Response Mechanisms for Dynamic Air Traffic Flow Management

Michael Ball, University of Maryland

Robert Hoffman, Metron Aviation

David J. Lovell & Avijit Mukherjee
University of Maryland

Sources of Uncertainty in Traffic Flow Management

- Demand (uncertain departure/arrival times)
- Capacity (forecast uncertainty)
- Control actions traffic managers may take
- Effects of coordination and timing of inter-related activities

Mitigating Uncertainty

- Reduce uncertainty by ***improving information quality.***
- Create plans that ***"hedge against" multiple possible future outcomes.***
- Create flexible systems that can ***dynamically react to changing conditions***.

How can this be done????

Prototype Example: Slot Credit Substitution (SCS)

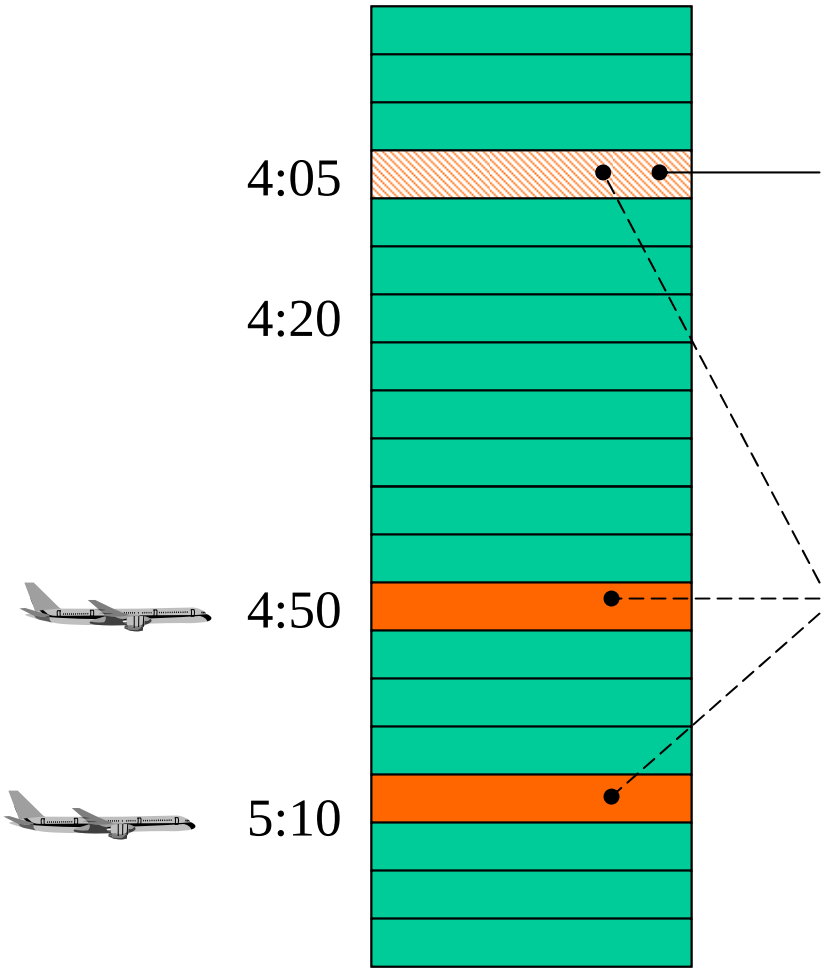
SCS and compression: used during ground delay program planning and control:

fill in "holes" in planned arrival sequences by executing inter-airline slot exchanges.

Compression is a "batch" process executed after time intervals of varying lengths, e.g. 1 to 2 hours.

