

# Spectrum Needs Estimation Using Different Methods

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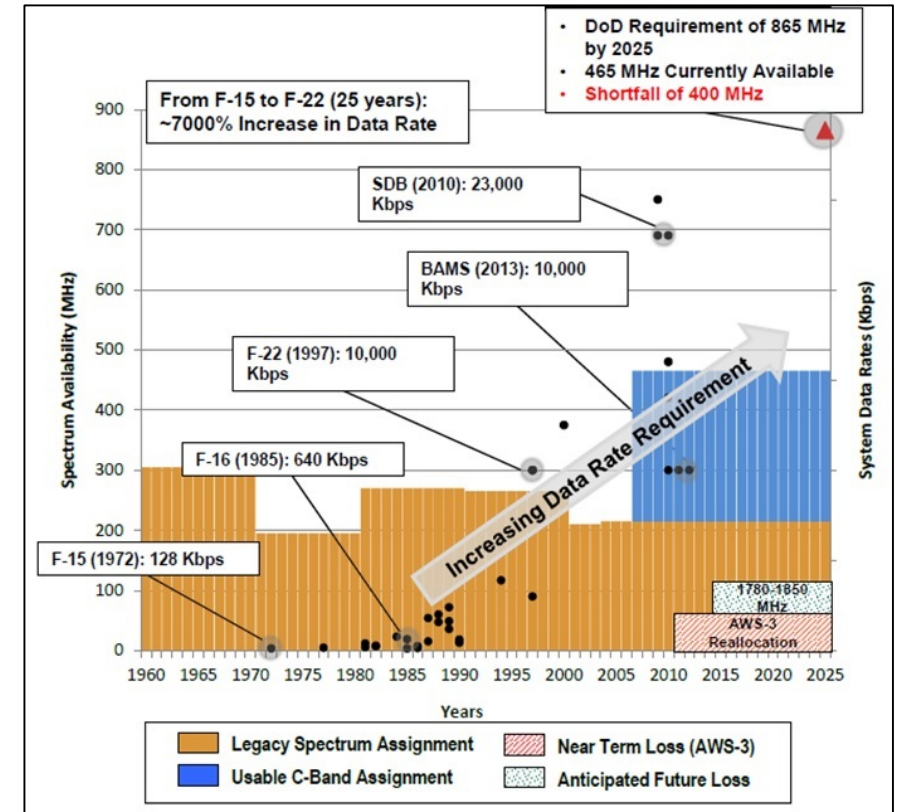
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# Background

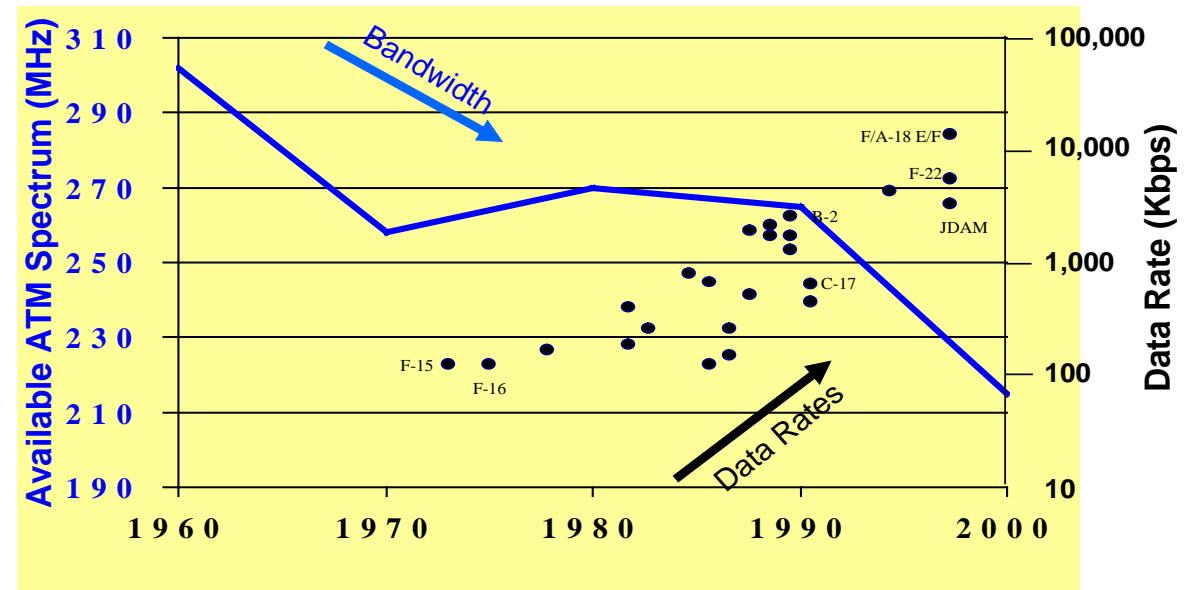
- Growing pressure to relinquish the DoD's allocation of choice parts of the electromagnetic spectrum for commercial applications
- Ability to accurately estimate spectrum needs is the first step toward meeting demand
  - To what extent does past usage reflect current and future needs?
  - What can we expect in the way of future needs? Trends?
- Spectrum demand prediction methods of past are inadequate
  - E.g., need methods that account for the effect of technology change (e.g., more efficient modulation methods, multiple access technology)



