Simulation Approach for Aircraft Spare Engines & Engine Parts Planning

Operations Research & Advanced Analytics

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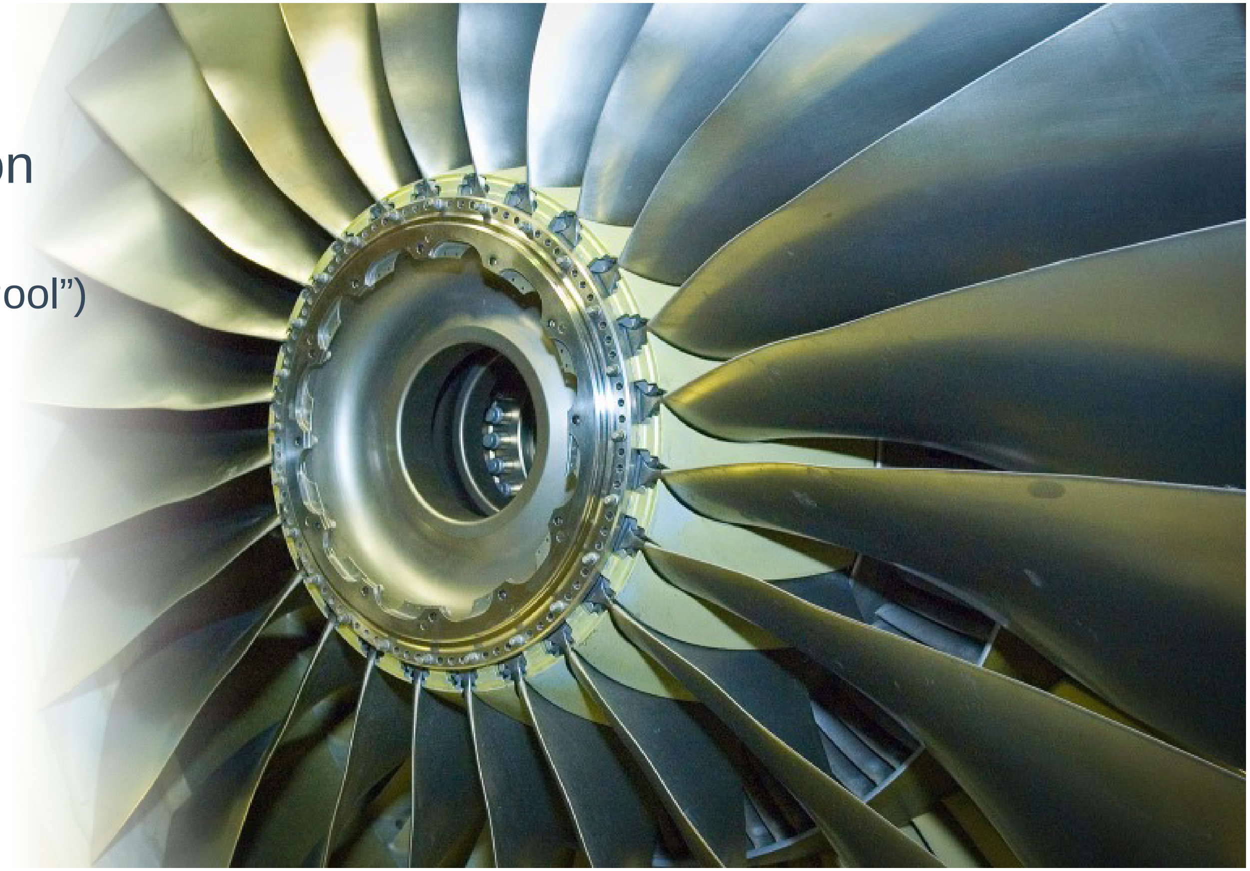
Outline

- Background
- Problem Description
  - Spare Engines
  - Engine Parts (“Shop Pool”)
- Approach
- Case Studies
- Impact to AA
- Conclusions



American Airlines

Largest airline in the world

More than 1000 aircraft

More than 500,000 bags per day

More than 300,000 passengers per day

Operations Research & Advanced Analytics Group at AA

- Internal consulting and decision support for business units:
  - Technical Operations (Tech Ops), Revenue Management, Network Planning, Airports and Customer Service
- 36 practitioners from more than 12 countries, 6 continents, 20 languages
- 60+ advanced degrees in Operations Research or equivalent
- 20 patents and 75+ journal articles

Operations Research

Maintenance Operations in American Airlines

- Critical in operations support
  - Reliability of aircraft
  - Utilization of aircraft
- Multiple bases
  - Tulsa, OK
  - Charlotte, NC
  - Dallas, TX
- Different capabilities
  - Engines
  - Landing gear
  - Avionics systems
  - Full aircraft overhaul
- OR consulting services
  - Inventory & supply chain
  - Line maintenance
  - Aircraft overhaul
  - Reliability & asset planning

Operations Research

Spare Engines & Engine Parts Planning

- Engines and parts are high cost assets

Engine ownership + Part inventory →

- Significant savings can be obtained from good planning

Good Planning →

Spare Engines Planning

Critical Process

- Operationally
  - Engines require periodic overhaul
  - Spare engines required to cover the operation during overhaul

