Design Considerations for Shortcut Path-Based Time Recovery

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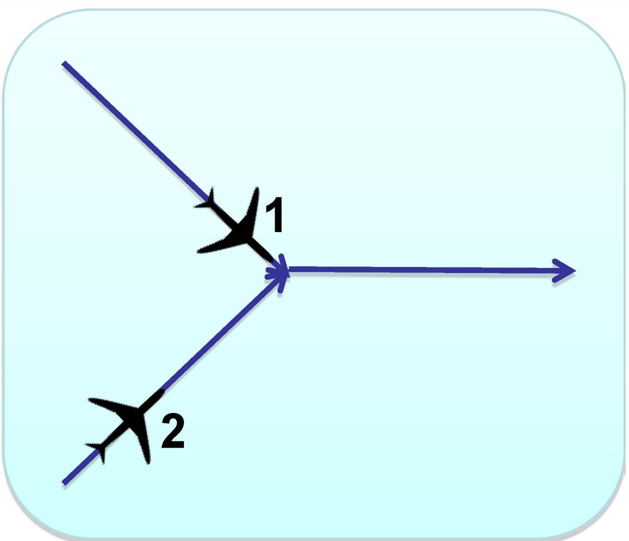
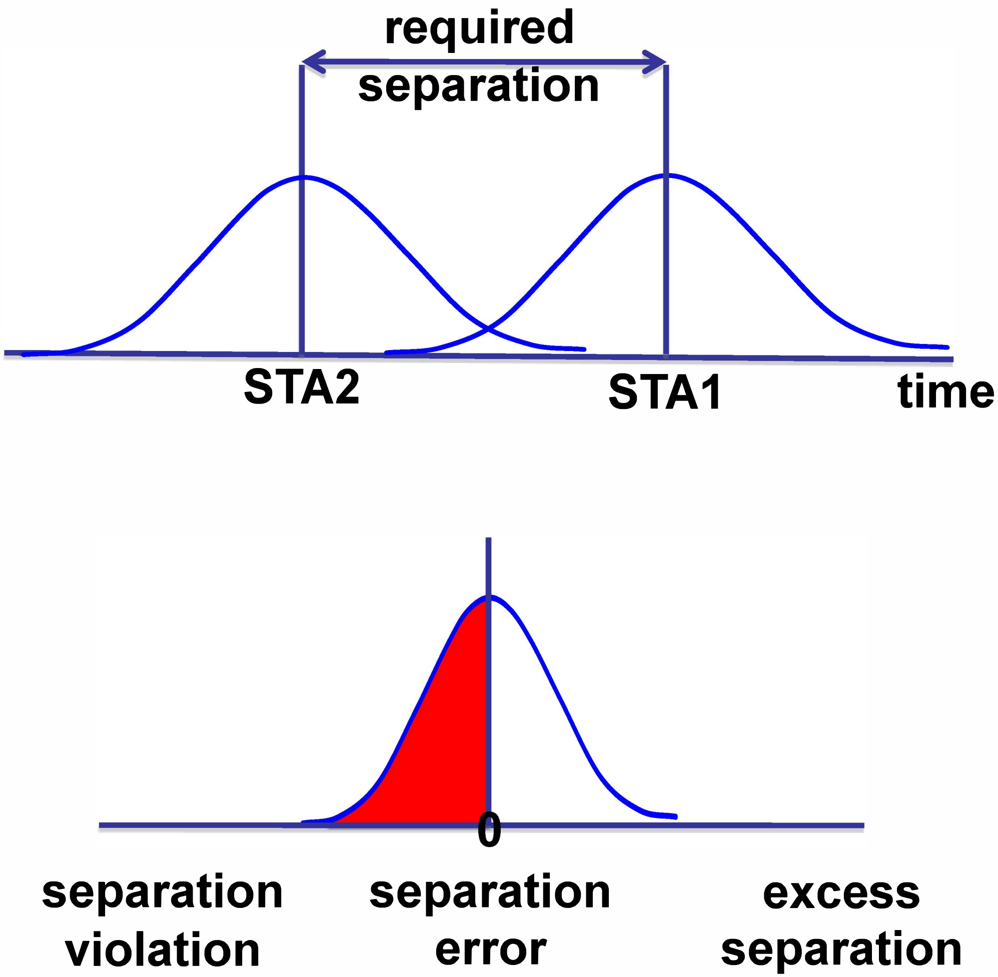
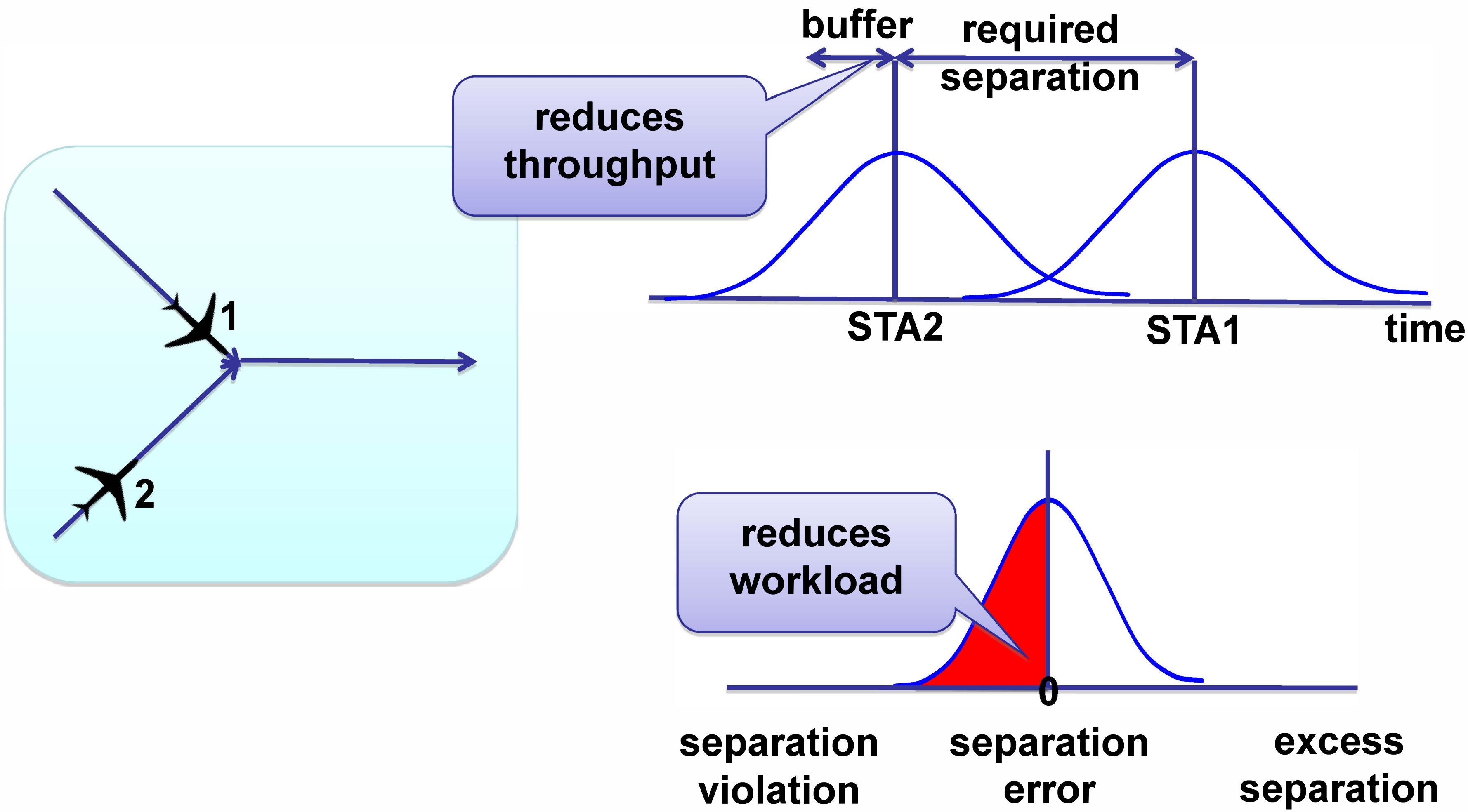
Scheduling and Spacing