# DoD Spectrum Needs Continue to Grow

## Key Factors Driving DoD's Demand

- Increased system complexity
- Expanding use of high definition video
  - Order of magnitude increase in 10 years leading up to 2006 study
- Larger testing footprints
  - Higher altitudes + faster speeds → greater distances for flight tests
- Need for more and better testing in a shorter timeframe
  - Race with peer adversaries
  - Cost pressures
  - Heightened safety concerns



Blue line shows amount of ATM spectrum available for DOD use (left scale)  
Black dots show ATM data rates of major aircraft and missiles (right scale)

Sources:

[Ernst 2003] Ernst, D. and Kahn, C., "Economic Impact of Telemetry and Its Essential Role in the Aerospace Industry," MITRE Technical Report (MTR 04B0000016), December 2003.

[ErnstMITRE 2007] Ernst, Darrell E., Kahn, Carolyn A., Portigal, David L., "The Economic Importance of Adequate Telemetry Spectrum," MITRE Technical Report, MTR060202, Feb. 2007

# Multiple Spectrum Needs Estimation Methods Explored

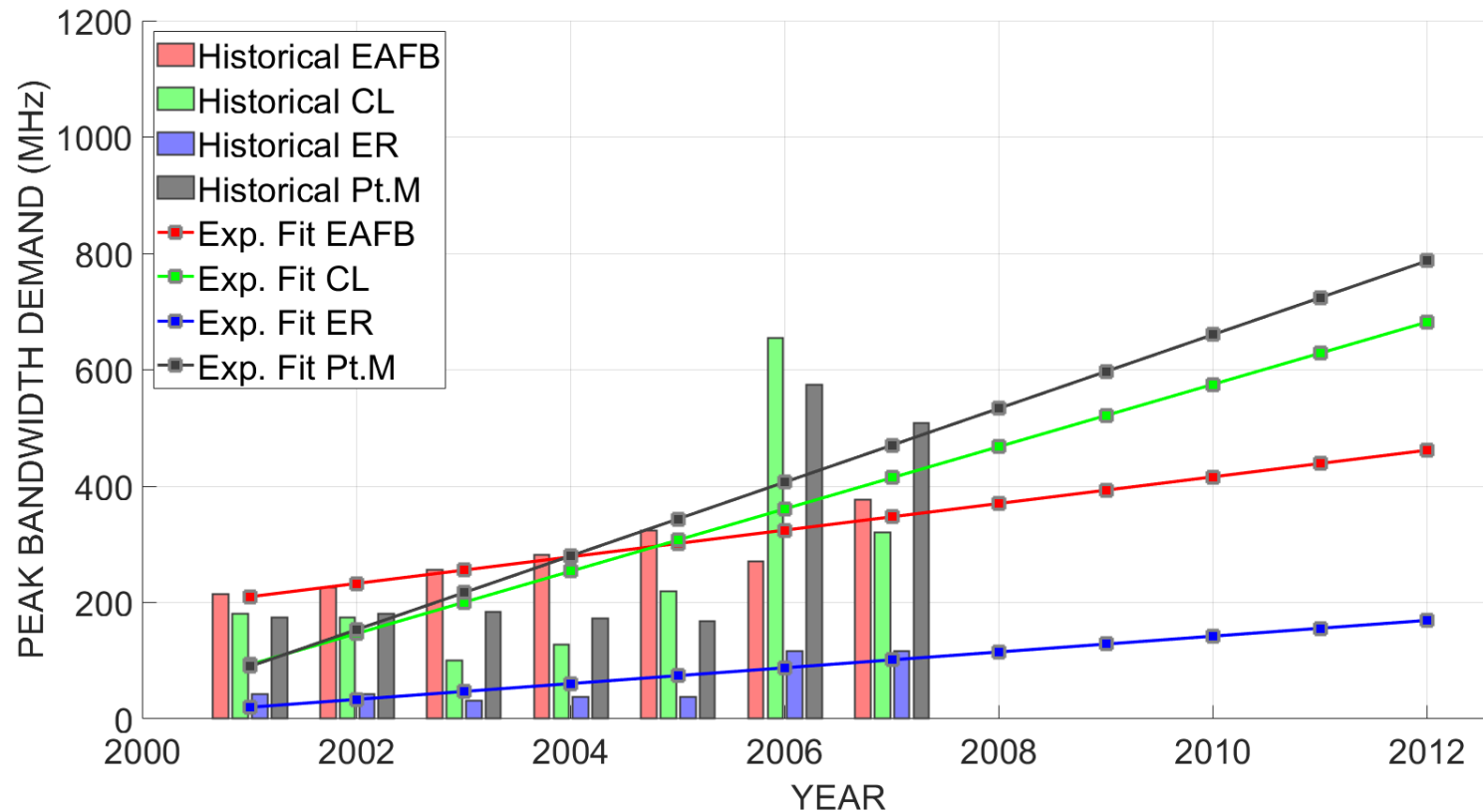
- Analytic
  - Uses historic data and regression analysis for predictions
  - Individual programs or in aggregate
- Bottom-up
  - Based on planned test operations and the consequent frequency needs
  - Centered on frequency needs ignoring constraints of other resource types
  - Characterized in terms of test phases and the number or rate of recurring test operation types
- Queueing-model-based
  - Models test operations like a single-server queue
  - Simulate model and test accuracy by comparing with actual deconflicted schedule