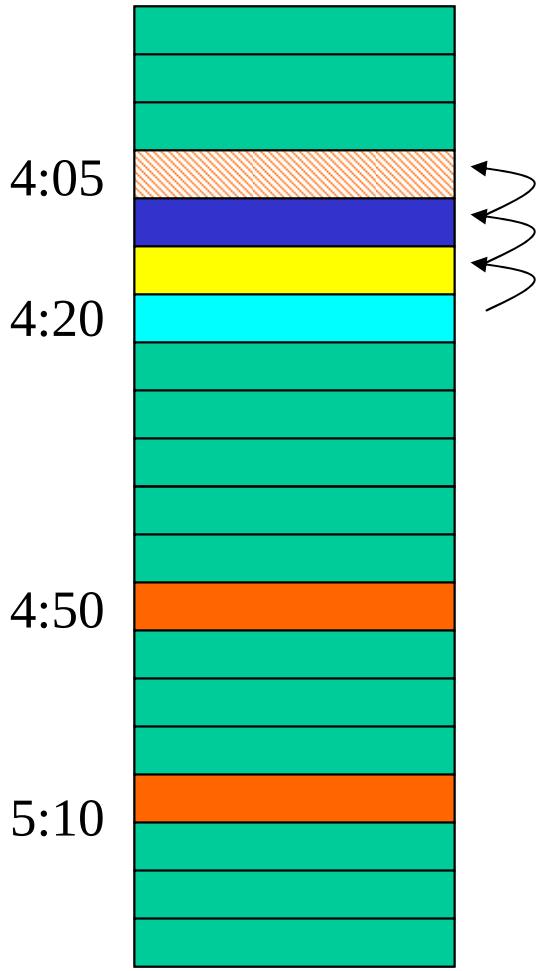
SCS is a near-real-time process executed in reaction to airline exchange requests.