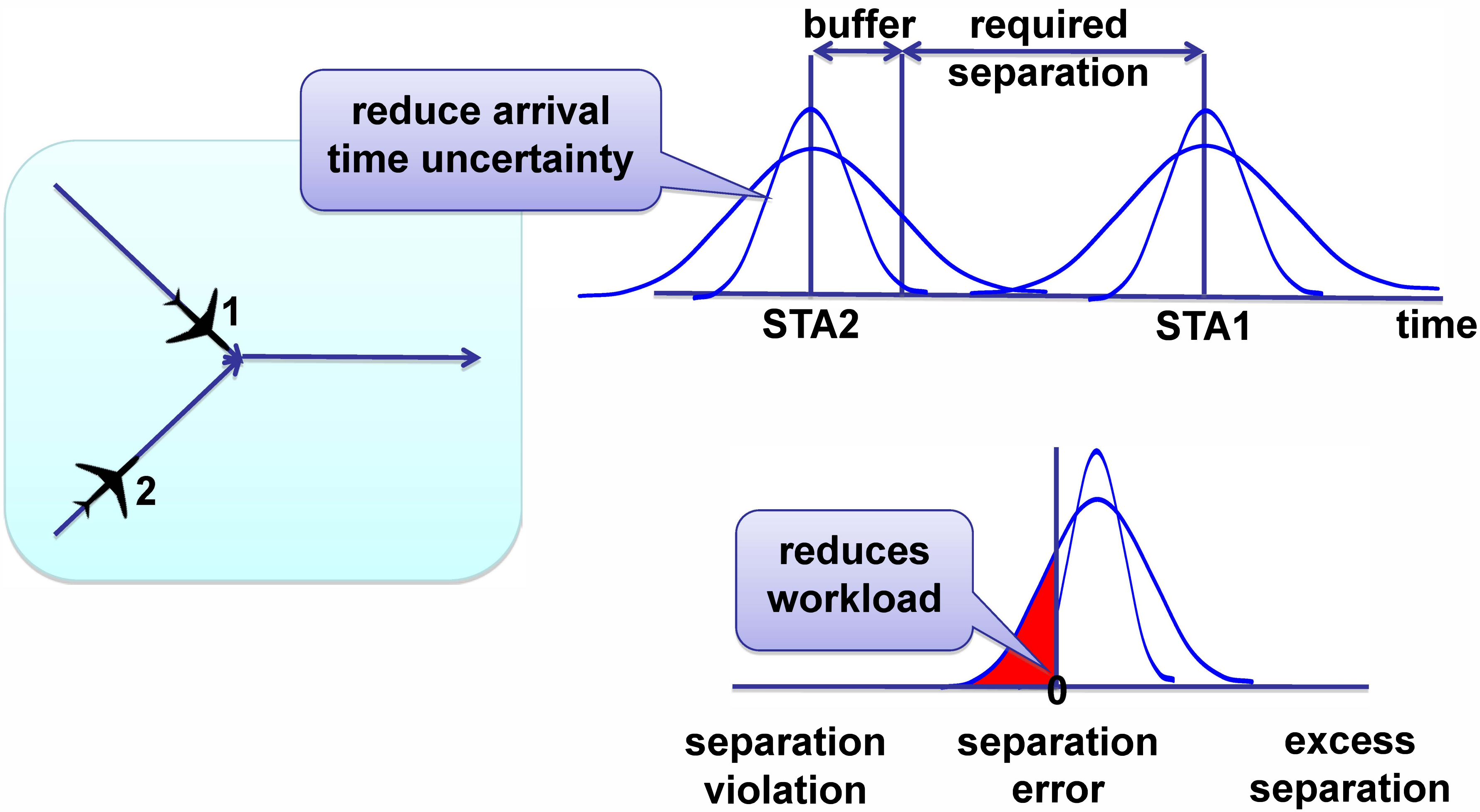
STA=Scheduled Time of Arrival

Scheduling and Spacing



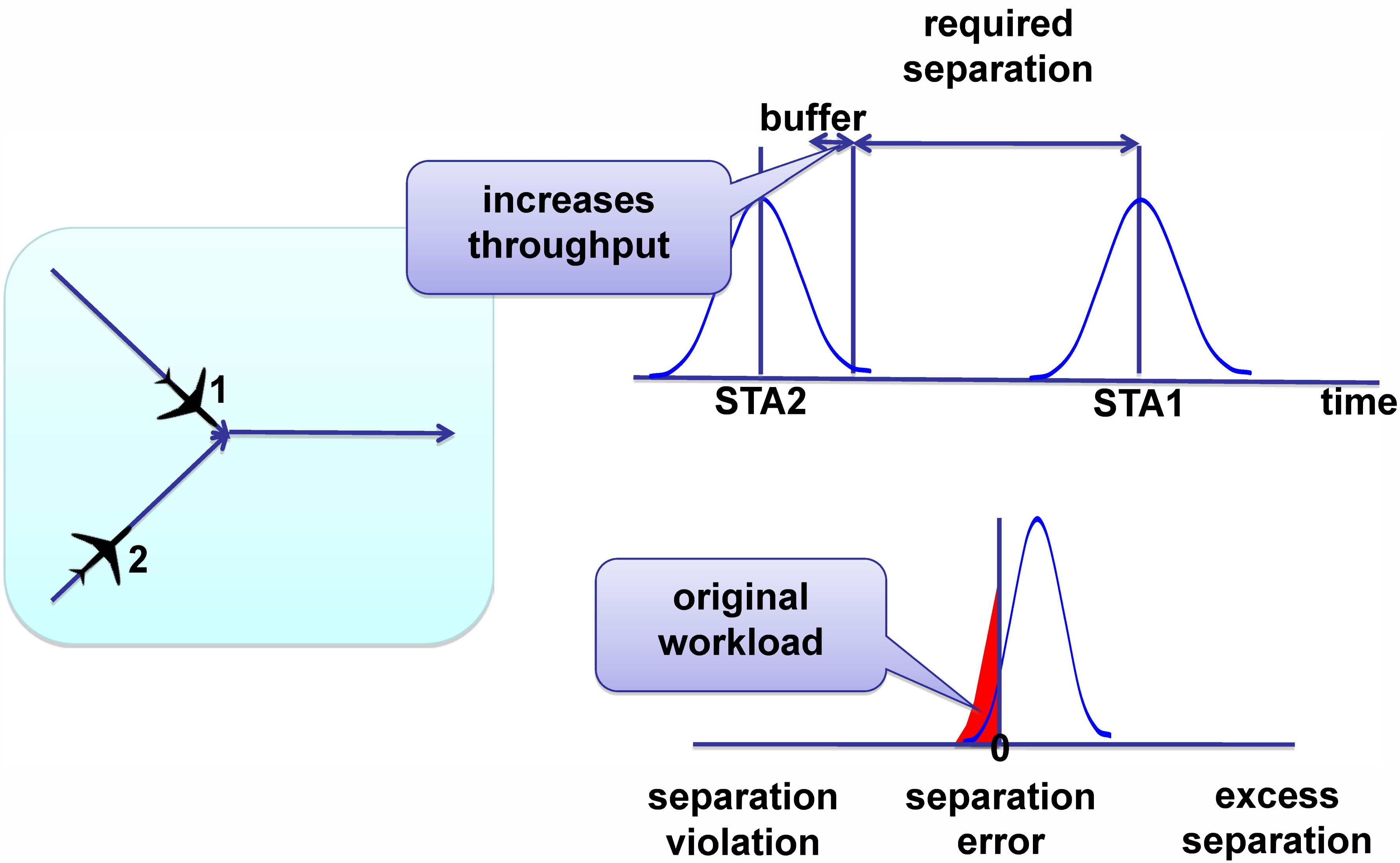
STA=Scheduled Time of Arrival

Precision Scheduling and Spacing



STA=Scheduled Time of Arrival

Precision Scheduling and Spacing



STA=Scheduled Time of Arrival

What's the catch?