# Analytics-based Telemetry Spectrum Needs Estimation

# Methodology

- Approach based on MITRE model described in [ErnstMITRE\_2007]
- Separates demand into two categories, FOG and MUP
- Future and On Going (FOG)
  - $\text{FOG} = (\text{mean number of users}) * (\text{median user bandwidth demand})$
  - Think of this as the “noise floor” of general use
  - Uses median user bandwidth because max users skew the average
- Max User Program (MUP)
  - Think of this as a large “signal” on top of the FOG “noise floor”
- Regression analysis to produce trend curves for FOG, MUP, and combined

# Analytics-based Spectrum Needs Estimation Tool



- Integrated within the Spectrum Management Metrics Toolkit (SMMT)
- Methodology builds upon and extends MITRE's approach
- Curve fit using regression with linear model or exponential

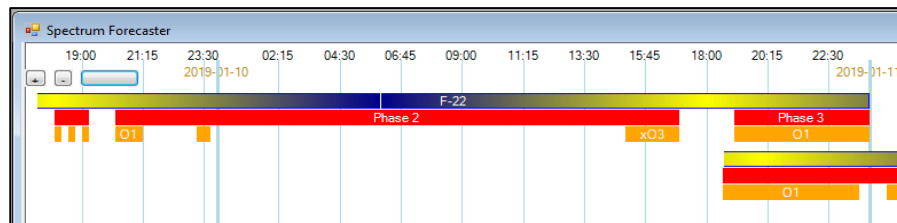
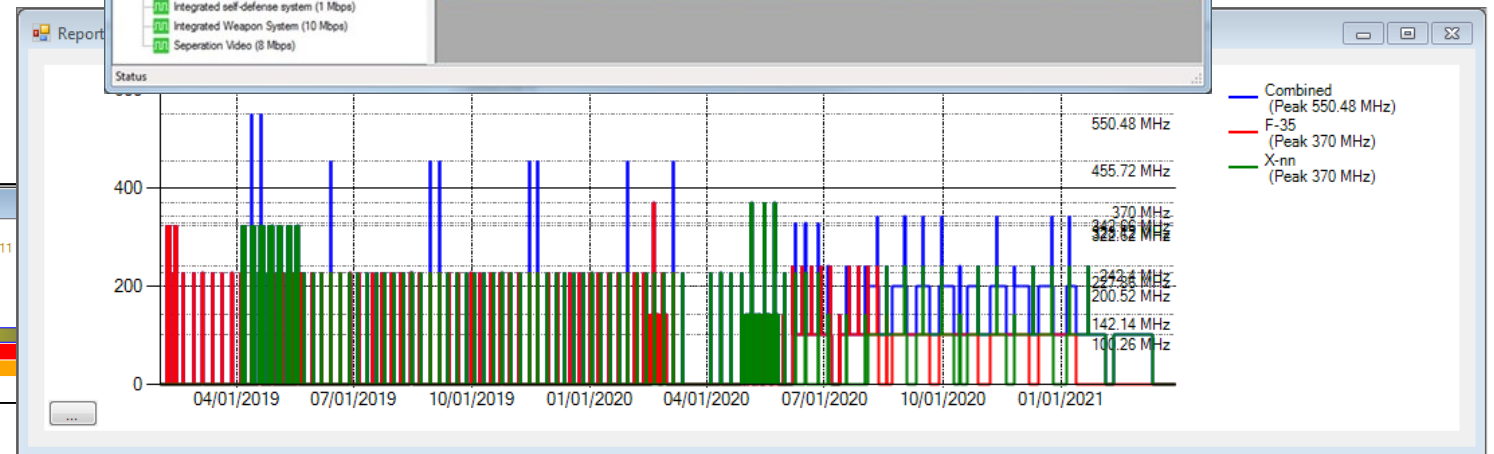
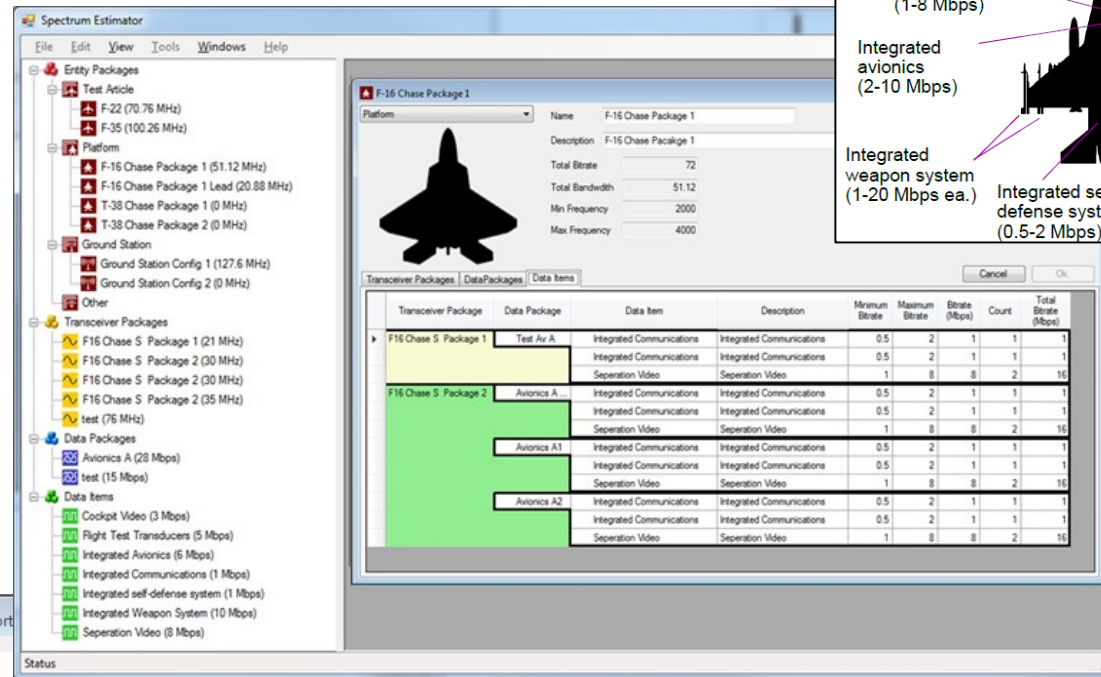