Boeing 737 Fleet: 250+ Planes and increasing… requiring $180M in spare engines

- Financially

Boeing MD80 – JT8D Engine

$1M

Boeing 737 – CFM56 Engine

$13M

Boeing 777-200 – Trent Engine

$35M

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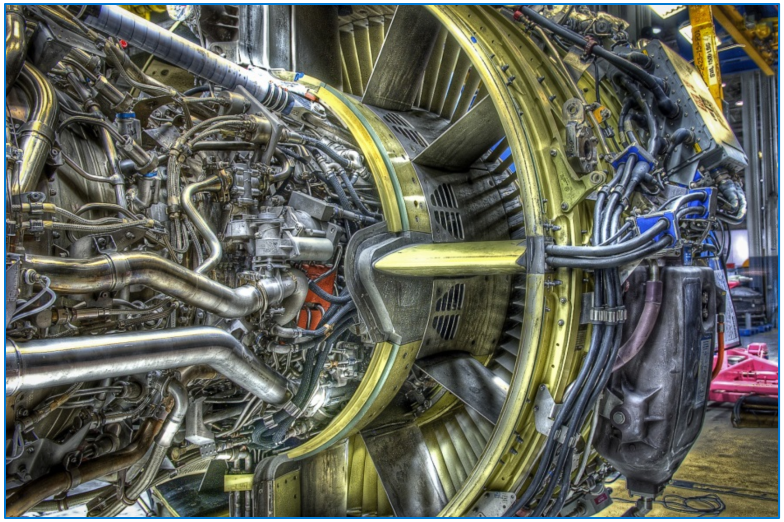
Engine Parts Planning

- The engine repair process is complex
  - Many sources of variability and uncertainty
  - Complex part repair process
    - Scrapping
    - Cannibalization or borrowing of parts from other engines
    - Engine harvesting
  - Accurate engine parts planning (Shop Pool)
    - Reduce engine repair time & repair time variability
    - Reduce spare engine inventory ownership
  - Engine parts can also be very expensive: shop pool investments range above $70M



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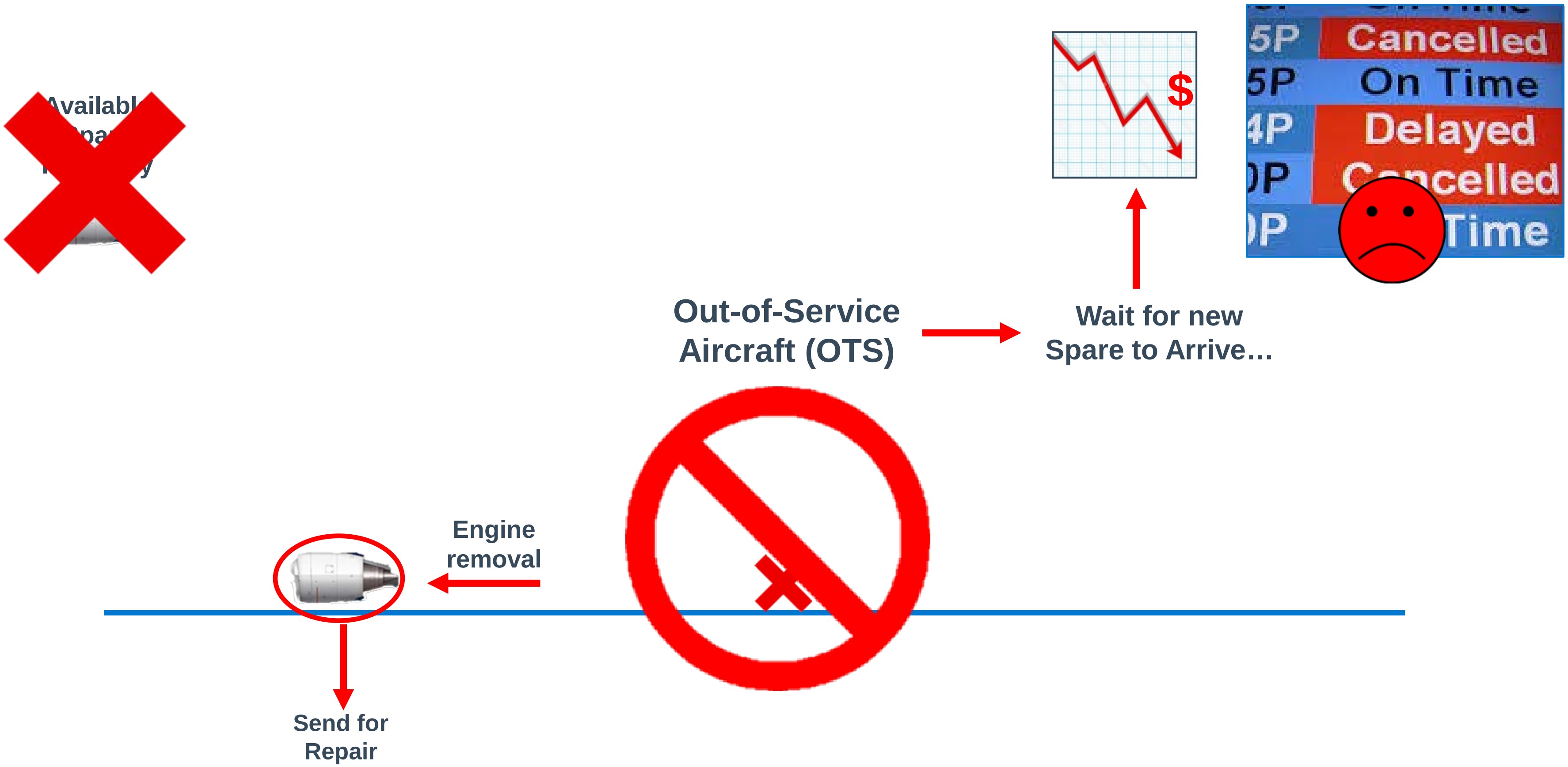
Spare Engines:
Removal Operations and Replacement Operations