- Precision scheduling uses fixed routing and mainly speed control to manage uncertainty
  - Uebbing-Rumke and Temme, 2011
  - Swenson et al., 2011
  - Kupfer et al., 2011
- Speed control bounds
  - Time delay can increase time-to-fly by 10%
  - Time recovery can decrease time-to-fly by 5%

Need more controllability, especially for time recovery.

Objective

Explore design considerations for path-based time recovery methods (shortcuts).

Main Message

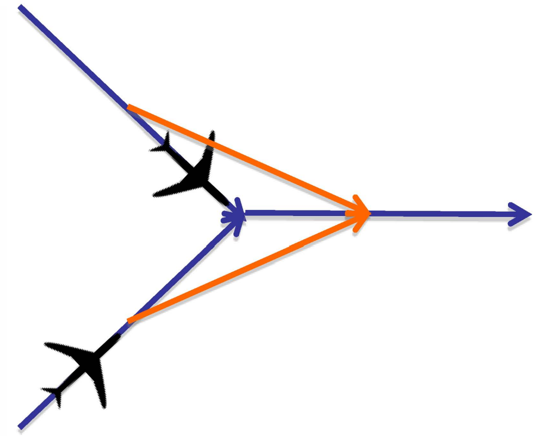
- Shortcuts increase controllability by extending recovery time bounds, which can reduce scheduling buffer size and increase throughput.
- The amount of time a shortcut is design to recover is stable with respect to the expected arrival time uncertainty.
- Several shortcut use policies were tested and performed well for full range of demand levels.

Outline

- Shortcut Design Parameters
- Parametric Sensitivity Analysis
- Demand Analysis
- Conclusions
- Future Work

Shortcut Design Parameters

Single Point Merge



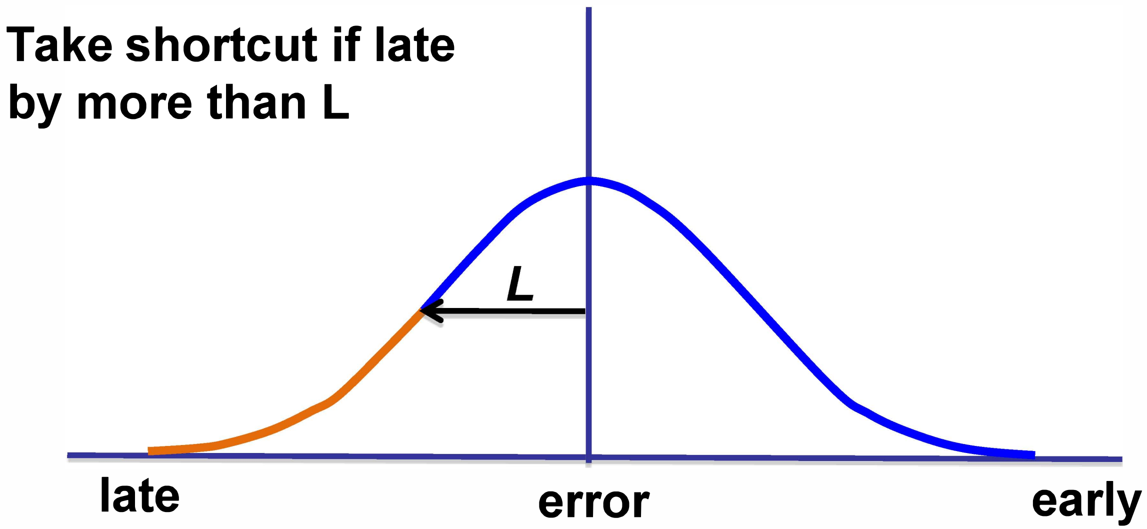
- **Shortcut Recovery Parameter** - nominal time recovered when using the shortcut, generalizes shortcut route geometry and nominal speed
- **Shortcut Usage Parameter** - determines whether or not a flight should use the shortcut
  - Schedule-based
  - Spacing-based