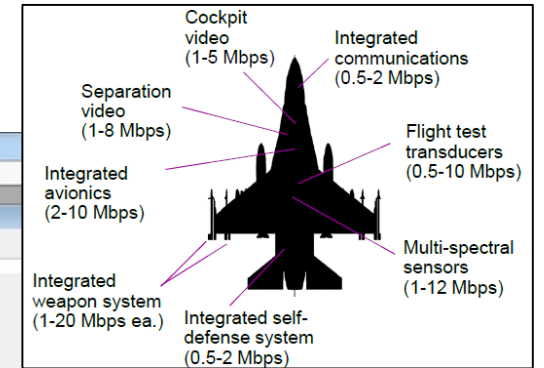
# Strengths and Limitations of Analytics-based Approach

- More an exercise in data cleaning and data discovery
- Models should be range-specific
- Apparent trends may shift in the future
- Forecasts less accurate the further you go out in time
  - Exponential vs. straight-line curve fit?
- “Rear view mirror” focused

# Knowledge-based Telemetry Spectrum Needs Estimation

# Knowledge-based Spectrum Needs Estimation Tool

- Structured approach to capturing test program spectrum needs
  - Instrumentation engineer:
    - “Platform” capabilities
      - Data sources and bitrates
      - Transceiver “packages”
  - CTF scheduler:
    - Test program phases and operation
    - Transceiver “packages” req’d
  - Mbps translated into MHz



# Definition of Telemetry Capabilities

**Entity Package** *Collection of Transceiver Packages attached to an "Entity" (Test Article, Platform, Ground Station, Other), total bitrate, total BW*

