MP99W0000270

MITRE PRODUCT

The Concept of Path Objects: Making the FMS More Useful

December 1999

Dr. John N. Barrer

Center for Advanced Aviation System Development
McLean, Virginia

MP99W0000270

MITRE PRODUCT

The Concept of Path Objects: Making the FMS More Useful

December 1999

Dr. John N. Barrer

MITRE-Sponsored Research
Dept. No.: F082

Project No.: 02MSR055-B2
This document has been approved for public release; distribution unlimited.

Center for Advanced Aviation System Development
McLean, Virginia

MITRE Department Approval: ______________________________
Melvin J. Zeltser

MITRE Project Approval: ______________________________
Dr. Glenn Roberts

Table of Contents

The Concept of Path Objects: Making the FMS More Useful

Dr. John N. Barrer
The MITRE Corporation
Center for Advanced Aviation System Development

Presented at the
ATA-FMS Task Force
December 16, 1999

Objective: Make the FMS (RNAV) More Useful in an Automated World

- The utility of the FMS can be increased significantly by addressing problems associated with
  - The complexity of the pilot-FMS interface
  - The increasing size of the FMS database
  - Limitations on the flexibility of RNAV routes
- The Concept of Path Objects offers a simple 'path language' for expressing FMS/RNAV routes, which should
  - Simplify the pilot-FMS interface
  - Reduce the size of the pre-stored database
  - Offer a means to have dynamically generated random 3D RNAV capability (primarily) for terminal area operations

The current Air Traffic Control (ATC) system is not making full use of the capabilities of advanced Flight Management Systems (FMSs) and Area Navigation (RNAV) systems. This underutilization is due in part to the difficulty for the pilot in altering the flight path—it is very cumbersome to key in waypoints while flying an aircraft.

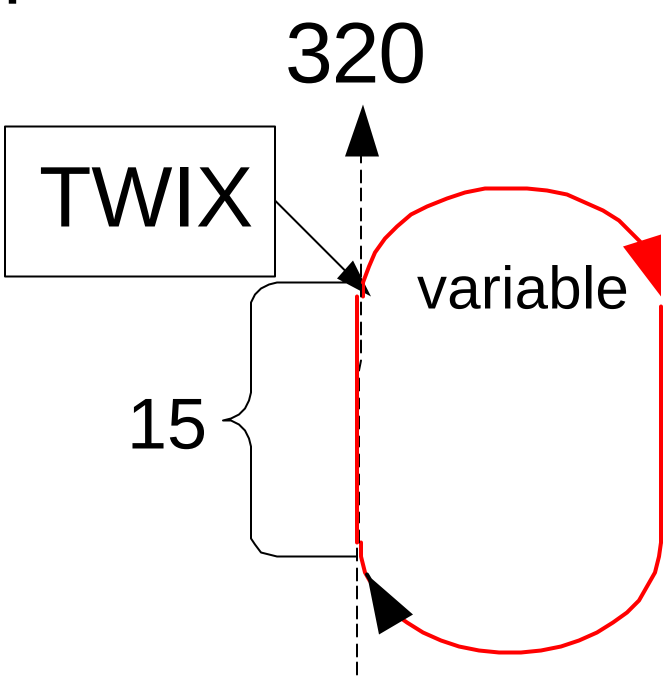
The current plan is to increase the number of pre-stored routes; however, this has the drawback of increasing the size of the FMS/RNAV database, which is updated every 28 days. Moreover, even a large number of pre-stored routes does not provide complete flexibility.

The Concept of Path Objects (POs) offers a simple *path language* for expressing FMS/RNAV routes that is designed to simplify the pilot-FMS interface. The ability to dynamically generate routes could reduce the size of the pre-stored database and offer a means to have dynamically generated random three-dimensional (3D) RNAV capability (primarily) for terminal area operations.

Current Uses of Flight Management System (FMS)

Currently, pilots can use the Flight Management System (FMS) to fly patterns such as holding patterns by entering only a *few* key *parameters* that are then used to *construct* the flight path

To get started, think of POs as an extension of the “holding pattern”



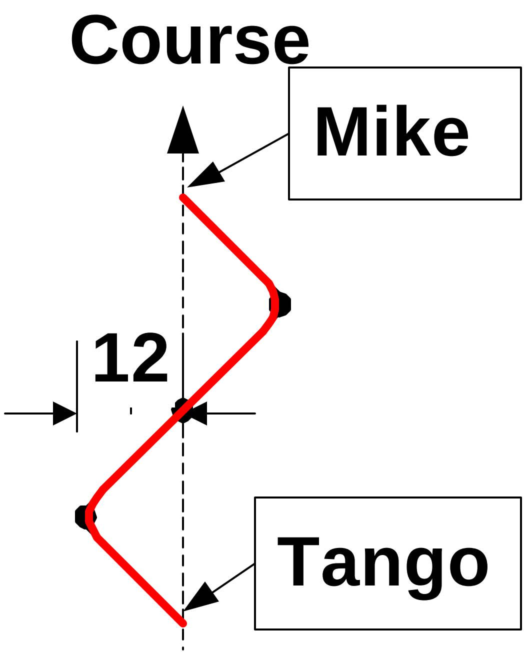
At present, a pilot can use the FMS to fly patterns such as holding patterns by entering only a few key parameters that are then used to construct a flight path. The pilot enters the holding point, course, and length of each leg. The FMS or RNAV then computes the pattern and executes the instructions.