Shortcut Design Parameters

Schedule-Based

L **= late threshold (usage)**

S **= shortcut recovery**

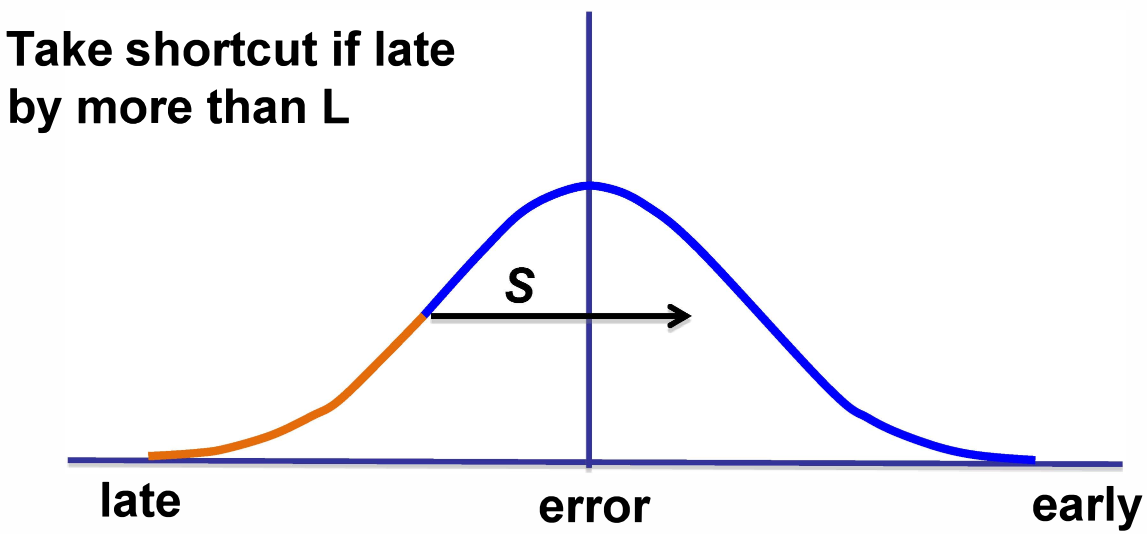


Shortcut Design Parameters

Schedule-Based

L **= late threshold (usage)**

S **= shortcut recovery**



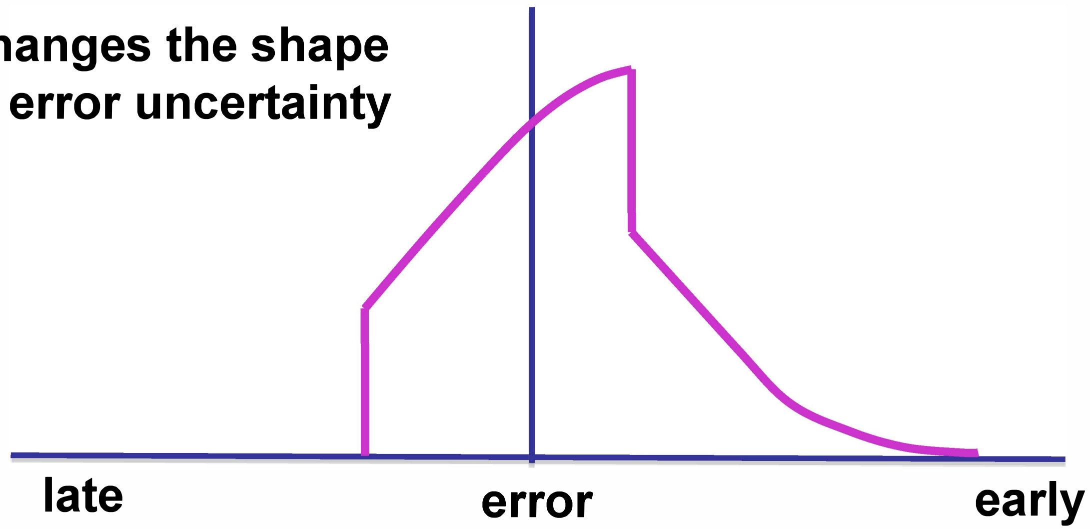
Shortcut Design Parameters

Schedule-Based

L **= late threshold (usage)**

S **= shortcut recovery**

Changes the shape of error uncertainty



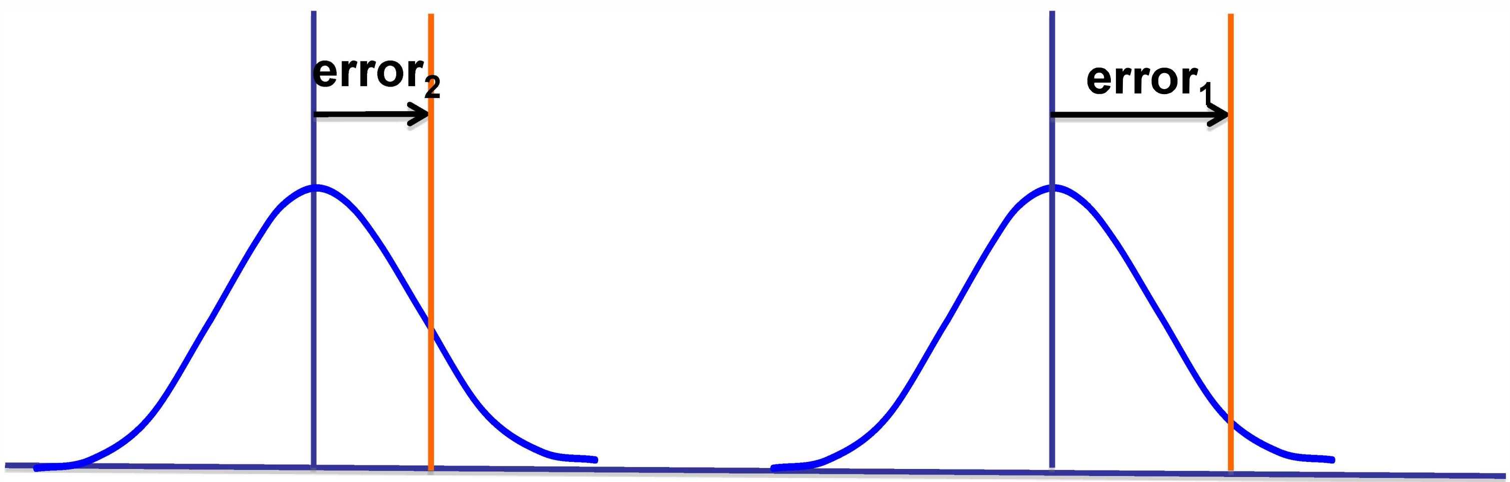
Shortcut Design Parameters

Spacing-Based

R **= relative error threshold (usage)**

S **= shortcut recovery**

Take shortcut if the resulting separation error ($error_2$-$error_1$) will be less than R



Parametric Sensitivity Analysis

Analyze the sensitivity of aircraft spacing error to changes in shortcut parameters

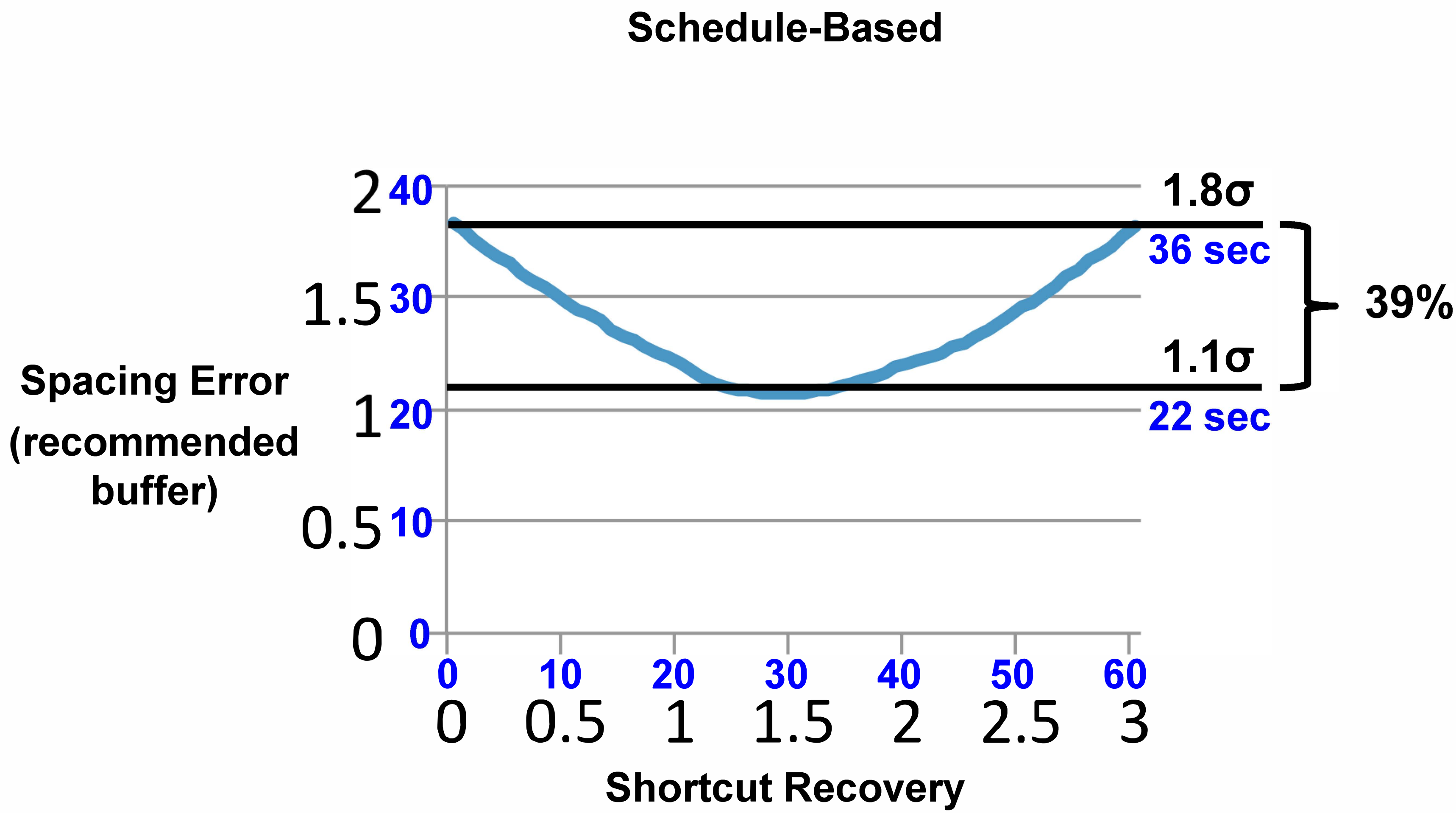
- Shortcut Recovery Parameter
- Shortcut Usage Parameter

Parametric Sensitivity Analysis

Method

- Create sequence of 10,000 flight arrival time errors with Gaussian distribution.
- Modify the arrival time errors based on the shortcut design parameters.
- Compute spacing error as trailing minus leading flight modified arrival time error.
- Recommended scheduling buffer is based on 90^{th} percentile spacing error.