**Transceiver Package** *Logical set of Data Packages, modulation method, min/max frequency (MHz), add'l BW, total BW*

**Data Packages** *Logical grouping of Data Items, total bitrate*

**Data Items** *Data Item descriptor + Min/Max/Default bitrate*

# Test Program Definition

## Program Definition

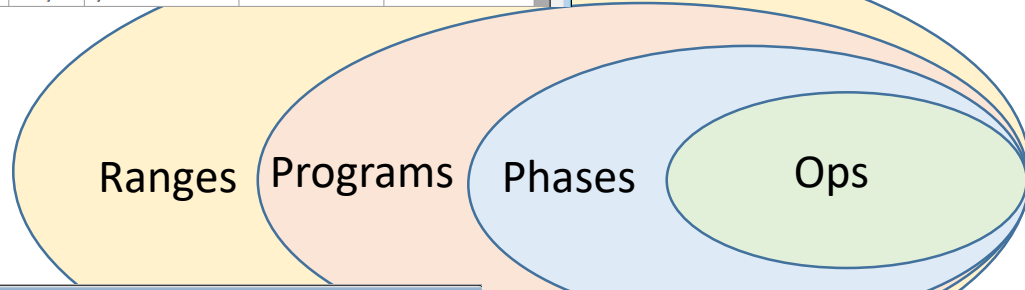
- Program name
- Program start / end dates
- Phases listing w/phase details

Phase	Description	Bitrate (Mbps)	Bandwidth (MHz)	Start Offset	Duration	Start	End
Lightning Phase I	Lightning Phase I	526	550.48	0 days	1 year	2/1/2019 12:00:00 AM	2/1/2020 12:00:00 AM
Lightning Phase II	Lightning Phase II	398	370	1 year	3 months	2/1/2020 12:00:00 AM	5/1/2020 12:00:00 AM
Lightning Phase III	Lightning Phase III	288	242.4	460 days	1 year	5/6/2020 12:00:00 AM	5/6/2021 12:00:00 AM

Entity	Description	Type	Bitrate (Mbps)	Total Tunable Range	Bandwidth (MHz)	Count	Total Bandwidth (MHz)
Ground Station Config 1	Ground Station Config 1	Ground Station	110	1435 - 4000	127.6	1	127.6
1435-1525 (L)	1435-1525	Other	0	1435 - 1525	32	1	32
F-16 Chase Package 1	F-16 Chase Package 1	Platform	18	2000 - 4000	20.88	1	20.88
F-16 Chase Package 1 Lead	F-16 Chase Package 1 Lead	Platform	18	2000 - 4000	41.88	1	41.88
F-35	F-35	Test Article	135	1435 - 4000	100.26	1	100.26

## Operation Definition

- Operation name
- Entity packages
- Duration
- Start parameters
  - Time of day
  - Day of week