POs can be thought of as generalizations of that idea … store the pattern in the aircraft so that it can be identified by only a minimal number of parameters.

When the author was explaining this concept to a former controller, the controller said that he had used a similar concept in the early 70s while controlling traffic going into Los Angeles. By prior agreement with the pilots of certain airlines, the controllers had established a convention for delivering instructions for a delay maneuver. If the controller said “delay left, one minute,” that meant that the aircraft was to turn left 30 degrees, fly one minute, turn right 60 degrees, fly two minutes, turn left 30 degrees, and rejoin the route. That convention saved issuing and reading back two vectors per aircraft.

Path Objects: Other Patterns That Aircraft Could Fly

For example, an 'S-turn' could be programmed in a similar fashion, in an FMS or any GPS/RNAV unit



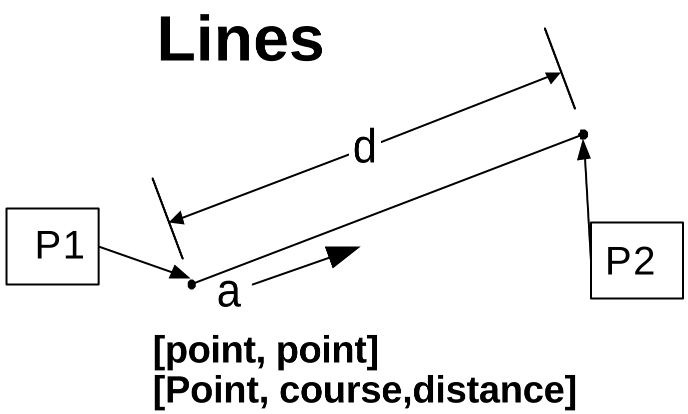
[STL1, Start, Stop, Width]

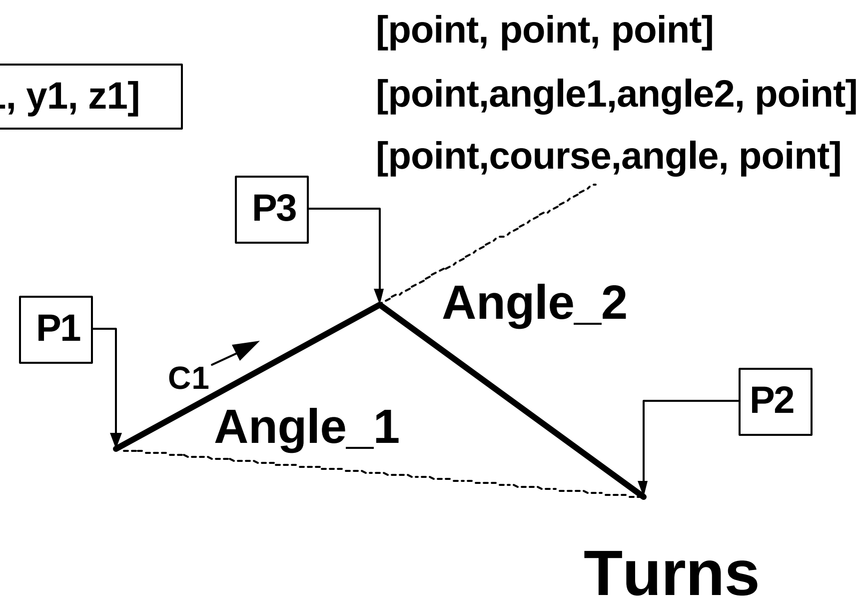
The notion of a path-stretching PO is shown here. This concept is similar to the anecdote about the delay maneuver used in Los Angeles. The idea is that an aircraft traveling from **TANGO** to **MIKE** must insert an *S-turn* maneuver 12 miles off course between **TANGO** and **MIKE**. By specifying the deviation, the maneuver is completely defined.

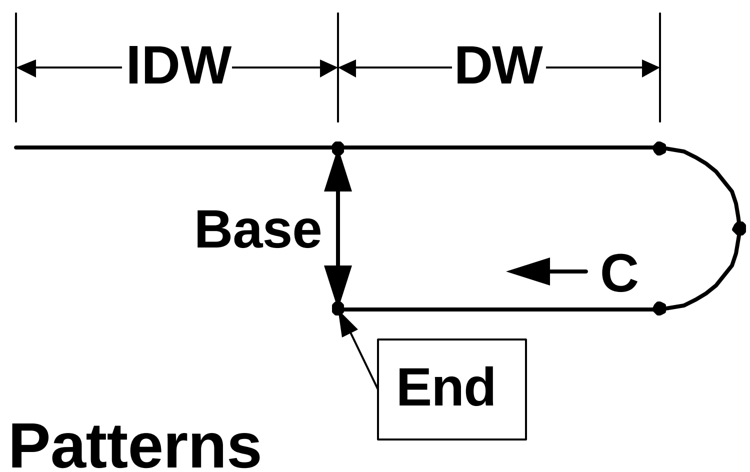
In addition, once the path is defined, the extra distance flown as well as the added time required to fly it can be calculated. Alternatively, an ATC application may know how much time or distance it wants to add, and then construct the deviation required to achieve it. Or the FMS could have a function that inserts a delay of exactly so many seconds by calculating an s-turn that achieves that objective. The pilot could simply enter a “90-second delay” command and the s-turn would be calculated and transmitted according to a pre-defined convention.