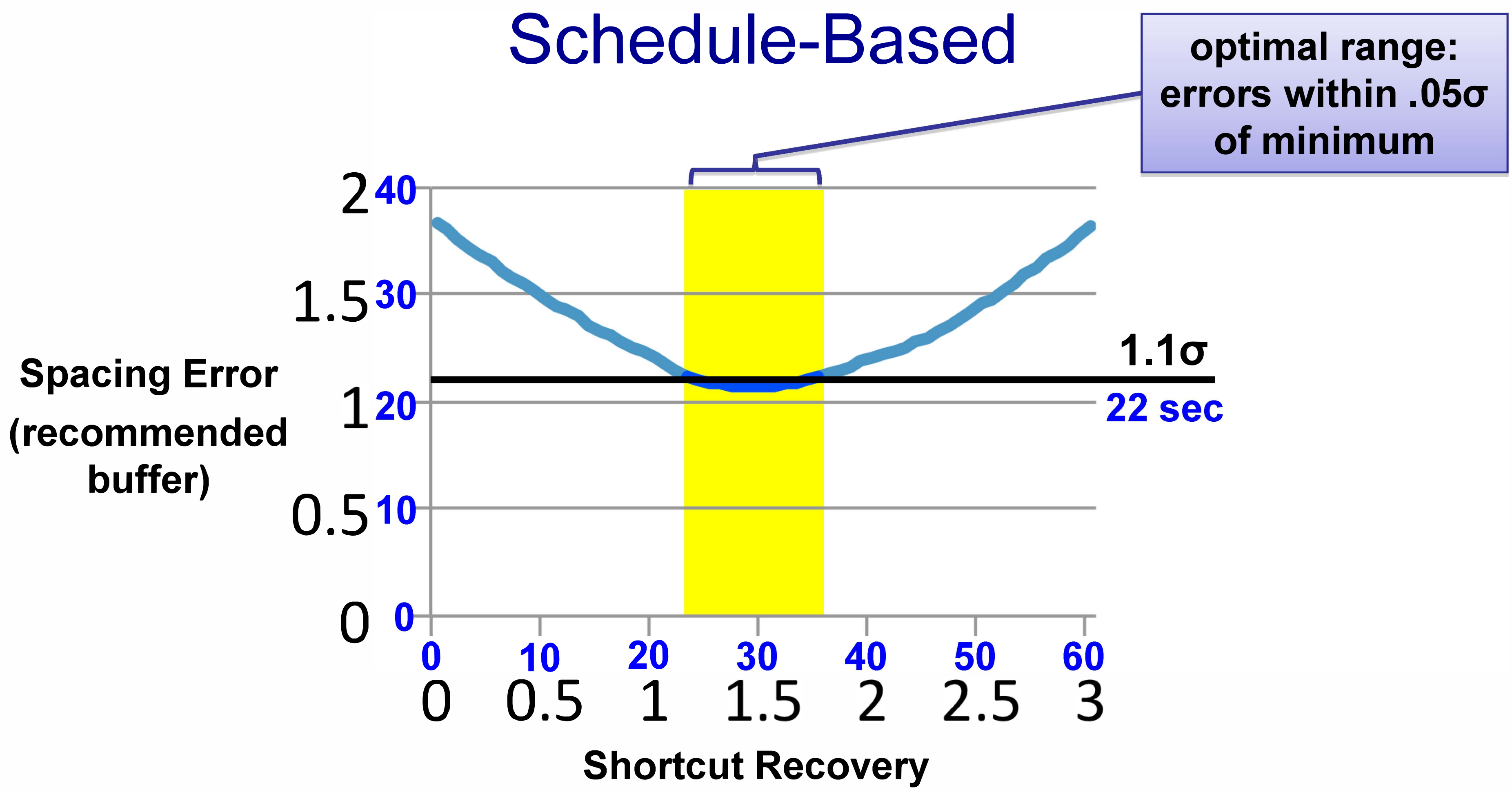
Sensitivity Results



Units: seconds if σ=20 seconds

Units: multiple of uncertainty σ

Sensitivity Results



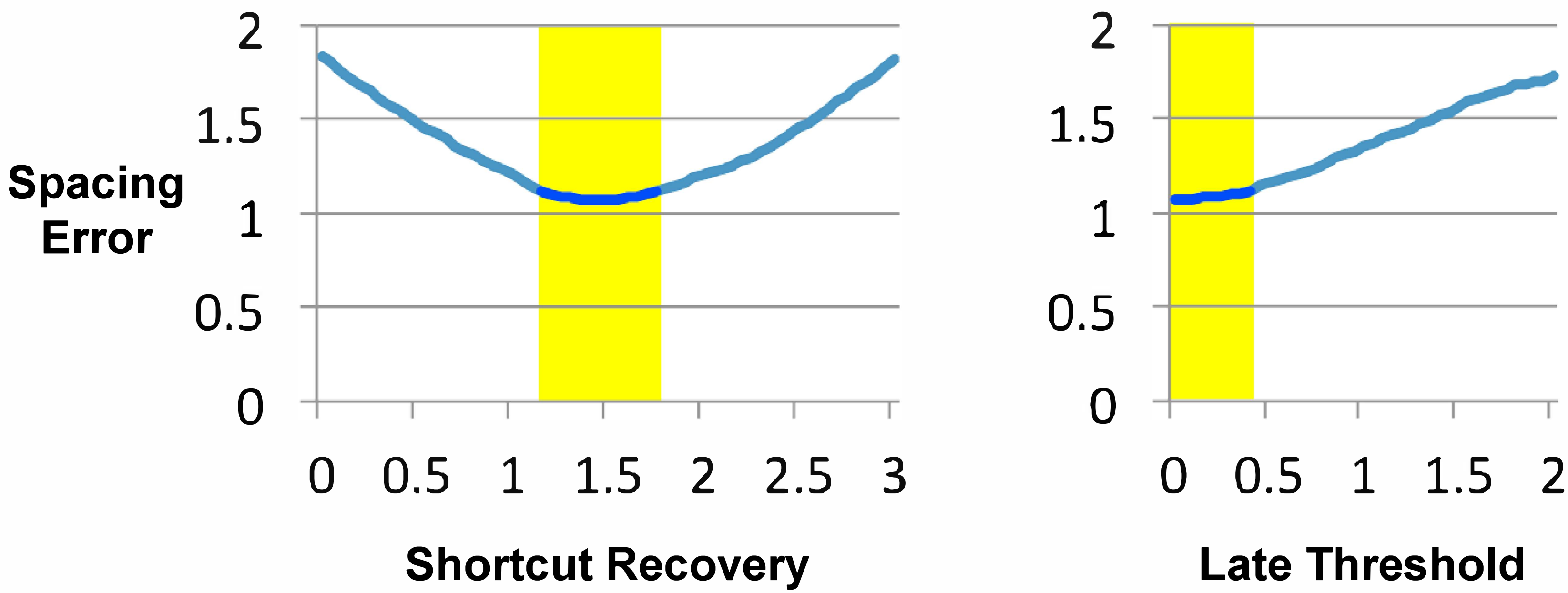
1.5σ Shortcut Recovery allows +-15% variation in time-to-fly