Basic Slot Exchange Concept



Earliest time of arrival: 4:20

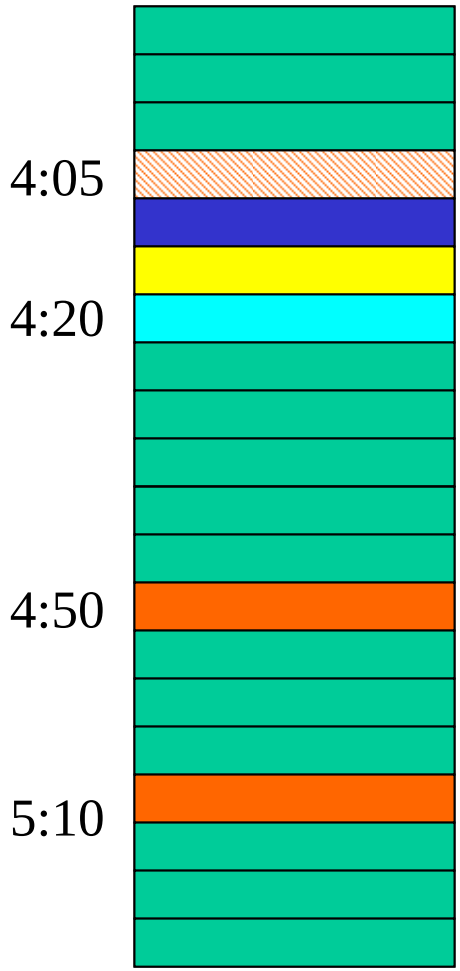
Basic Slot Exchange Concept



Competitor's flights move up to free the 4:20 slot for airline A

Earliest time of arrival: 4:20

Basic Slot Exchange Concept

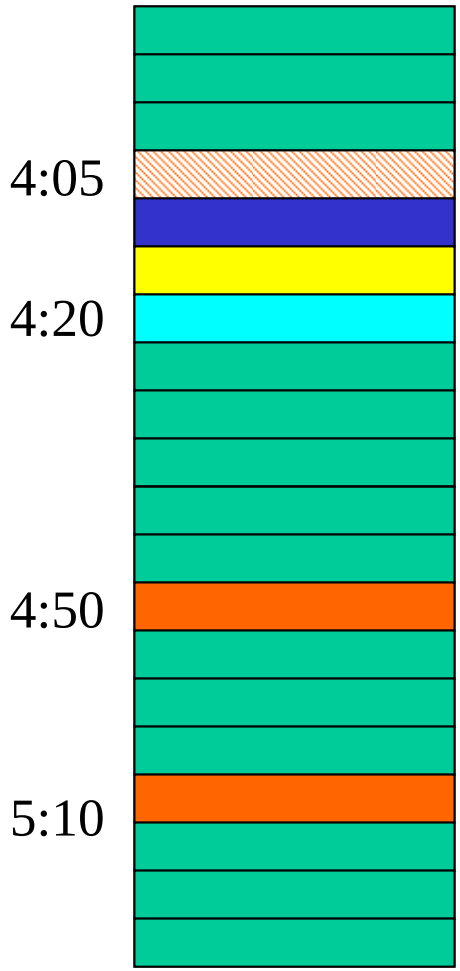


Earliest time of arrival: 4:20

Competitor's flights move up to open a slot for airline A

Airline A flight moves up to earliest slot it can use

Basic Slot Exchange Concept



Earliest time of arrival: 4:20

Competitor's flights move up to open a slot for airline A

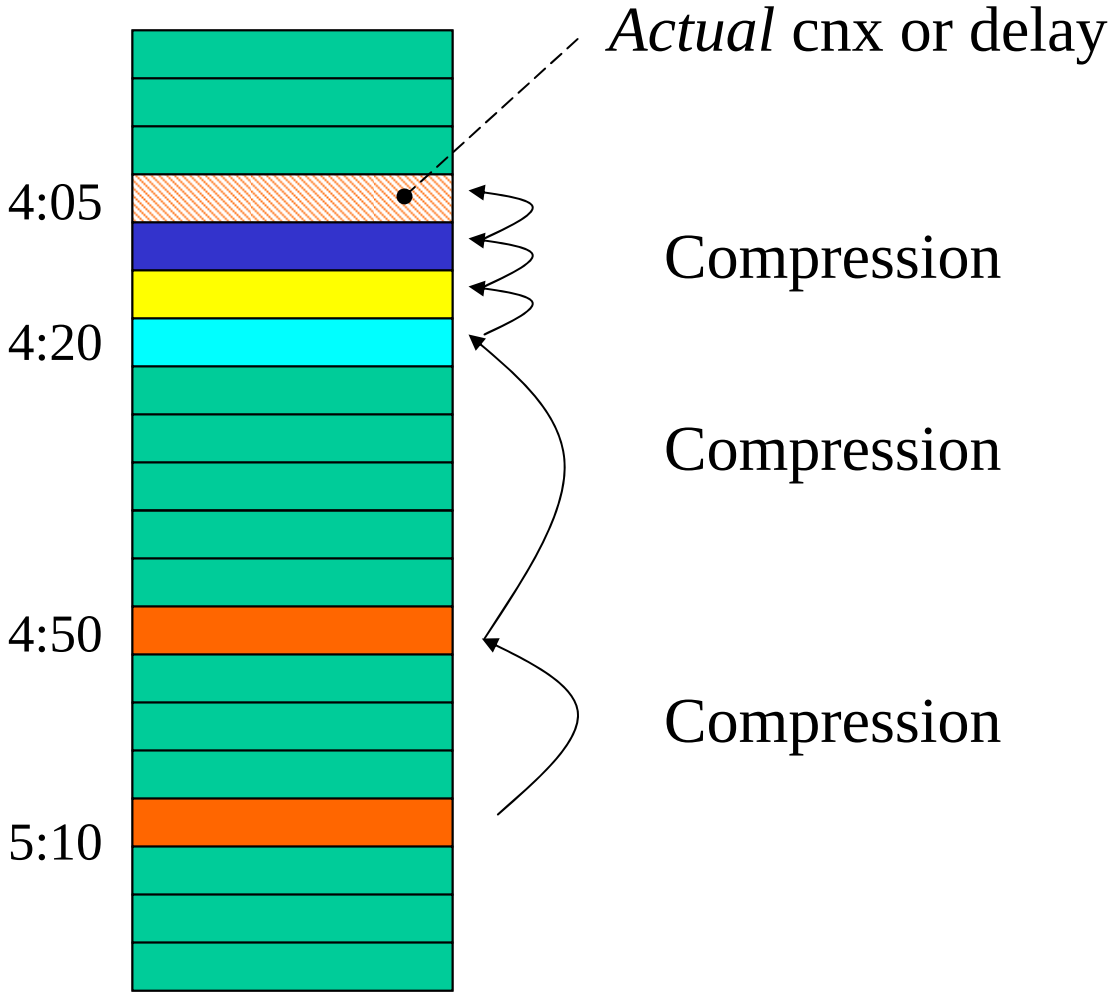
Airline A flight moves up to earliest slot it can use