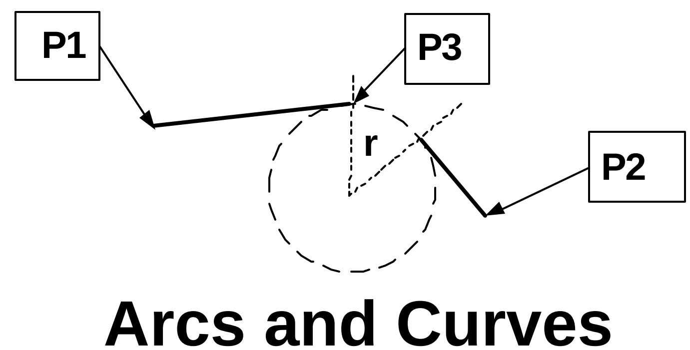
Types of Path Objects: Lines, Turns, Arcs, and ATC Patterns

P1 = [x1, y1, z1]









The set of basic POs will include lines, turns, and arcs.

For example, if a line's path is called "L1," then it only needs two points to implement it, and the simple notation, [L1, **P1**, **P2**], where **P1** = (x1,y1,z1) and **P2** = (x2,y2,z2) completely defines the path. The fixes—**P1** and **P2**—are 3D fixes using latitude, longitude, and barometric altitude. The PO in this case consists of the instructions (stored in the computer under the label 'L1') and the two parameters (**P1** and **P2)**.

Arcs may be segments of a circle, parabola, or other curves. The turn radius object could also be useful in a *free flight* setting if an aircraft wanted to convey to the ground that it was going to deviate around a thunderstorm.

In addition, some commonly used ATC maneuvers will be included:

- The hold is already there and will be augmented by:
    - *A traffic pattern*
    - An s-turn
    - A procedure turn
    - Standardized arrival and departure paths

- The traffic pattern shown can be defined by:
    - A fix
    - A course
    - Three adjustable dimensions:
        - The initial downwind (IDW)
        - The downwind (DW)
        - The base, which is the width of the pattern

Characteristics of Path Objects vs. FMS Routes

It is expected that there will be fewer than 20 POs

By specifying the parameters, the aircraft will be able to construct any of the (thousands of) routes stored in the FMS today

The path objects are shapes that exist independent of location (FMS/RNAV routes are strings of waypoints)

Table look-up links POs to any desired ‘Fixed Routes’

Path Object Concept allows *dynamic alteration* of FMS/RNAV routes: maintaining precision while adding flexibility

A ‘Path Object Processor’ (POP) is needed to convert between aircraft trajectories and their representations as path objects

Pilots (FMSs) will fly POs and routes will become strings of POs

Controllers will issue/alter POs—not give radar vectors

The use of POs could reduce the size of the database necessary to represent the fixed routes of the world. There would be a simple data table to link named routes to the POs that define them. PO shapes are defined independently of their location. Consequently, an aircraft with RNAV capability, such as GPS, need only carry these shapes with it to be able to fly any FMS route anywhere in the world. The control system can dynamically change FMS routes by changing only the relevant parameters rather than a string of waypoints.

However, the most important aspect of POs is that, once an aircraft is **established** on a PO segment, the PO can be modified by simply changing one or more of the parameters that define it. This PO feature offers increased flexibility through dynamic alteration of RNAV routes with minimal increase in workload. It also offers a tremendous increase in flexibility over the current pre-defined FMS routes that must be loaded into the FMS prior to take-off. POs are based entirely on RNAV.

Another important change would be that controllers could use POs rather than radar vectoring to alter flight paths. The use of POs could maintain precision in path definition while reducing workload. A single PO can replace several vectors and could be issued prior to an aircraft's reaching the point where the PO segment begins.

Operational Objectives of the Use of Path Objects—Airside Perspective

- Pilot's Perspective
  - FMS will be easier to use for maneuvering
  - Improved Situational Awareness by
    - Eliminating radar vectoring
    - Always displaying entire path to runway
    - Standardizing patterns worldwide
  - Improved communication
    - Less time to communicate changes
    - Common "Path Language"
- Airline
  - More use of FMS's optimization features
  - Smaller FMS NAV Database (lower maintenance)
  - Improved terminal area operations
  - Improved training requirements

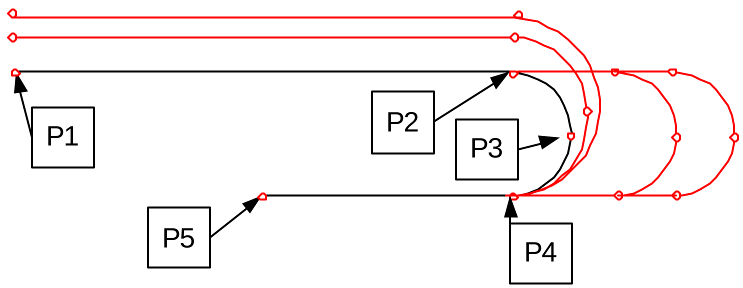
From the pilot’s perspective, the objective of POs is to make the FMS easier to use for maneuvering in the transition and terminal area. In addition, it is expected that the use of familiar POs will improve situational awareness by eliminating the need for radar vectoring and by having standardized patterns worldwide. Since the entire path to runway is always known, the pilot would know how to configure the aircraft as the flight progresses.

Using a common *path language*, POs are also expected to result in improved communication by requiring less time to communicate changes to the flight path.