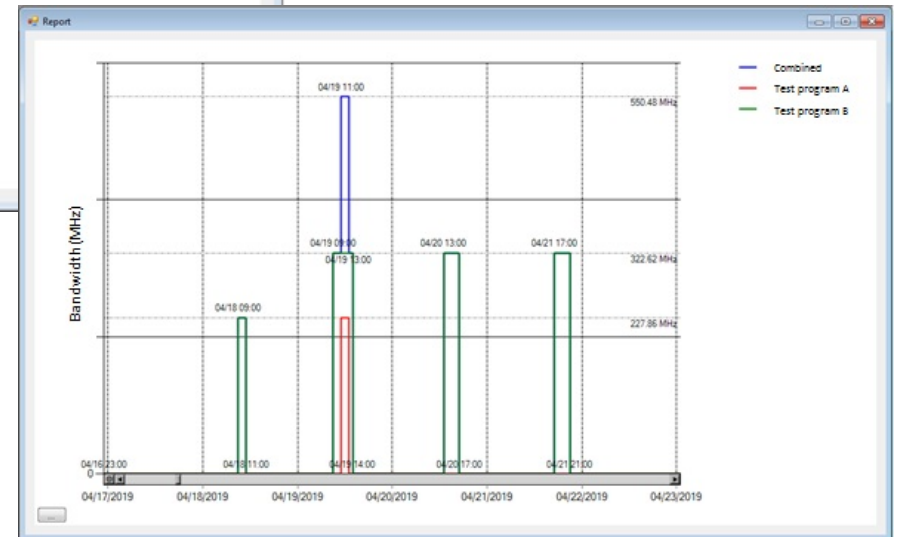
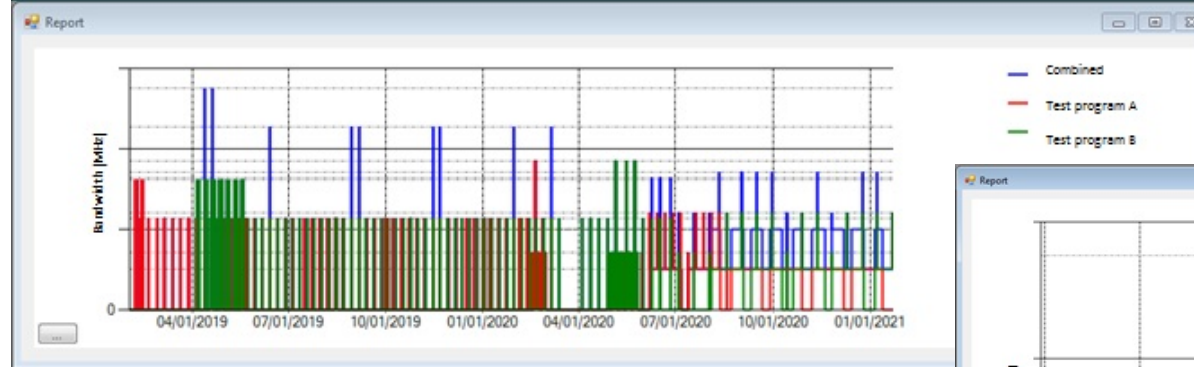
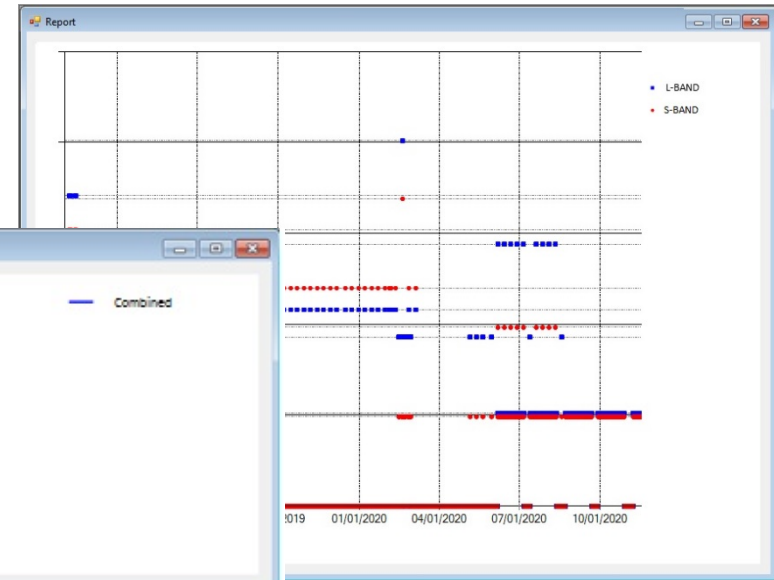
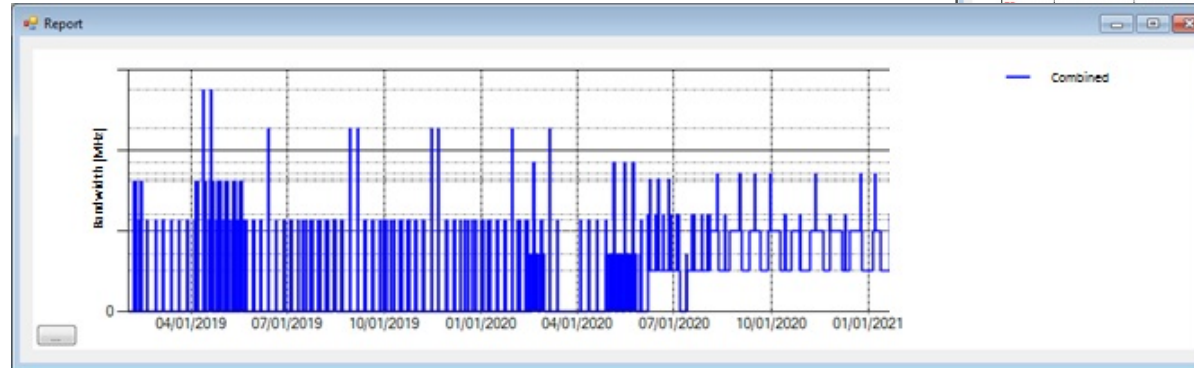


## Phase Definition

- Phase name
- Phase duration
- Start offset
- Operations listing w/operation details

Activity	Description	Start Offset	Duration	Restart Delay	Repeat	Entity Count	Total Bitrate (Mbps)	Total Bandwidth (MHz)
F-35 Operation 1	Operation 1	3 days	2 hours	1 day	1	5	281	322.62
F-35 Operation 2	Operation 2	1 week	2 hours	2 hours	2	2	245	227.86