Additional substitution

Compression: batch process

Compression executes all of the slot exchanges needed to fill the *open* slot.

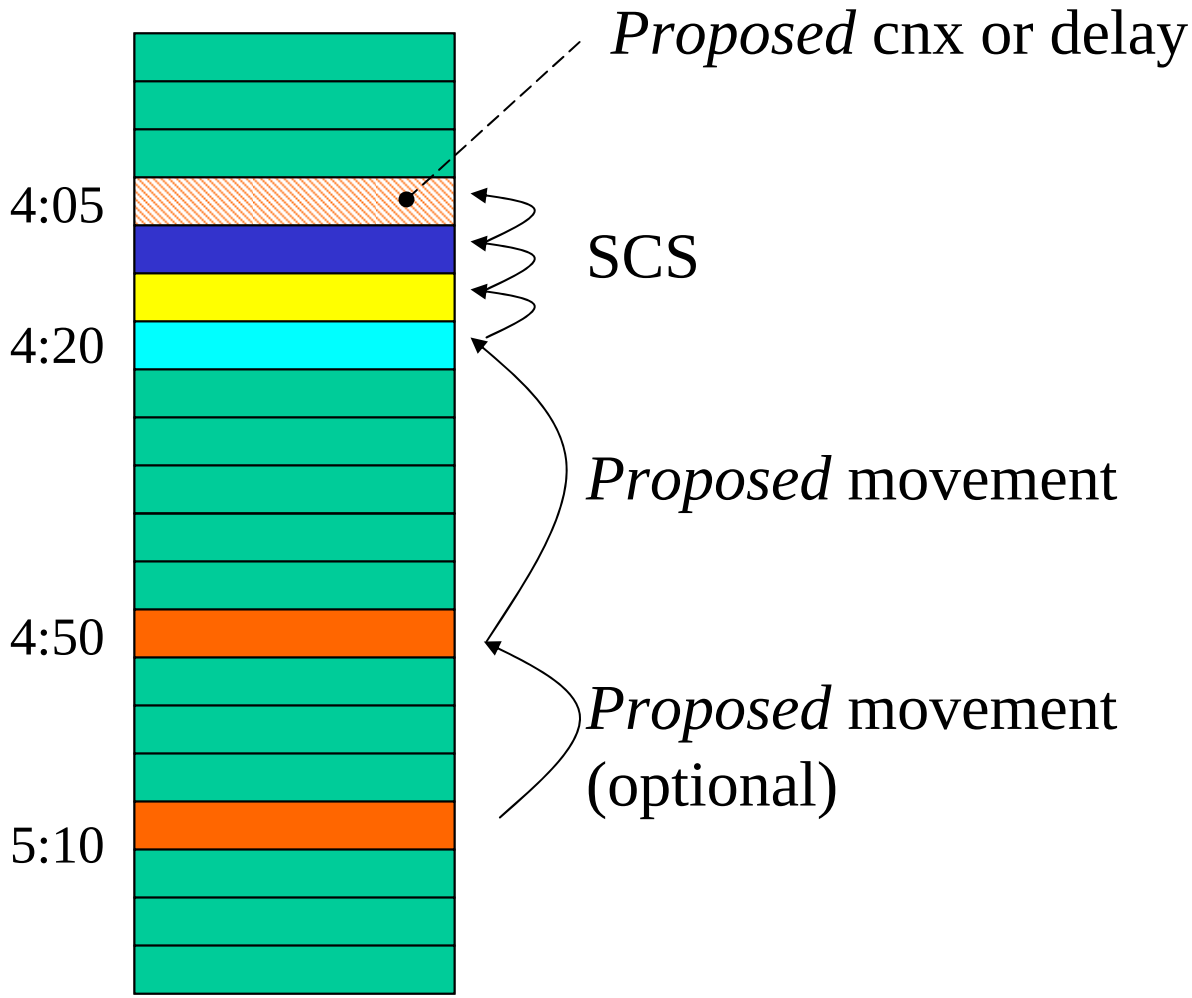
Open slots are batch processed.