Units: seconds if σ=20 seconds

Units: multiple of uncertainty σ

Sensitivity Results

Schedule-Based

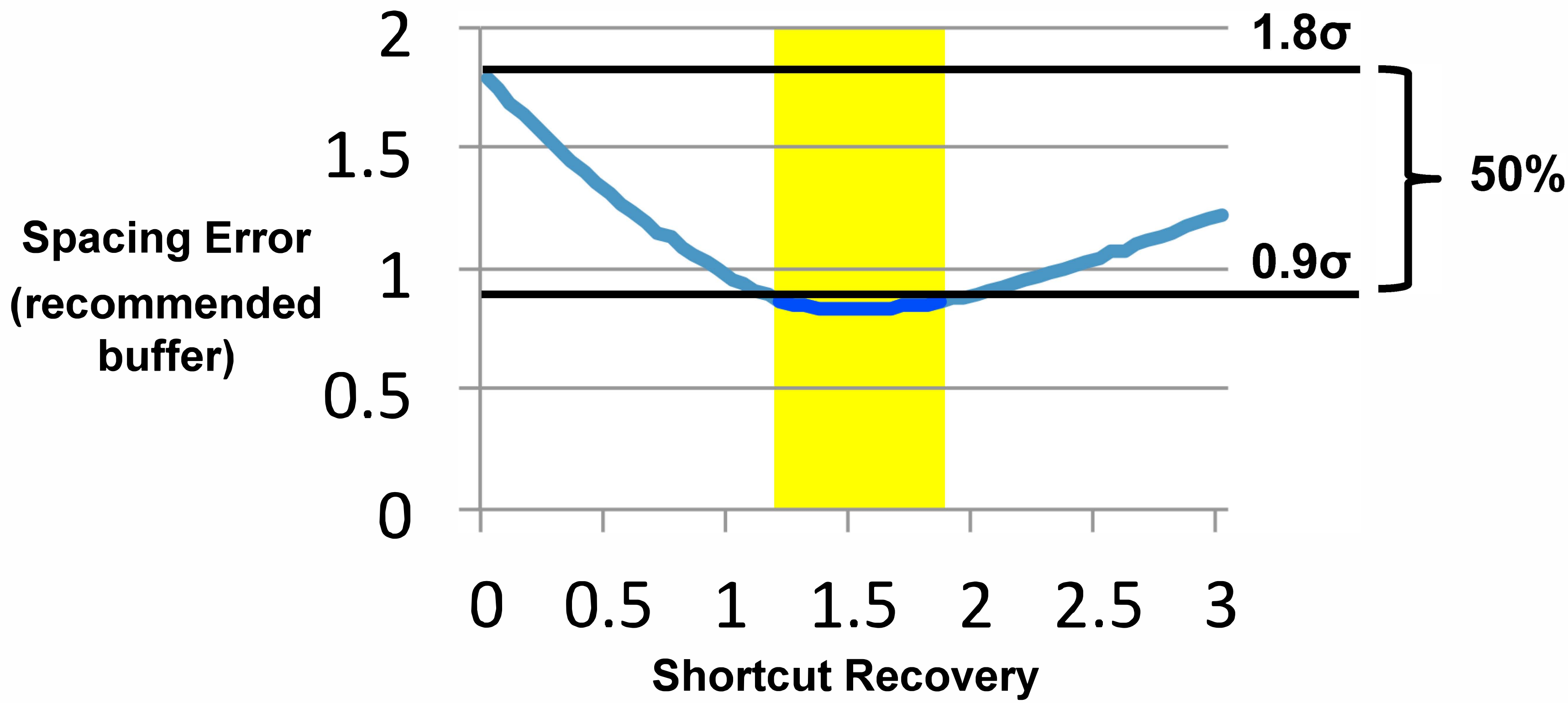


Take shortcut if late

Units: multiple of uncertainty σ

Sensitivity Results

Spacing-Based

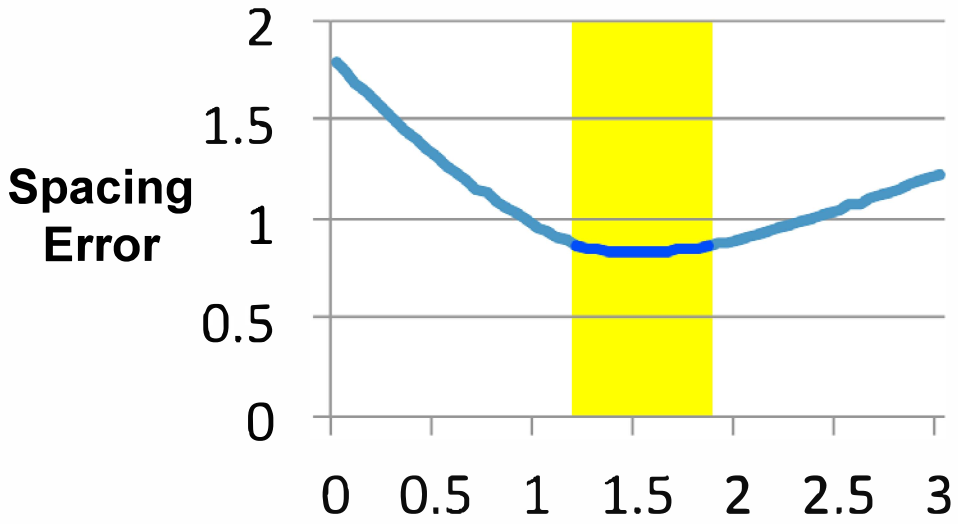


Spacing-base Shortcut Recovery optimal range similar to schedule-based

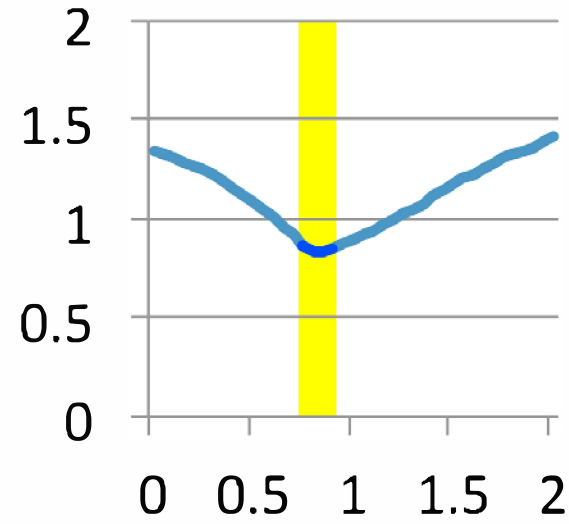
Units: multiple of uncertainty σ

Sensitivity Results

Schedule-Based



Shortcut Recovery



Relative Error Threshold

Spacing-based use policy uses the shortcut to remove all scheduling buffer

Units: multiple of uncertainty σ

Demand Analysis

How do delay and throughput benefits change with demand?

Demand Analysis

Method

- Create sequences of 100 flights with arrival rates ranging from 0.01 to 1.00 flight per minimum required slot.
- Schedule flights with buffer appropriate for each use policy.
- Simulate shortcut usage for 1000 runs of each arrival rate and shortcut use policy.

Demand Analysis

Scheduling According to Shortcut Use Policy

Use Policy	Shortcut Recovery	Shortcut Usage Parameter	Scheduling Buffer
No Shortcut (scheduled to shortcut)	None	None, already scheduled to shortcut	1.8σ
Schedule-based	1.5σ	If late, take shortcut	1.1σ
Spacing-based	1.5σ	Take shortcut as long as required separation is maintained	0.9σ
Hybrid (Schedule-based or No Shortcut)	1.5σ or None	If late or scheduled to shortcut, take shortcut	1.1σ or 1.8σ

