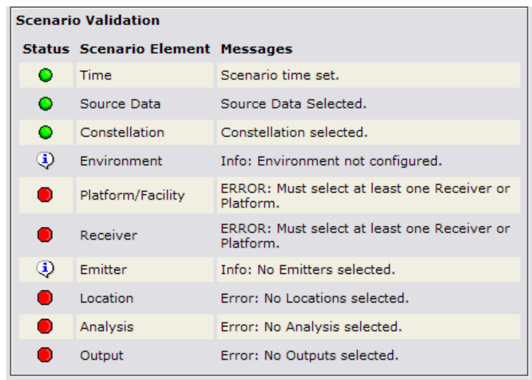
Another unique feature of the Navigation Manager is the validation and execution screen. See Figure 3. This screen provides the user a summary of the scenario about to be executed. For each main area in the scenario, the user is presented with a status indicator, as follows:

- Green: Good
- Yellow: Warning
- Red: Error
- Info: Information only

A yellow warning indicates to the user that some part of the scenario is non-standard or lacking in some way. Navigation Tool Kit allows the user to execute the scenario with warnings.

A red error indicates a critical piece of the scenario is missing and MUST be fixed prior to execution. Navigation Tool Kit does not allow the user to execute a scenario with errors.

The Information notice is provided to indicate there are items in the scenario that are have not been configured or selected, yet are not needed to run the Scenario. For example, the user may wish to assess performance in a non-hostile environment; that is, without emitters causing interference. The Information notice that Emitters have not been selected is informational, but does not prevent operation.


Scenario Validation

Status	Scenario Element	Messages
	Time	Scenario time set.
	Source Data	Source Data Selected.
	Constellation	Constellation selected.
	Environment	Info: Environment not configured.
	Platform/Facility	ERROR: Must select at least one Receiver or Platform.
	Receiver	ERROR: Must select at least one Receiver or Platform.
	Emitter	Info: No Emitters selected.
	Location	Error: No Locations selected.
	Analysis	Error: No Analysis selected.
	Output	Error: No Outputs selected.

Figure 3. Scenario Validation screen

Catalog Manager

A unique feature of the Navigation Tool Kit is that pre-defined objects can be inserted from an object catalog. The catalog is a storehouse for creating, editing, and storing objects used in scenarios. See Figure 4. The following catalog objects are included with version 1.0 of the Navigation Tool Kit:

- Almanacs
- GPS Receivers
- GPS Satellites
- Altimeters
- Primary Platforms
- Secondary Platforms
- Emitters
- Facilities
- Emitter Antennas
- GPS Receiver Antennas

Each of these catalog objects has a default, representing a basic or generic case for that type of object. For the case of GPS satellites, the GPS constellation as of July, 2004 is included as well as templates for Block II, IIA, IIR, IIR-M, IIF and III satellites. The GPS Receiver default catalog objects are: Civilian Recreational, Civilian Survey, Military 12 channel aviation, Military 4 channel aviation, Military guided munitions, and Military single-frequency handheld. Each receiver has more than 40 separate variables that can be specified, from the frequencies and codes tracked, to the orders of the tracking loop filters. While the default values for receivers will suffice for most users, there is enough flexibility in the receiver design to allow the engineer to vary parameters and analyze the results. The primary platform object allows for Altimeter and/or Inertial Navigation System (INS) aiding.