There are also expected benefits to the airline or aircraft operator because of having the FMS in the control loop at all times. Because of the standardization of procedures, it is expected that airlines would:

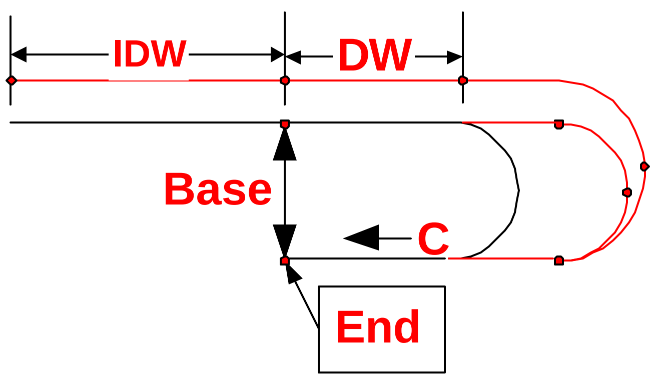
- Get more use of the FMS’s optimization features
- Be required to maintain a smaller FMS NAV database
- Improve their terminal area operations
- Realize improved training requirements

‘Multiple-Fixed’ Vs. ‘Flexible’ FMS Routes: Reduced Size of FMS Database



- “Fixed” FMS Routes require more storage than POs
- No ‘real-time’ flexibility because they have to be pre-stored in FMS

All of the above fixed routes can be generated from a single PO



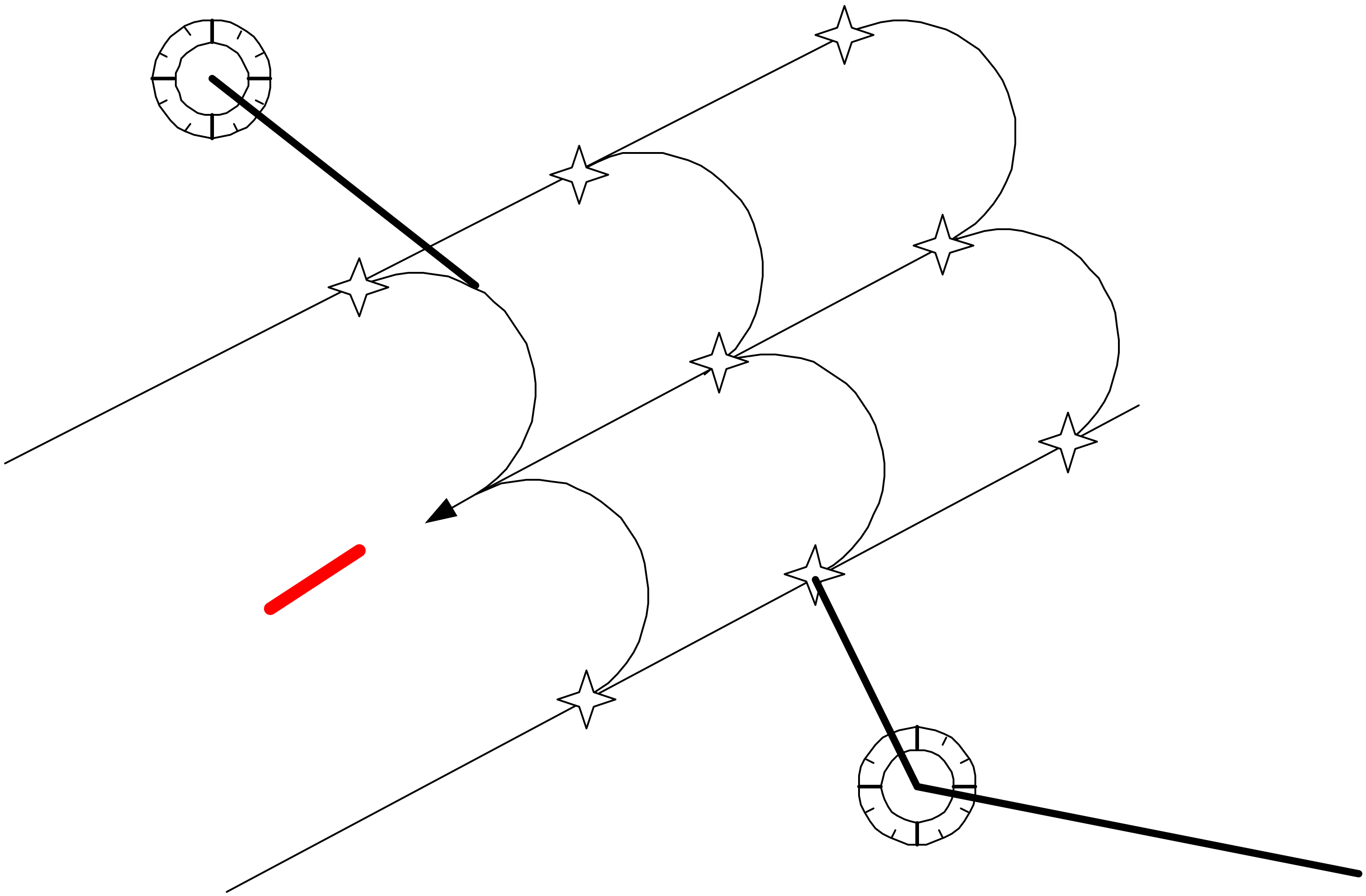
- “Flexible” FMS Routes are compact
- Routes do not have to be pre-stored (of course, PO is stored)

While it is possible to publish many precalculated routes and store them in an aircraft's FMS, doing so provides only a limited amount of flexibility while increasing the size of the FMS database.