Spare Engines:
Removal and Replacement Operations

Financially, it is beneficial to have the right amount of spares without overstocking!

Available Spare Inventory

Request new spare

Engine removal

Send for Repair

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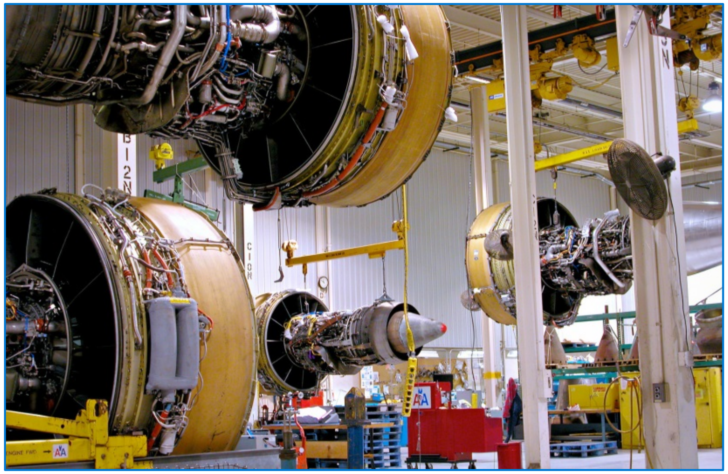
Engine Removal, Disassembling, Piece-Part Repair

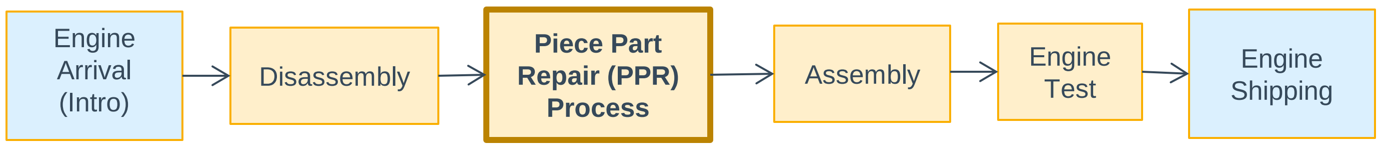
Engine Repair Programs



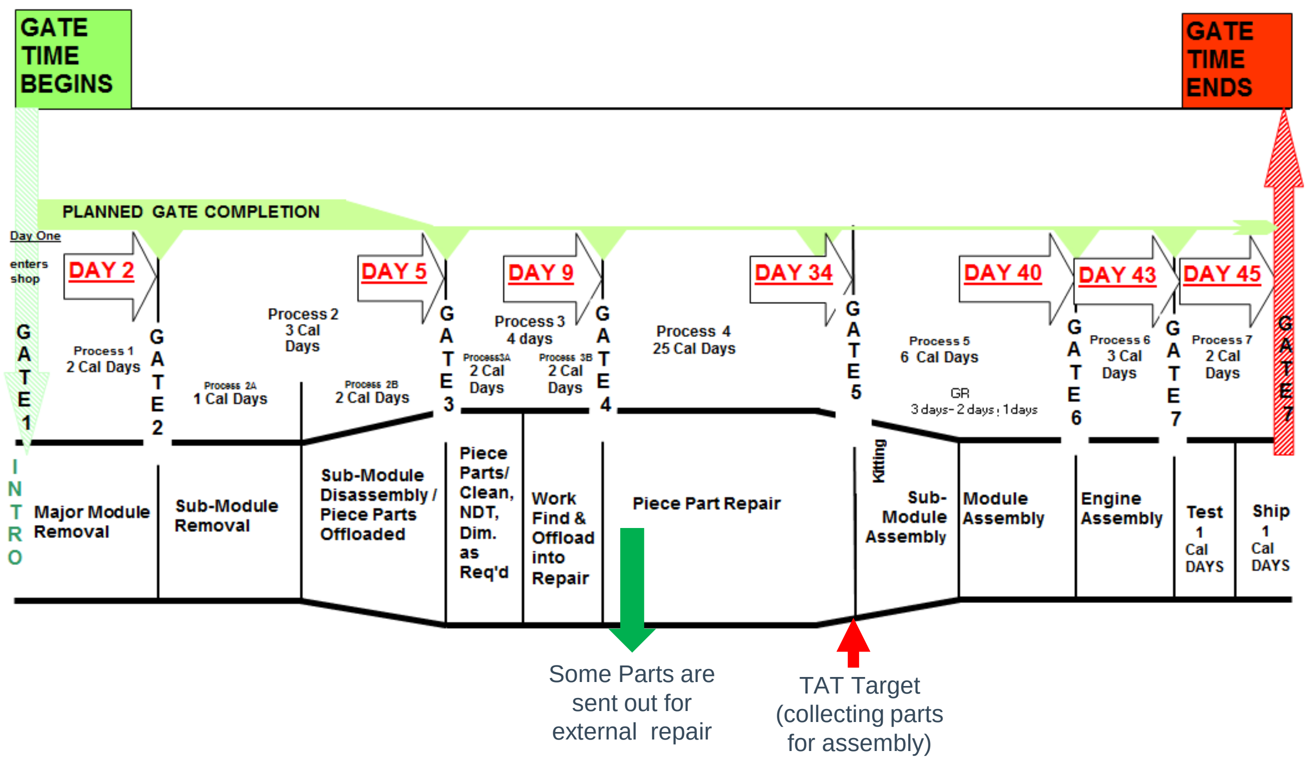
- Engines are repaired under different repair programs: Light & Heavy
- Opportunities for harvesting are considered in some cases
- Heavy repairs → longer turn-times and are more expensive (every 8-15 years)
- Process can include capacity constraints, scrapping procedures, and borrowing of parts