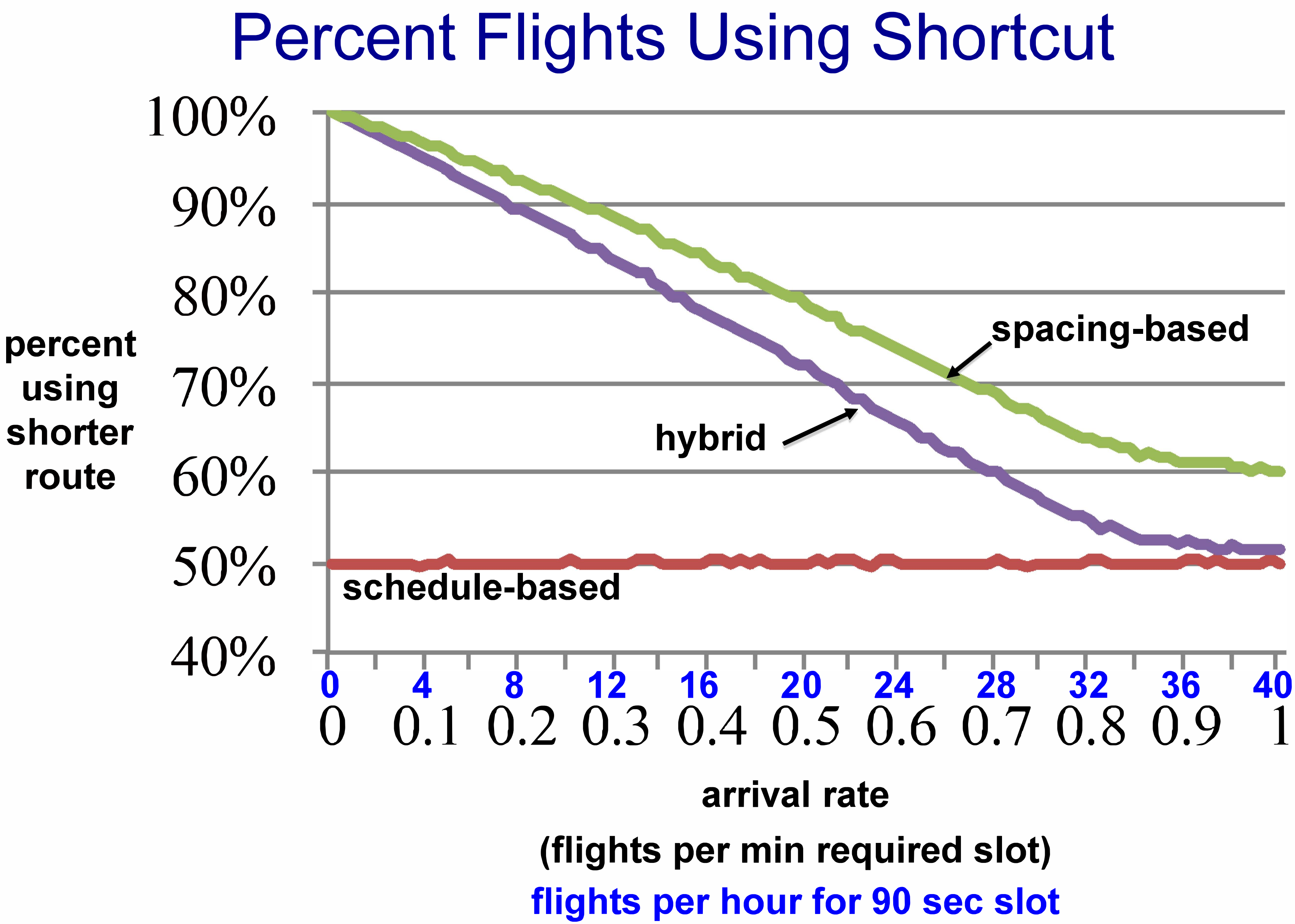
Demand Analysis

Metrics

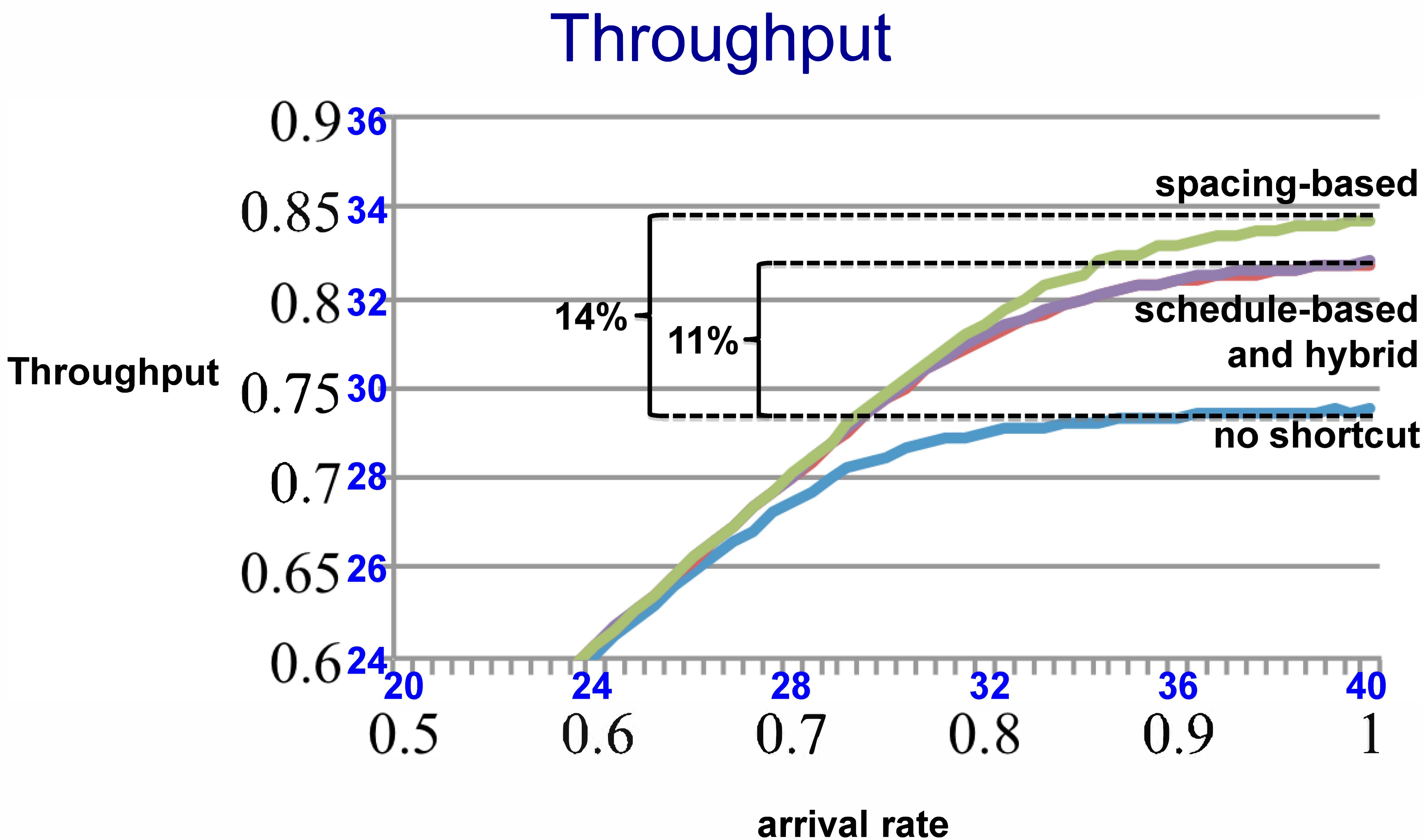
(average and standard deviation of 1000 runs)

- Percent of flights using shortcut
- Throughput (make span / 100 flights)
- Delay (scheduled delay + path delay)