The use of POs has the potential to permit the dynamic alteration of FMS routes and to increase flexibility while maintaining the integrity of the intent information without the proliferation of fixed, predefined FMS routes.

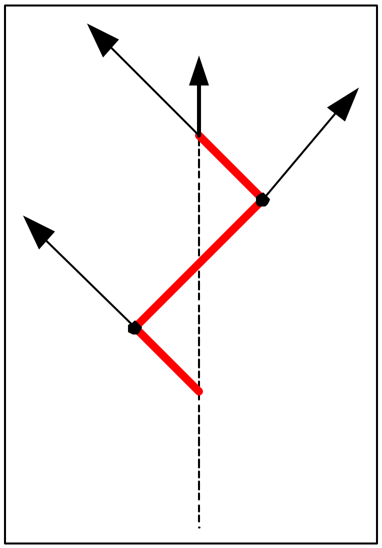
The phrase that is being used to describe this capability is "dynamically calculated random 3D RNAV routes."

FMS Routes Are Starting to Appear on Approach Charts



Because the use of FMS-based RNAV routes has clear operational advantages, airports are starting to create and publish these routes. The picture shown on this slide is of FMS transitions into the airport in Frankfurt, Germany. However, as noted in the previous slide, all of these routes could be generated dynamically without having to publish all the alternatives on one page.

Path Objects Vs. Radar Vectoring

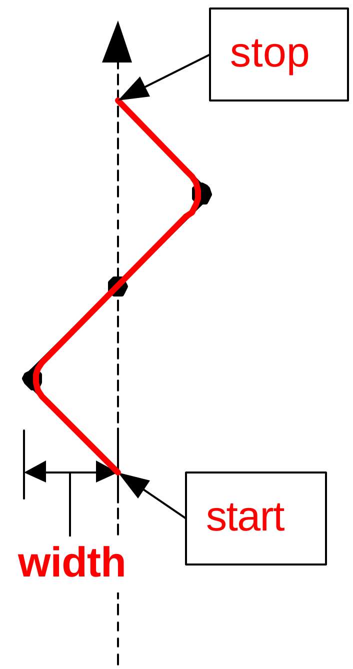


3 vectors
produce s-turn

Aircraft and automation lose intent information

Multiple instructions for simple maneuvers increase workload

[STL1, start, stop, width]



Path Objects compactly express an aircraft's intended route

Can easily be changed for operational reasons

POs are a compact, flexible, and precise expression of intent

MITRE CAASD

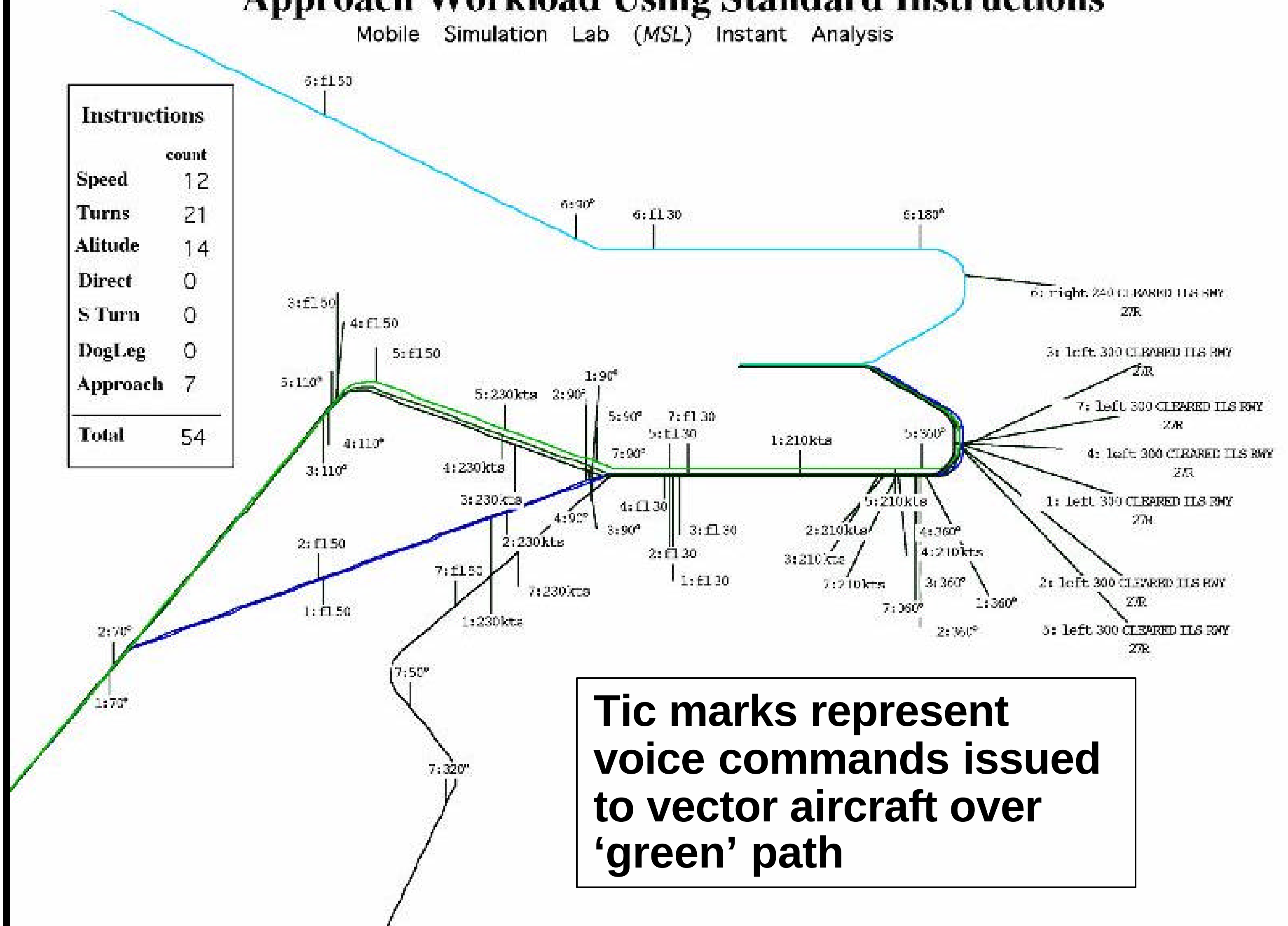
It is expected that there will be decreased workload when using POs rather than radar vectors. In this example of an s-turn, the control system (automated or manual) must issue three heading changes to instruct an aircraft how to fly an S-turn. In addition, the instructions must be timed so that they are issued when the aircraft needs to fly the turns.