# Reports



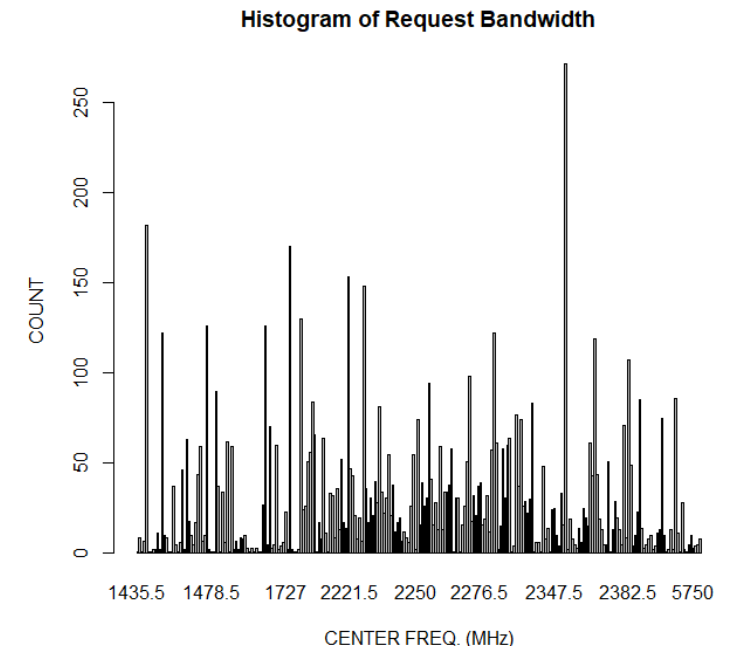
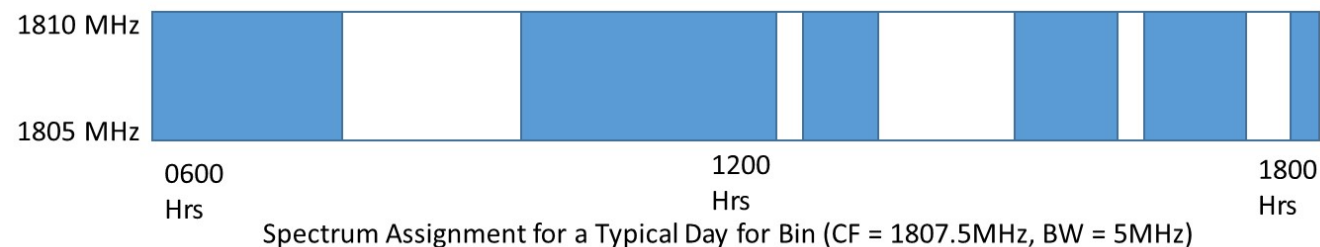
# Lessons Learned

- Simple demand aggregation in terms of Megahertz hours (MH) straightforward; peak MHz is not
- Possible approach to calculating maximum simultaneous spectrum demand:
  - Identify peak demand test or training scenario
  - Schedule the scenario at a fine-grained level (hour-by-hour)
  - NOTE: Same steps for cross-program calculation
- Prototype tool provides a structured method to define spectrum needs
  - Provides extensive “duplicate” and “save-as” features

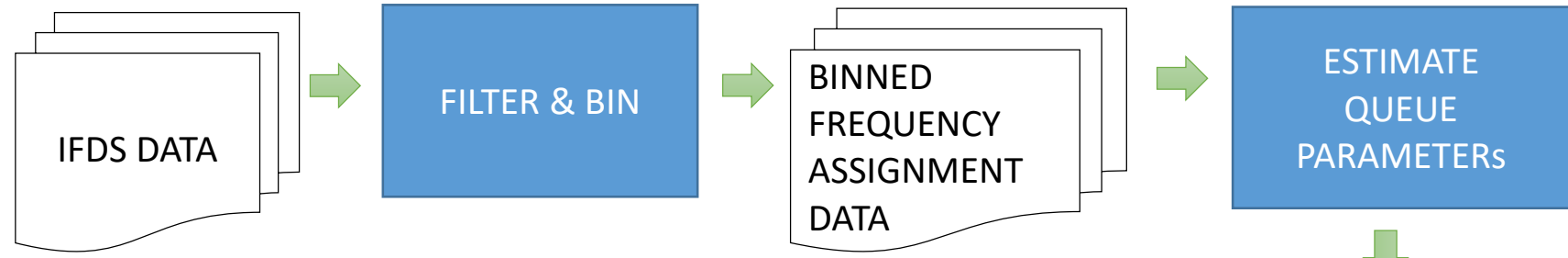
# Queueing-model-based Unaccounted Demand Estimation