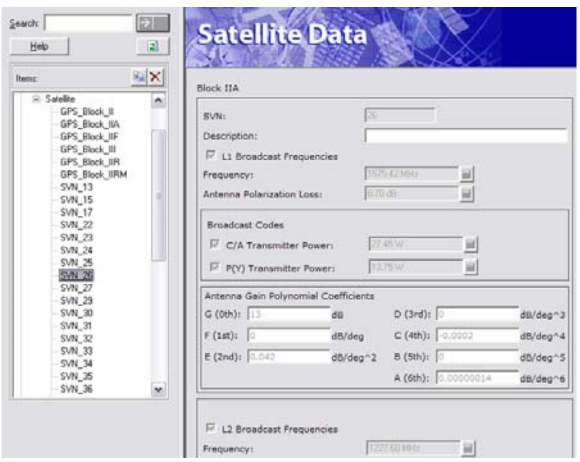


Figure 4 - Catalog Manager

Download Manager

While the user can use default objects or modify these defaults to suit their needs, there is also the ability to download objects from the AGI file transfer protocol (FTP) site: ftp.agi.com. From time to time, AGI or Overlook Systems will supply modified or new catalog objects for use in the tool. These objects can be downloaded from the FTP site directly into the user's catalog by using the tool's Download Manager. The Download Manager provides an interface for the user to easily download the data required by Navigation Tool Kit. With this tool, the user can load a catalog object from the local file system (say, supplied by a manufacturer or created by a colleague) or from AGI's FTP site. Additionally, the user may download the Scenario's Source Data from the Navigation Data Service. Here the user can pick and choose between the different Source Data file types and download those relevant to the scenario. As a convenience, the Navigation Manager has Download buttons where downloadable data is required. When the user presses a download button, the file appropriate to the scenario time and type (Navigation assessment or prediction) is downloaded from the Navigation Data Service automatically. This allows the user to concentrate on the specifics of the scenario and not on the minutiae of specific data files. The Navigation Data Service is a service that AGI provides free to users of Navigation Tool Kit. Data that the users may retrieve include past accuracy data (> 24 hours old), GPS predicted accuracy data (> 6 hours in the future) and data that defines the current state of the constellation's health. This service is provided through NavCom Technology, Inc.

Constellation Availability

In modeling navigation systems, one of the biggest problems a user faces is determining which navigation satellites are active and which are inactive (i.e., set unhealthy) at any given time. Inactive satellites will not benefit an actual receiver and thus, to be modeled correctly, must be removed from the constellation in Navigation Tool Kit as well. In Navigation Tool Kit, constellation availability as it is called can be controlled automatically or manually. The Navigation Data Service provides SOFs, which contain historical, current, and predicted outages for GPS satellites. These outages are derived from the Notice Advisories to Navstar Users (NANU) issued by the 2 SOPS and are checked for updates 24 hours a day by the Navigation Data Service. When the user creates a scenario in Navigation Tool Kit and selects a constellation to use, implementing the SOF is as simple as clicking the Availability Summary button, then the download button to get the outages applicable to the scenario. If desired, the user may override these outages, or insert outages manually for what-if analyses. See Figure 5.

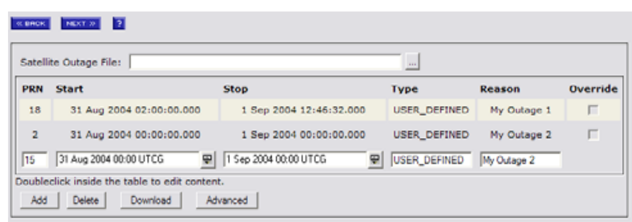


Figure 5. Satellite Outage screen

Advanced Navigation Analysis

Creating scenarios is helpful and provides useful results for the operator and the analyst. Often though, the analyst may want to go one step further and be able to perform a more advanced navigation analysis. Typically these types of analyses will center on the knowledge the analyst has on how one receiver performs, or how one specific constellation configuration provides coverage, but not how many different objects perform given the same scenario parameters. Holding all scenario variables constant, the analyst can perform analyses on permuted conditions, varying specific parameters only and then analyzing the results. The variables that can be permuted in the Advanced Navigation Manager are:

- Time
- Almanacs (Constellation Definition)
- Receivers
- Satellite Outages (Availability)

In time analysis, the user is allowed to break a long duration scenario into shorter scenarios. For example, a scenario that is one week long may be broken into seven one-day long scenarios. The benefit this gives is that information for each day may be easily determined without having to create seven one-day scenarios.

Constellation analysis allows the user to create many different constellation types by creating hand-built almanacs. One almanac may contain a constellation of GPS Block III satellites for example, while another almanac may have optimized satellite positions for today's constellation for which the user would like to verify receiver performance. With the Advanced Navigation manager, the same scenario can be run with these two almanacs (or more) to see how they affect the scenario.

Another type of permutation allows the user to see how different receivers affect the analysis in a scenario. Receivers have many parameters that can be set and the task of deciding which type of receiver to use in a specific situation can be made quickly by using the Receiver Analysis option. The user must first create the receivers in the Catalog Manager, and then choose those receivers to create scenarios from within the Advanced Navigation Analysis.

The final type of analysis allows the user to make sets of satellites unhealthy in order to "remove" K satellites at a time from the scenario (in addition to those already specified as out in the scenario itself), where the user specifies the value of K. Navigation Tool Kit will use the value of K to create $\binom{N}{K} = \frac{N!}{K!(N-K)!}$ scenarios; with each scenario having at least K satellites out at a time. In this manner, Navigation Tool Kit will create all the scenarios necessary to remove all combinations of satellites. In the equation above, N is equal to the number of satellites in the scenario's constellation minus any removed through the Constellation Availability screen.

Data Archiving

Whenever a scenario is executed in Navigation Tool Kit, a data deposit is made in the data archive. The user can review any data from the archive by using predefined reports and graphs or creating custom reports and graphs. This capability is helpful for looking at data produced with scenarios run previously—without having to run the scenario again. Additionally, the user can use another feature of the Advanced Navigation Analysis: the ability to compare any two data archives and view the differences in them. Navigation Tool Kit is delivered with a DOP difference report already defined, but the user can easily extend this to compare any archived parameters. By way of an example, the user who is comparing two different constellations may want to look at the differences in DOP as defined by each constellation. The user runs the Constellation Analysis tool and then uses the DOP Manipulation style (MNP file type) to view the differences in the DOP values for the scenario. To make the difference easy to view, the values that are different are highlighted in the report. This is a highly effective tool for understanding the effects of changes to a constellation, receivers or satellite availability.