SCS: transaction-based process

SCS executes the slot exchanges needed to complete *proposed* movement(s).

Movements are processed as requests are made.



Questions:

What advantages does a transaction-oriented process like SCS have over a batch-oriented process like compression?

Can these advantages be quantified?

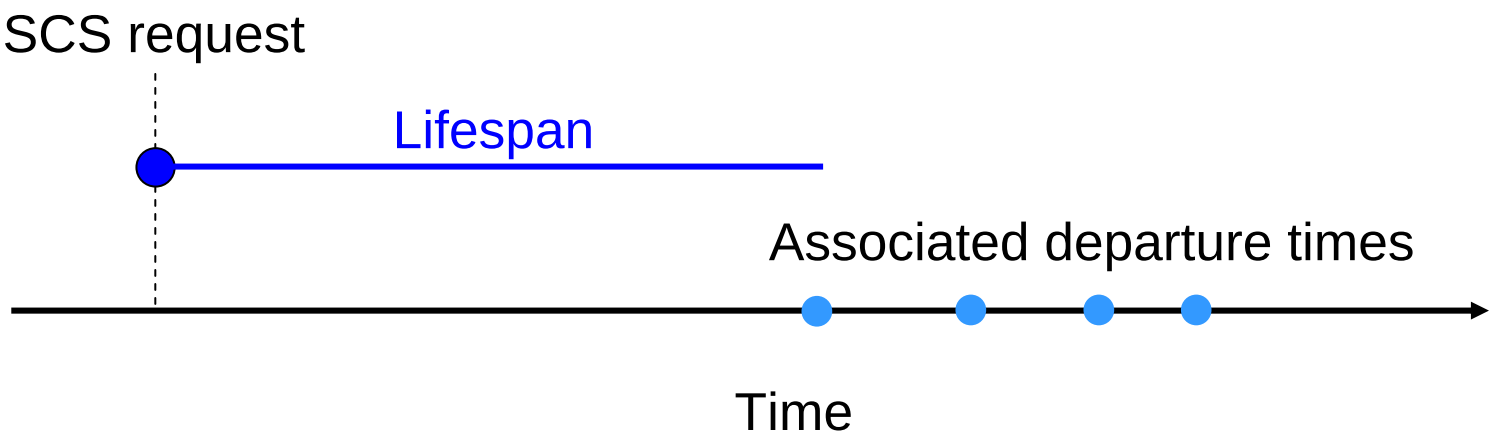
Can these advantages be achieved in other application contexts?