Demand Analysis Results



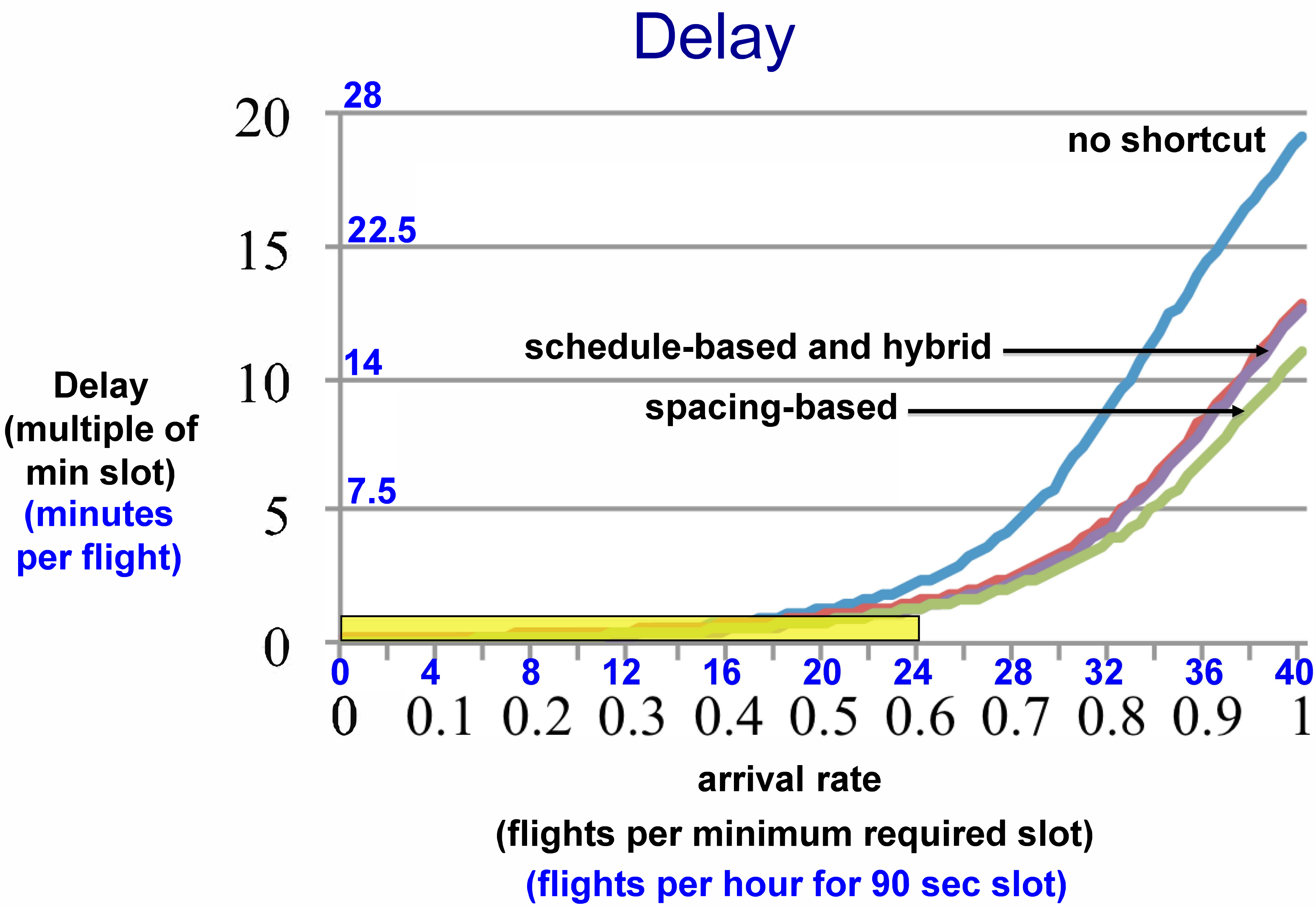
Demand Analysis Results



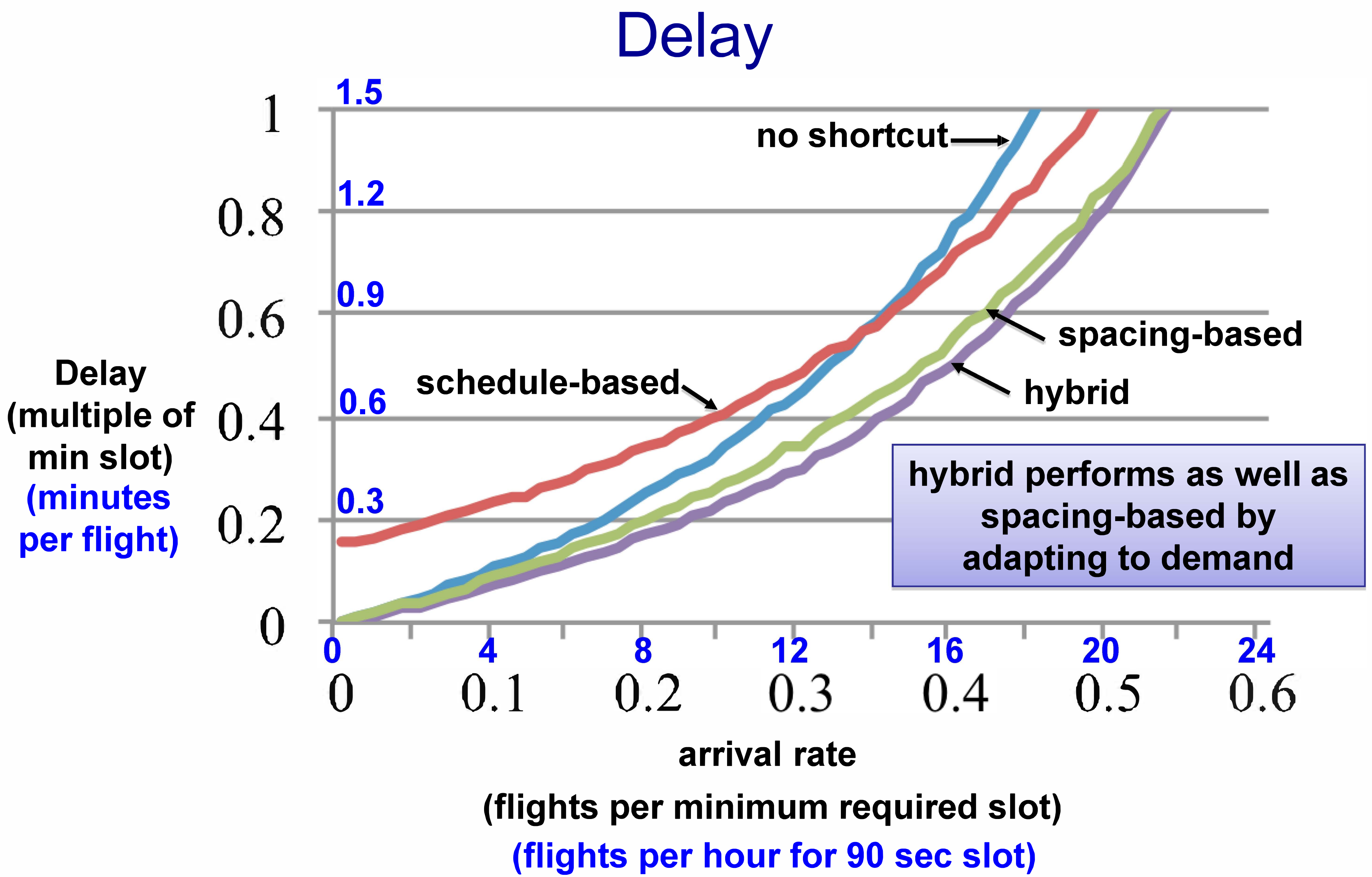
Units: flights per hour for 90 sec slot

Units: flights per min required slot

Demand Analysis Results



Demand Analysis Results



Conclusions

- Shortcuts increase controllability by extending recovery time bounds, which can reduce scheduling buffer size and increase throughput 11-14%.
- Shortcuts should be designed to recover 1.5 times the expected uncertainty, which is robust to +-15% time-to-fly variation.
- Spacing-based and hybrid schedule-based use policies perform best, adapting to changes in demand.

Future Work

- Extend shortcuts concept to accommodate multi-point scheduling and mixed aircraft performance.
- Explore operational considerations associated with route geometry and use policy implementation.

Questions

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