With POs, the control system need only issue one command, and this can be at its convenience, anytime before an aircraft reaches the starting point. With POs, moreover, the control systems on the ground and in the aircraft retain full knowledge of that aircraft's intent.

Pilots will gain increased situational awareness by being on FMS routes and flying familiar patterns expressed as a simple series of POs. As controllers and pilots become familiar with these POs, vectoring will be significantly reduced, if not eliminated.

Approach Workload Using Standard Instructions

Mobile Simulation Lab (*MSL*) Instant Analysis



Instructions

	count
Speed	12
Turns	21
Alitude	14
Direct	0
S Turn	0
DogLeg	0
Approach	7
Total	54

Tic marks represent voice commands issued to vector aircraft over 'green' path

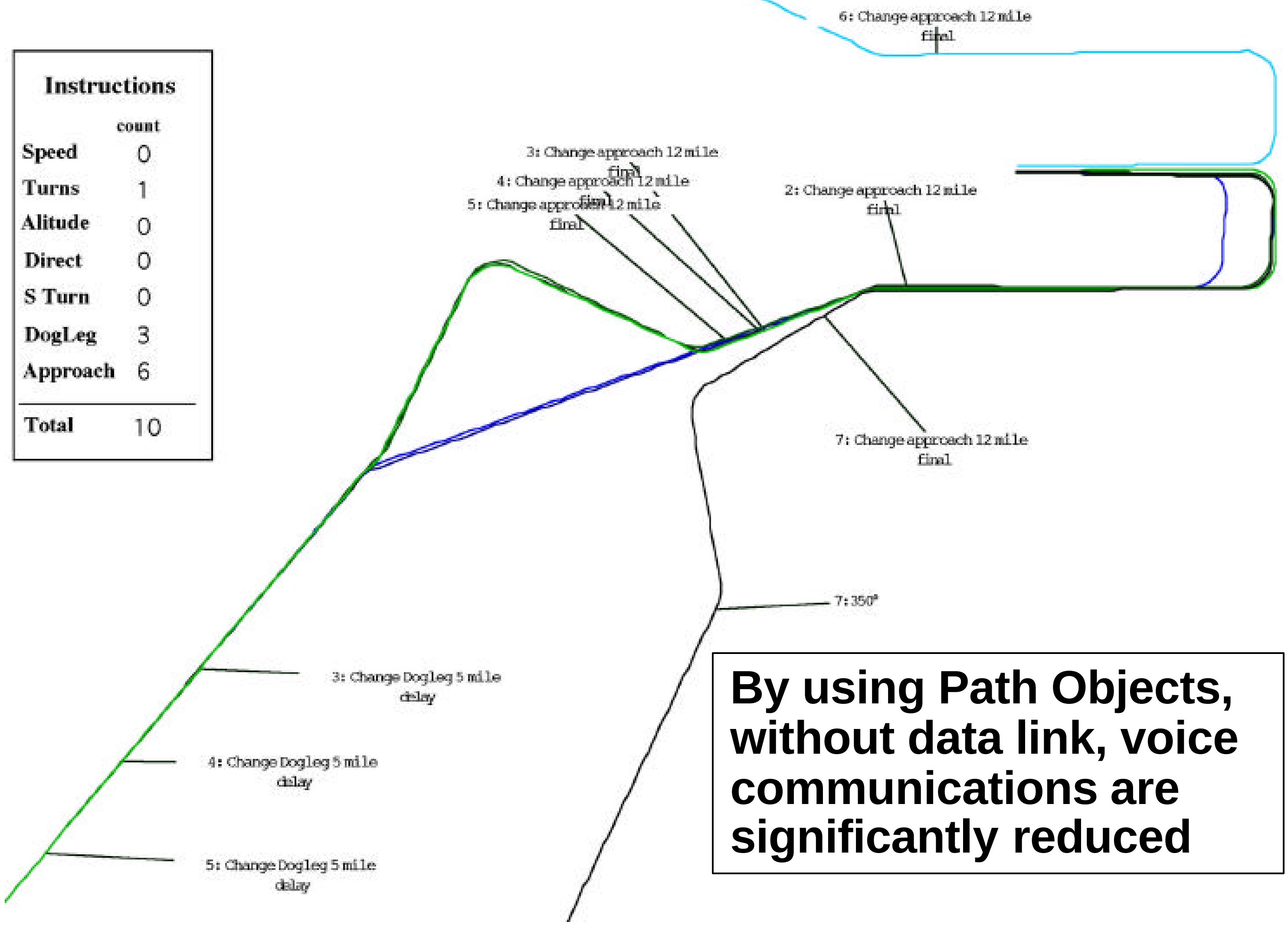
This is a representation of the results of a computer simulation conducted at MITRE. A published FMS/RNAV route brings aircraft to the downwind leg of an airport's traffic patter (from the lower left along the blue line).