Engine Repair Process

General Engine Repair Process



A typical process map for engine overhaul



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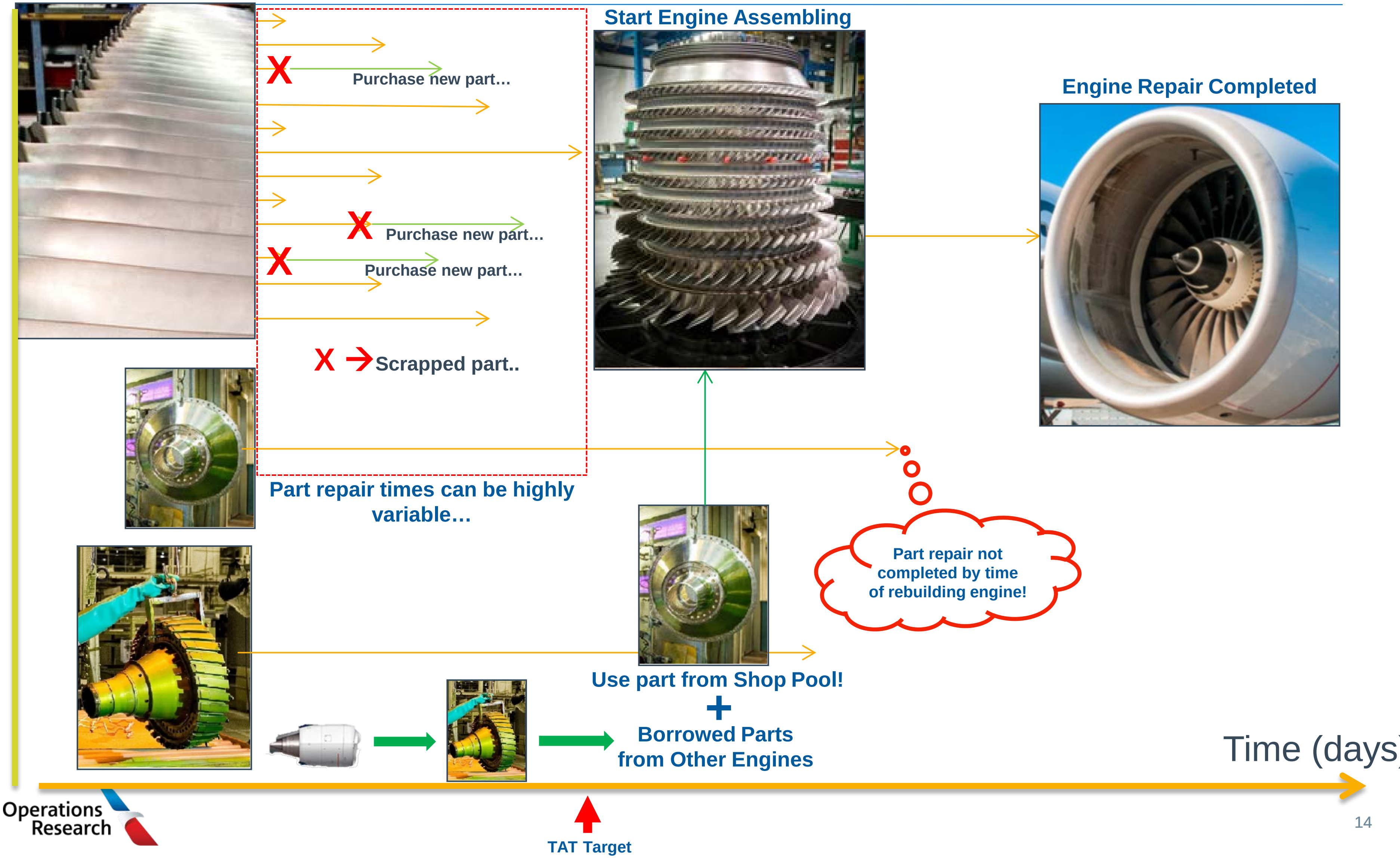
Engine Parts Repair Process: Piece-Part Repair, Assembling