Model of SCS requests

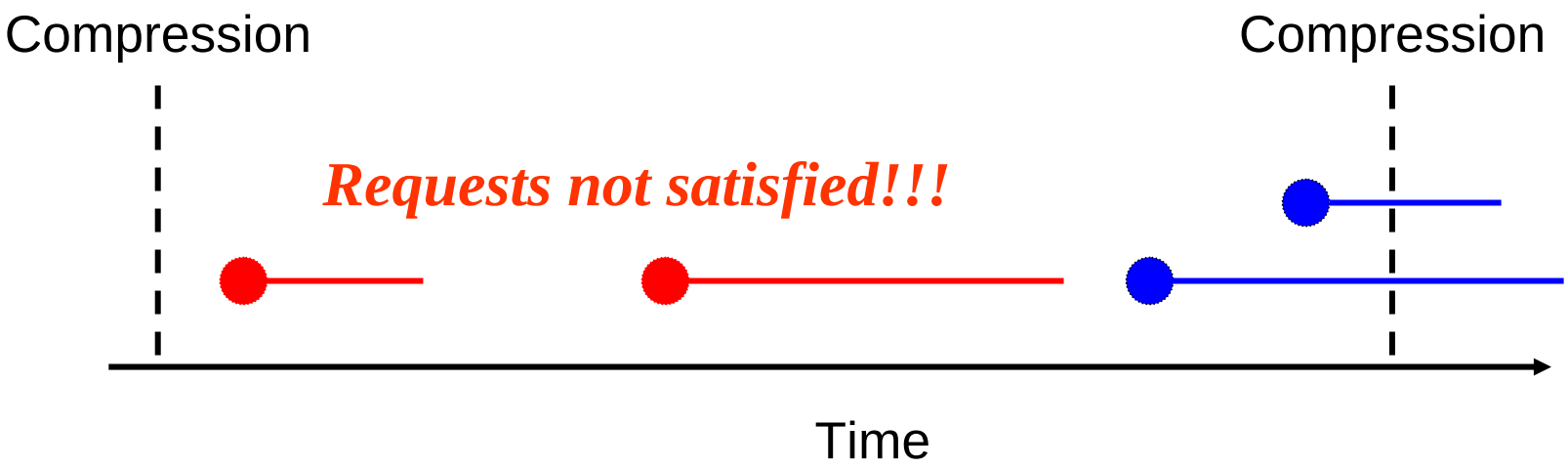
Each SCS request requires a set of ***arrival*** slot exchanges to be executed

Each arrival slot exchange implies a revision of the ***departure time*** of a flight.

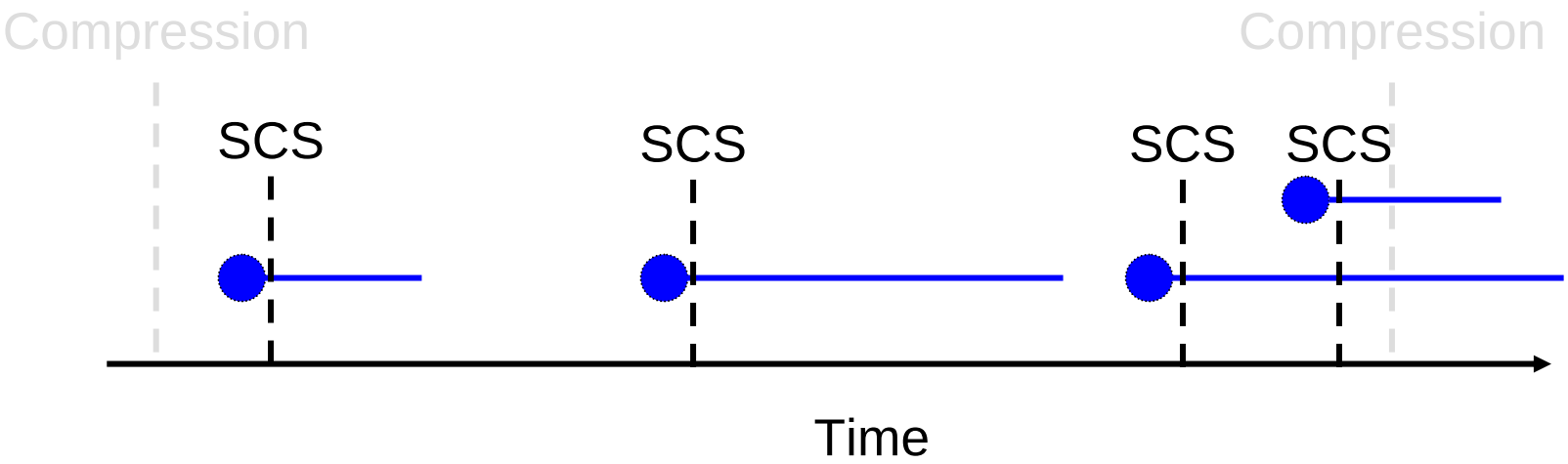
In order to implement the exchange, the transaction must be completed before the earliest revised departure time, i.e. the request has a ***lifespan*** within which it must be executed