# Queueing-model-based Unaccounted Demand Estimation Model

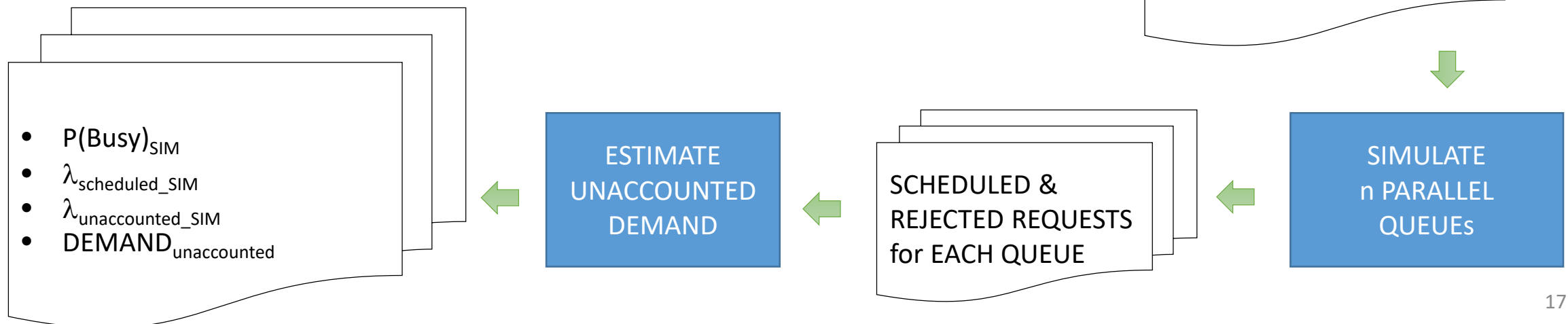
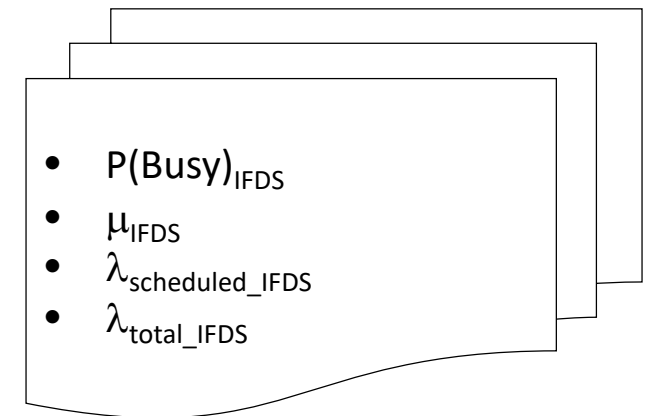
- Can we estimate unaccounted spectrum demand from frequency assignment data?
  - Unaccounted = Rejected, cancelled, not requested (expecting it won't be assigned)
- Intuition
  - If average request size is known (modeled as BinWidth in MHz), and
  - If probability of spectrum resource being busy (modeled as Prob(Busy)) is known, then
  - The unaccounted demand in bandwidth = Prob(Busy) \* BinWidth
- Solution approach -> use steady state properties of a M/M/1/K queuing system to estimate unaccounted demand
  - Based on M/M/1/K model (K = server + waiting room = 1 + 0)
  - Estimate  $\Pr\{\text{busy}\}$ ;  $\pi_1 = \rho / (1 + \rho)$ ; solve for  $\rho$ ;  $\rho = \lambda/\mu$
  - Estimate  $\mu$
  - Estimate  $\lambda_{\text{total}}$  using  $\lambda_{\text{observed}} = \lambda_{\text{total}} [1 - \Pr\{\text{busy}\}] = \lambda_{\text{total}} - \lambda_{\text{unaccounted}}$
  - $\lambda_{\text{total}} = \mu * \Pr\{\text{busy}\} / [1 - \Pr\{\text{busy}\}]$



# Methodology Overview



- Leverage IFDS historical data to estimate queue parameters
- Simulate parallel queues representing frequency bins
- Monitor scheduling performance of the queues
- Check actual versus simulated model parameters
- Estimate unaccounted demand



# Observations

- Queueing model approach appears promising as a way to estimate unstated demands
- Need to do a better job of capturing “cancelled” and “rejected” request data
- Need to further refine and validate queueing model

# Final Thoughts...

- Planned future testing more informative than historical patterns of use in estimating demand going forward
- Current spectrum allocations may limit spectrum and give the impression that the need is satisfied
- Need to further develop knowledge-based spectrum needs estimation method / tool
- Need to further test and validate queueing-model-based approach
- Should explore correlation of telemetry spectrum demand with:
  - Number of test programs
  - Developmental test and training budget year over year
  - Spectrum-efficient technology adoption levels

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