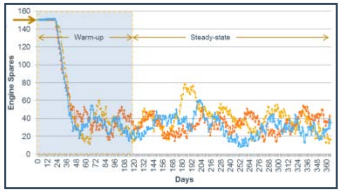
Objective

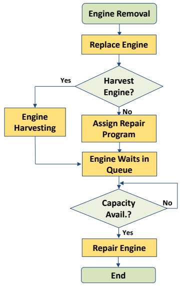
To determine the minimum number of spare engines and spare engine parts to support the flying schedule

Approach

- Closed-Form development
  - No mathematical model or formula is known for our scenario
    - Multiple sources of variability
    - General demand and repair distributions
  - We derived and solved a basic model with infinite repair capacity (paper to be submitted)
  - Limitations in the analytic approach led to simulation

- Simulation-based approach
  - Flexibility to model complex details
    - Borrowing of parts, scrapping, capacity constraints, engine harvesting processes
  - Use probability distributions for repair times, demand, etc.
  - Provides insight of the relationship between engine spare parts ownership and spare engines
  - Provides performance metrics for commercial aviation:
    - Out-of-Service (OTS) aircrafts
  - Allows What-If analysis





- Two models
  - Spare engines
  - Shop pool (spare parts)

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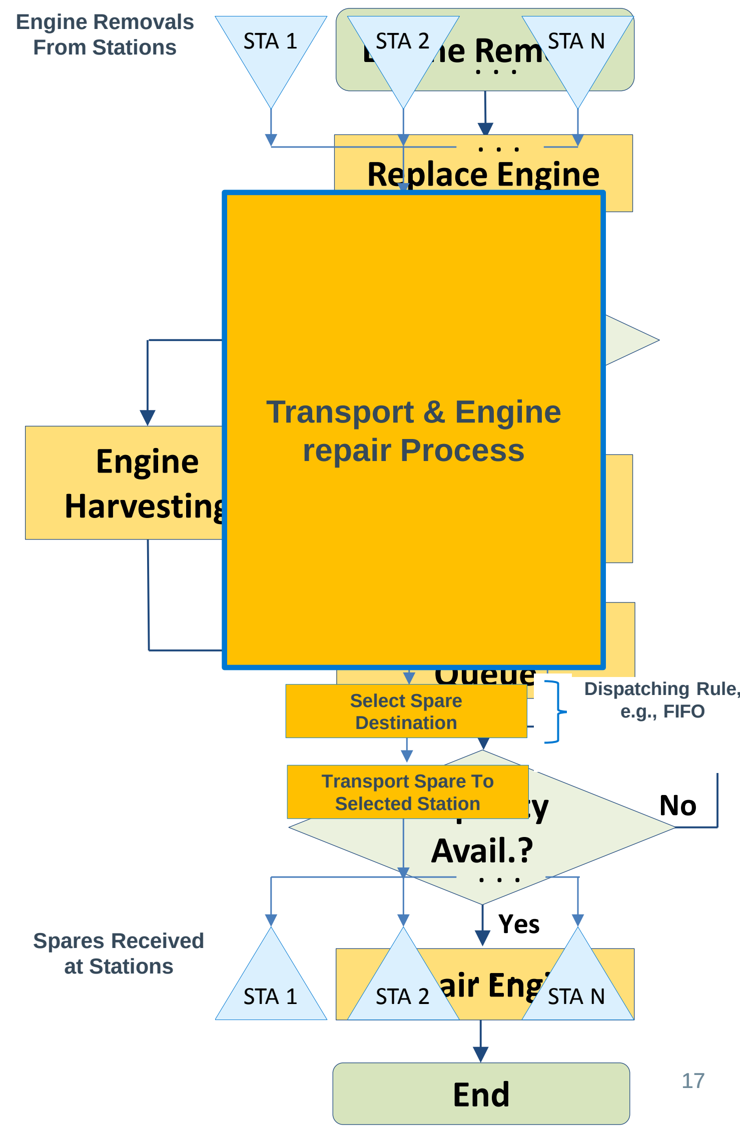
Engine Spare Model

- Repair is centralized
- Available inventory
  - Centralized: single location
  - Distributed: multi-location

- Key parameters:
  - Repair time
  - Demand
  - Capacity constraints
  - Harvesting schedule

- In the multi-location setting, dispatching rules are utilized to decide on the next station to receive the next serviceable spare

- Simulation is conducted in multiple replications where the output corresponds to variation of the spare level over time