In this example, a pop-up aircraft arrives, and the controller wishes to create a gap in the arrival stream to accommodate the pop-up. Each tic mark represents a voice command issued by the controller to the aircraft in the arrival stream, directing them to follow the 'dog-leg' and return to the downwind leg.

In the next slide, POs are used for the same scenario.

Approach Workload Using Path Object Instructions

Mobile Simulation Lab (*MSL*) Instant Analysis



Instructions

	count
Speed	0
Turns	1
Alitude	0
Direct	0
S Turn	0
DogLeg	3
Approach	6
Total	10

By using Path Objects, without data link, voice communications are significantly reduced

In this scenario, the aircraft in the arrival stream are issued a PO command to execute a particular PO maneuver that takes them off the nominal route and returns them to the original route. Both the FMS and the ground systems have knowledge of the precise path that is desired, and the workload involved in exchanging that information is significantly reduced.

Operational Objectives of the Use of Path Objects—ATC Perspective

ATM Perspective

- Common ‘Path Language’ de-couples ‘functions/applications’ development from FMS development
- Easier route designs (less reliance on paper-based products)
- Only need certify PO algorithms once (faster development cycle)

Controller Perspective

- Maneuvering by POs, rather than radar vectors, reduces communications workload and surveillance workload
- Increases compliance with instructions
- Maintains situational awareness in automated environment
- Provides simple interface for modifying FMS instructions
- Allows FMS routings with partial data-link equipage
- Encourages FMS-ATM integration

The PO concept offers advantages to the ATM developers, as well. The existence of a common path language de-couples *functions/applications* development from FMS development. An ATM developer can calculate flow management algorithms for using path control in the terminal area without having to worry about modifications to the FMS. The instructions from the ATM algorithm can be communicated to any aircraft using POs.

This would also lead to easier route designs with less reliance on paper-based products. In addition, the certification efforts could be directed to an aircraft's ability to fly POs, rather than certifying that aircraft to fly each new traffic flow management pattern. It would only be necessary to certify PO algorithms once, which would result in faster development cycles.

From the controller's perspective, it is anticipated that maneuvering by POs rather than radar vectors could reduce the communications and surveillance workloads. By keeping an aircraft's FMS/RNAV system in control of the flight path definition, use of POs should result in an increased compliance with instructions. In an automated world, the controller could maintain situational awareness by assigning aircraft to POs rather than strings of waypoints. Use of POs could also provide a simple interface for modifying FMS instructions.

‘Functionality’ Can Be Added to FMS and ATM, Independently

Path Objects

Aircraft Control Functions:

- Maneuvers
- Delays
- Patterns
- Fuel management
- Dynamic routing

Air Traffic Control Functions:

- Merging
- Sequencing
- Metering
- Separation
- Conflict Resolution

By having a common *path language*, ground automation systems development would not require modifications to the airborne components, and vice versa.

Thoughts on Initial ATC Applications: Transition Slowly to Full Automation

- **ATIS/Broadcast mode in terminal area to adjust**
  - **STARS for weather, traffic, noise, airspace changes**
    - **For example, if a thunderstorm blocks normal STAR, ATIS updates arrival information by inserting a 'dog-leg' to avoid TS**
  - **Departure routes to intercept airways or en route course**
- **Simple path objects as a substitute for radar vectoring**
  - **"S-turns" rather than holding (min. path extension)**
  - **Downwind extensions (better spacing)**
  - **Traffic pattern dimensions (flexibility)**
  - **'Dog-leg' (*deviate-from* and *return-to* course)**
- **ADS-B enhancements**
  - **Bit-encoding of simple POs to enhance intent information**
- **Applications to *free flight***

The benefits of POs increase as equipage increases. Initial applications would be simple and would replace existing functions. Arrival and departure information, currently provided by ATIS, can be made more flexible by referring to POs. Controllers can gradually replace radar vectoring with PO commands.

Automatic Dependent Surveillance-Broadcast (ADS-B) may possibly be enhanced by using a bit-encoding for common POs. For example, the code 01010 might express the fact that an aircraft was going to remain on its current course for more than 100 miles, and 01111 might mean that it will turn right at the next waypoint by more than 30 degrees.

This technology preserves the free-flight attribute of *freedom of route* by offering flexible arrival and departure routes to ensure that one can always be constructed that closely matches the user-preferred path. It also makes it easier for a pilot to communicate requests for changes to his aircraft's route.