Not all requests could be captured by Compression



All requests are captured by SCS



Formal Model

- Requests arrive according to a stationary Poisson point process.
- Request lifetimes are uniformly distributed over an interval [a, b].
- SCS immediately processes each request.
- Compression is executed every T minutes.

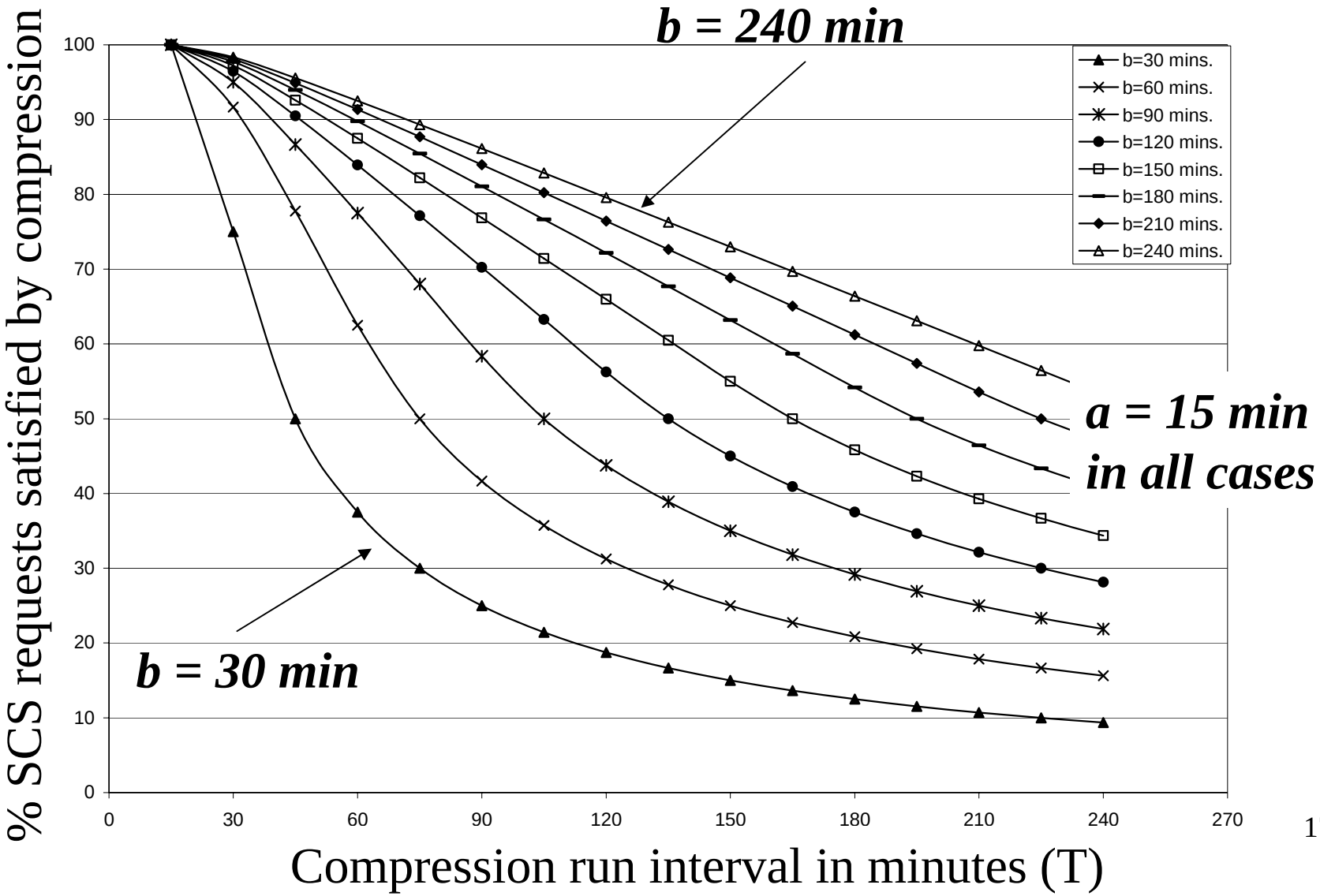
Probability of Compression Success

- s = lifespan of request
- t = time between request and next compression

Prob of request being captured by Compression:

$$\Pr\{s \geq t\} = \begin{cases} 1, & \text{if } a > T \\ \dfrac{a+b}{2T} - \dfrac{(b-T)^2}{2T(b-a)}, & \text{if } a < T < b \\ \dfrac{a+b}{2T}, & \text{if } a < b \leq T \end{cases}$$

Model results: compression vs. SCS



Compression & SCS Advantages

- Compression
  - ***Does not require that airlines proactively identify "opportunities"***
- SCS
  - ***Immediate response***
  - ***Conditional requests*** with confirmed executions

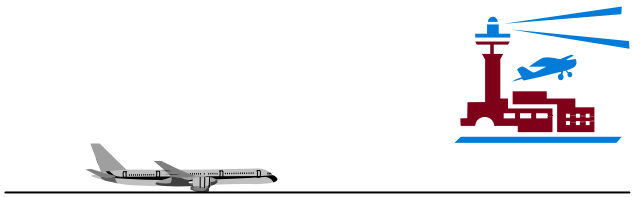