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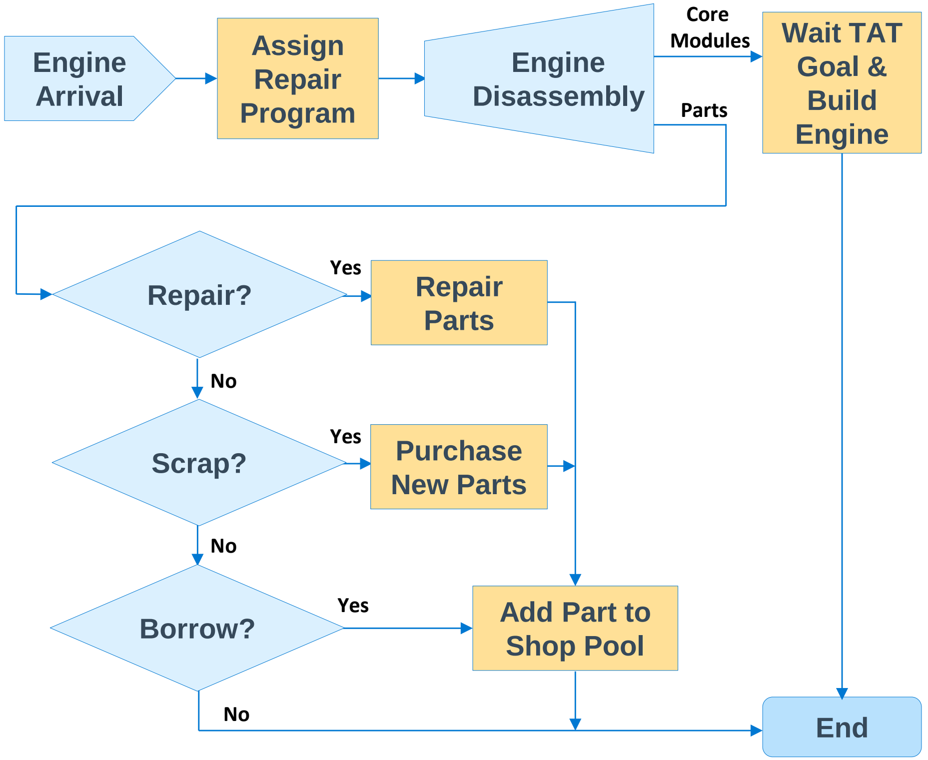
Performance Metrics & Estimating Ownership: Traditional Service Level & OTS Events

- Traditional Service Level:
  - Ratio of successfully satisfied engines or parts demand to the total number of spare requests received
  - Probability of availability of an engine or part when needed
  - Input used to estimate ownership from simulation output

- Out-of-Service (OTS) Aircraft Events Related-Metrics
  - Expected number of events
  - Expected duration

Shop Pool Model

- Lower level of the engine repair process
  - Piece-part repair (PPR) process
- Key parameters:
  - Engine turn-time (TAT) goal for PPR,
  - Repair probabilities
  - Scrap rates
  - Capacity constraints
- Simulation output corresponds to the variation of spare parts level over time
- Simulation conducted for 300+ different engine parts



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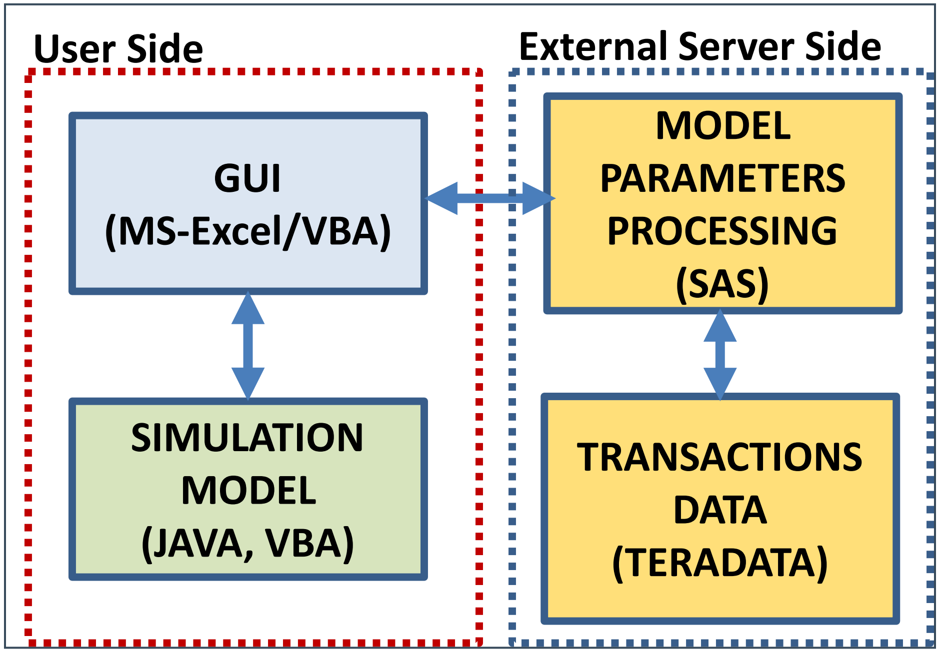
Software Implementation

- “Calculation tool” for the end-user
- Implements
    - User side
    - Server side



Shop Pool & Spare Engines Calculation Tools

- Software tools implemented for 4 different engines types CFM56 (B737), CF6-B6 (B767), RB211 (B757), and JT8D (MD80).
- Automation allows updating parameters using historical transactional data stored in AA's databases.