Path Objects Are Compatible With ARINC 424 Path Types and "Routes"

Path Objects can be *mapped* to existing FMS formats

- **For example, "Traffic Pattern" [TP, end, C, Base, IDW, DW] is composed of a semi-circle of radius 1/2 Base, and three straight segments**
- **ARINC 424 Path Type "FC" is a straight segment and path type "RF" is a fixed-radius turn**

"Routes" can be stored as *mappings* to Path Objects

- **For example, "Heathrow One Arrival" may be composed of two path objects**
  - **Turn [T1, fix1, fix2, angle]**
  - **Traffic pattern [TP, end, c, base, idw, dw]**

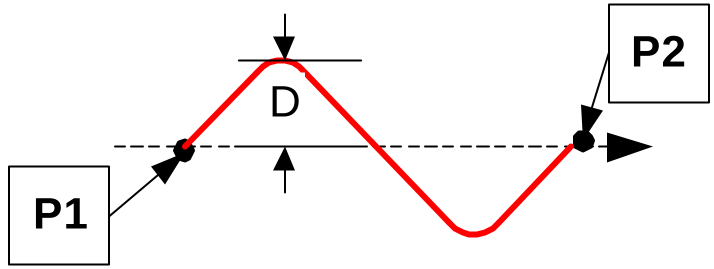
The concept of POs is compatible with current standards. Consequently, there can be a smooth transition from current technologies to one in which the majority of aircraft are communicating their intentions using POs and data link.

ARINC 424 is a standard that describes how segments of FMS routes could be stored in the FMS database. POs, which are operationally oriented, could be mapped into these expressions for processing by the FMS.

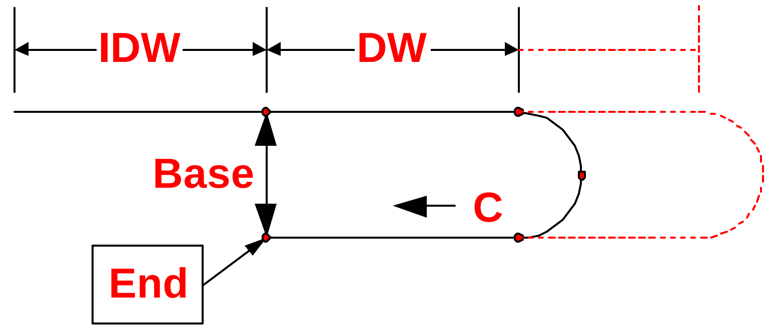
Existing *routes* can be expressed as sequences of POs. As ground-based navigational references are replaced by uniform latitude-longitude references, these routes will benefit from the compactness of POs.

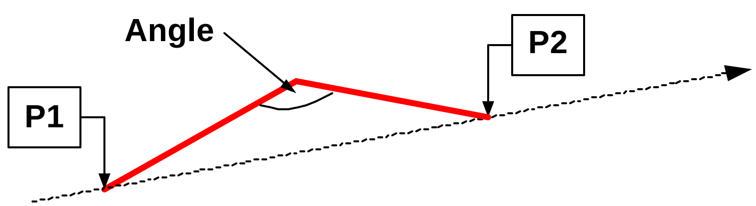
Proposal for the First Four Path Objects

S-Turns

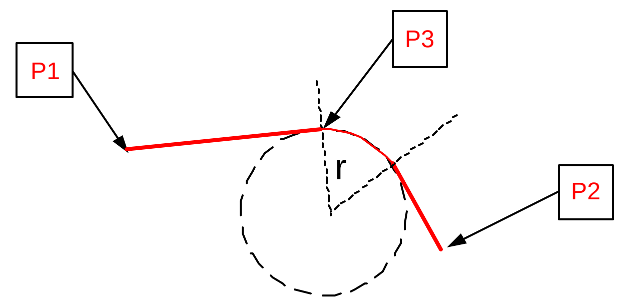


Extensions





Off-&-On Course



Controlled Arc

Initial POs could be simple. They could be used in a voice communications environment as an alternative to radar vectoring.

The first three POs to be implemented would be an s-turn, a traffic pattern, and a *dog-leg*, which is a single command to leave the route and return to it according to precise instructions.

With these commands, the controllers and pilots could begin using the FMS for terminal area maneuvering while transitioning to a fully-automated ATM system.

Conclusion: The Benefits and The Challenge

- The Path Object concept has the potential to solve many problems facing the world's future ATM systems
  - It offers a common 'language' for expressing intent
  - It solves practical problems related to
    - Maintenance of navigation databases
    - Commonality of procedures
    - Situational awareness
    - Charting and cockpit display of information
    - Efficiency of transmission
  - It presents new opportunities for ATM developers
  - It offers a way to use ATM functions during the transition to full data-link equipage
- <u>An international standard for Path Objects is needed</u>

The Path Object concept has the potential to solve many problems facing the world's future ATM systems. It does this by *incorporating an aircraft's FMS/RNAV system into the architecture of ATM systems*, thereby making the FMS more useful to the airlines, the pilot, the controller, and the ATM system.

It offers a common *language* that can reliably express complex information about an aircraft's intended path.

It solves practical problems related to the maintenance of navigation databases, commonality of procedures, situational awareness, charting and cockpit display of information, and efficiency of transmission.

It presents new opportunities for ATM developers by simplifying the solution set (flight paths), and it offers a way to use ATM functions with partial data-link equipage.

An international standard for path objects is needed.

Glossary

Glossary

ADS-B	Automatic Dependent Surveillance-Broadcast
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
CAASD	Center for Advanced Aviation System Development
FAA	Federal Aviation Administration
FMS	Flight Management System
MSL	Mobile Simulation Lab
NAV	Navigation
PO	Path Object
POP	Path Object Processor
RNAV	Area Navigation
STARS	Standard Terminal Automation Replacement System