DEVELOPMENT OF NAVIGATION TOOL KIT

Navigation Tool Kit is jointly developed by AGI and Overlook Systems. For version 1.0 of Navigation Tool Kit, Overlook defined the requirements and engineering while AGI implemented the requirements in code and maintains the baseline. This teaming arrangement has worked well; AGI is a leader in the satellite analysis and visualization software business, and Overlook is a leader in the satellite navigation industry, specifically in GPS performance analysis. Navigation Tool Kit product development started with Overlook creating a capabilities document describing all of the features a state-of-the-art navigation tool should have. Those features were then mapped to specific SATNAV applications, with each application mapped to different capabilities. A schedule was put in place and then the capabilities document was pared down to a version 1.0 list that would meet the schedule. From these version 1.0 capabilities, Overlook created a requirements document, an engineering design document, and an interface design document.

Overlook engineered most of the algorithms in Navigation Tool Kit—a process that began with algorithm development from first principles, algorithm prototyping in MATLAB™, and validation. The algorithms were then added to the engineering design document. When the algorithms were mostly complete, they were handed to AGI, where they were implemented in code. AGI took the navigation algorithms and combined them with existing algorithms already in place and in use in STK and developed the Navigation Tool Kit software. AGI provided low-level unit testing of code and Overlook provided the engineering and algorithm testing.
As future versions of Navigation Tool Kit are designed, new capabilities will be included.

NAVIGATION TOOL KIT VALIDATION

The validation process for Navigation Tool Kit algorithms involved developing a prototype in MATLAB implementing the algorithms, then validating the prototype against various existing GPS performance tools and data. The MATLAB prototype was in turn used to verify Navigation Tool Kit's performance.

Since AGI's Navigation Tool Kit is offering the GPS community higher fidelity in navigation-related analysis than has been previously available to the general public, the trick for the first point was finding validation sources we could rely on as truth. While there was no one single truth source to compare all Navigation Tool Kit analysis against, several separate validation sources were used for comparing either individual functions (orbit calculations), or groups of functions (producing DOP for visible satellites):

Where standard algorithms were implemented (e.g. those supplied in ICD-GPS-200), we compared the prototype outputs with hand calculations (using standard calculation tools such as calculators or Microsoft Excel).

Overlook Systems has a legacy product called Tactical Tool Suite (TTS) that produces some of the same analysis products we tested as part of our validation. Its outputs have been verified by comparisons of outputs with actual data and through many years of GPS analysis at the GPS Support Center. Where possible, we compared TTS outputs to Navigation Tool Kit outputs.

AGI's flagship product, STK, independently validated by AGI, was another truth source for our tests. In some cases, we used actual range test data from military jamming tests.

Along with the numbers it outputs, Navigation Tool Kit offers major new graphical capability. Both analysis and functionality had to be tested.

When testing the functionality of the tool, we ran test cases covering several operational areas including:

- The batch execution capability where multiple scenarios are executed without user intervention;

- The scenario permutation generator which creates multiple scenarios by permuting over all possible cases of a failure case (such as generating all possible combinations of removing 1 satellite from the GPS constellation, which leads to 29 scenarios);

- Testing the input of data files (almanacs, terrain data, GPS performance files, satellite outage files), to verify that Navigation Tool Kit reads in and uses the files properly;

- Testing that the tool produces the correct types of reports and graphs depending on the run type, such as site, region, and route;

- The 2-D map output (which is really the showpiece of Navigation Tool Kit)—insuring all the data is correctly displayed.

For testing the numeric outputs, our tests included:

- Basic GPS and satellite data such as: DOP, satellite positions and velocities, user position errors, and satellite visibilities under various conditions including terrain, receiver tracking, and jamming;

- GPS receiver-calculated outputs such as: signal to noise ratio (C/N0), jamming to signal ratio (J/S), and receiver noise;

- Verifying operation for different types of locations (sites, regions, routes);

- Testing that the accuracy and availability produced expected results..

SUMMARY

Navigation Tool Kit is an advanced satellite navigation performance analysis tool for assessing performance in various environments, including high and low dynamic operation under a variety of threat conditions. It incorporates high fidelity RF and receiver modeling to reflect the conditions experienced at satellite navigation receivers. Navigation Tool Kit will provide needed capability to a number of applications, including mission planning, GPS modernization and architecture evaluation, GPS service monitoring, and satellite operations.

REFERENCES

1. ICD-GPS-200C, 14 Jan 2003, Navstar GPS Space Segment / Navigation User Interfaces
2. AGI. Web site: www.agi.com/ navigation