SPC (SHOP POOL CALCULATOR) - CFM56 Engine Parts

CALCULATIONS SUMMARY CASES WITH QPE=1, 2

Main Menu

Run Calculation

INPUTS: In this works
per repair type, the c
of Parts per Engine (
data. DO NOT CHANG
CALCULATION RESU
current list by enterin

Budgeted Engines Per Repair Type

Rep. Type	Proportion	Yearly	TATGoal
ESV1	5%	3	29
ESV2, 2s	72%	46	29
C&R	5%	3	29
LCL	19%	12	29

Engine Turn-Time -PPR Process (Gates 3 & 4)-

Rep. Type	TAT G3	TAT G4	TOTAL TAT
ESV1	4	25	29
ESV2, 2s	4	25	29
C&R	4	25	29
LCL	4	25	29

Engine Spares Calculator - CF6 - Ver. 1

Run Simulation

Inputs: White Fields
Outputs: Grey Fields

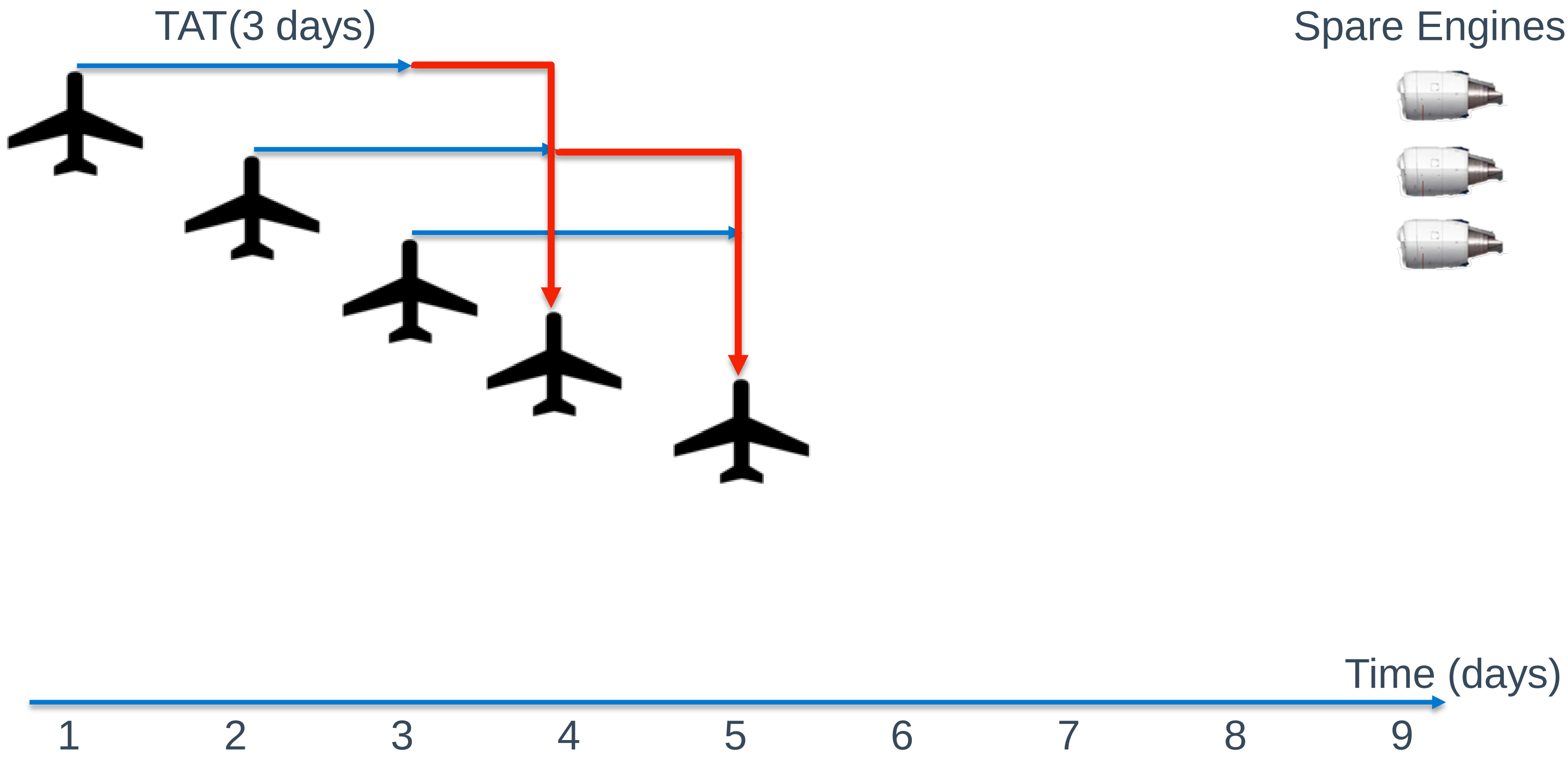
SCENARIO	REPAIR PROGRAMS TAT STATS & ENGINE REMOVAL FORECAST: EHM Mean	EHM Std. Dev.	EHM Forecast (racks)	HSC Mean	HSC Std. Dev.	HSC Forecast (racks)	HSM Mean	HSM Std. Dev.	HSM Forecast (racks)	C&R Mean	C&R Std. Dev.	C&R Forecast (racks)	LCL Mean	LCL Std. Dev.	LCL Forecast (racks)	OTHER PARAMETERS: PERIOD (Days)	SERVICE LEVEL (%)	CAPACITY HEAVY REPAIRS (Engines)	PRE/POST-INTRO WORK (DAYS): HEAVY	C&R	LCL	DEMAND STARVATION (Weeks)	SIMULATE SCENARIO (1-Yes / 0-No)		SIMULATION MODEL: OWNERSHIP	MAP	LAST SIMULATION RUN	WEIBULL MODEL: OWNERSHIP	MAP
1	42.4	9.3	14.0	42.4	9.3	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✓	1	7.20	3.27	7/17/2013 13:33	7.3	3.2
2	54.4	12.0	14.0	54.4	12.0	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✓	1	8.05	3.60	7/17/2013 13:33	8.2	3.5
3	64.4	14.2	14.0	64.4	14.2	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✓	1	8.61	3.72	7/17/2013 13:33	8.9	3.7
4	74.4	16.4	14.0	74.4	16.4	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✓	1	9.19	3.86	7/17/2013 13:33	9.7	3.8
5	84.4	18.6	14.0	84.4	18.6	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✗	0	9.80	4.04	7/17/2013 13:33	10.4	4.0
6	94.4	20.8	14.0	94.4	20.8	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✗	0	10.40	4.20	7/17/2013 13:33	11.1	4.2
7	104.4	23.0	14.0	104.4	23.0	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✗	0	10.97	4.33	7/17/2013 13:33	11.8	4.3
8	114.4	25.2	14.0	114.4	25.2	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✗	0	11.59	4.51	7/17/2013 13:33	12.5	4.5
9	124.4	27.4	14.0	124.4	27.4	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✗	0	12.09	4.58	7/17/2013 13:33	13.2	4.7
10	134.4	29.6	14.0	134.4	29.6	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	900	7	13	13	0	✓	1	15.14	5.17	7/17/2013 13:50	13.9	4.8
11	54.4	12.0	14.0	54.4	12.0	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	8.05	3.60	7/17/2013 13:34	8.2	3.5
12	64.4	14.2	14.0	64.4	14.2	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	8.60	3.72	7/17/2013 13:34	8.9	3.7
13	74.4	16.4	14.0	74.4	16.4	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	9.22	3.90	7/17/2013 13:34	9.7	3.8
14	84.4	18.6	14.0	84.4	18.6	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	9.78	4.03	7/17/2013 13:34	10.4	4.0
15	94.4	20.8	14.0	94.4	20.8	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	10.43	4.3	7/17/2013 13:34	11.1	4.2
16	104.4	23.0	14.0	104.4	23.0	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	11.07	4.5	7/17/2013 13:34	11.8	4.3
17	114.4	25.2	14.0	114.4	25.2	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	11.72	4.7	7/17/2013 13:34	12.5	4.5
18	124.4	27.4	14.0	124.4	27.4	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✗	0	12.4	5.0	7/17/2013 13:34	13.2	4.7
19	134.4	29.6	14.0	134.4	29.6	6.0	54.3	12.6	2.0	57.4	36.5	8.0	14.7	15.8	5.0	365	95%	9	7	13	13	0	✓	1	18.14	8.5	7/17/2013 13:50	13.9	4.8