- Important driver for both: ***flexible plan*** – flight arrival times can be updated without airline confirmation (based on earliest-runway-time-of-arrival data field set by airlines).

SCS in Practice

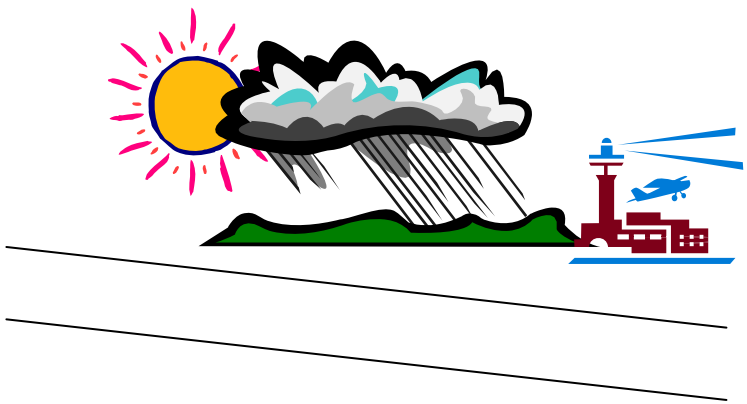
- SCS introduced in May, 2003.
- Messages/GDP hour -- 2003: .32 ➔ 2004: 1.25; 2004: 45 min SCS ground delay reduction per GDP hour.
- SCS use varies substantially by airline.
- FAA Command Center uses SCS extensively to find new arrival slots for flights that miss their controlled time of departure; this use, which was not originally anticipated, accounted for 50% of delay savings in 2004.

Fast Response Mechanisms: other application areas

A: Take advantage of break in convective weather by quickly deciding to launch aircraft



B: Take advantage of return to VFR conditions to immediately fill up available airport arrival capacity.



Some Important Features of Fast Response Mechanisms

- Flexible plans
- Distributed Decision Making and Control
- Buffers
- Flexible assets and physical preparation
- Conditional requests and decision impact queries