HOS5026	1	0	0	1	1	2	3	4	✓	1	✓	1	2/4/13 1:10 PM	$ 10,586.00	1	1	Fan Frame
HOS5027	1	0	0	0	0	0	1	1	✓	1	✓	1	2/4/13 1:10 PM	$ 2,750.70	1	3	Fan Frame
HOUX106	1	0	0	0	1	2	3	3	✓	1	✓	1	2/4/13 1:10 PM	$ 3,867.00	1	1	Fan Frame
LEA3623	2	1	1	2	3	4	5	6	✓	1	✓	1	2/4/13 1:10 PM	$ 2,641.00	0	0	Fan Frame
LINX562	1	0	0	0	0	0	0	0	✓	1	✓	1	2/4/13 1:10 PM	$ 2,097.80	6	7	Fan Frame
LINX563	1	0	0	0	0	0	0	1	✓	1	✓	1	2/4/13 1:10 PM	$ 2,108.20	5	6	Fan Frame
LINX602	2	0	0	0	0	1	2	3	✓	1	✓	1	2/4/13 1:10 PM	$ 1,027.00	8	6	Fan Frame
MOUX057	1	0	0	1	1	2	2	3	✓	1	✓	1	2/4/13 1:10 PM	$ 2,428.00	3	1	Fan Frame
MOUX062	1	0	0	1	1	2	2	3	✓	1	✓	1	2/4/13 1:10 PM	$ 37,515.00	3	0	Fan Frame

INSTRUCTIONS | CALCULATIONS SUMMARY QPE=1,2 | CALCULATIONS SUMMARY QPE>2 | CALCULATIONS QPE=1,2 | CALCULATIONS QPE>2 LB | CALCULATIONS QPE>2 UB | COMPLETED RACKS | AUTHORIZED POOL & BOOKED QTY

Operations Research

Case Study:
Impact of Engine Repair TAT in Spare Ownership



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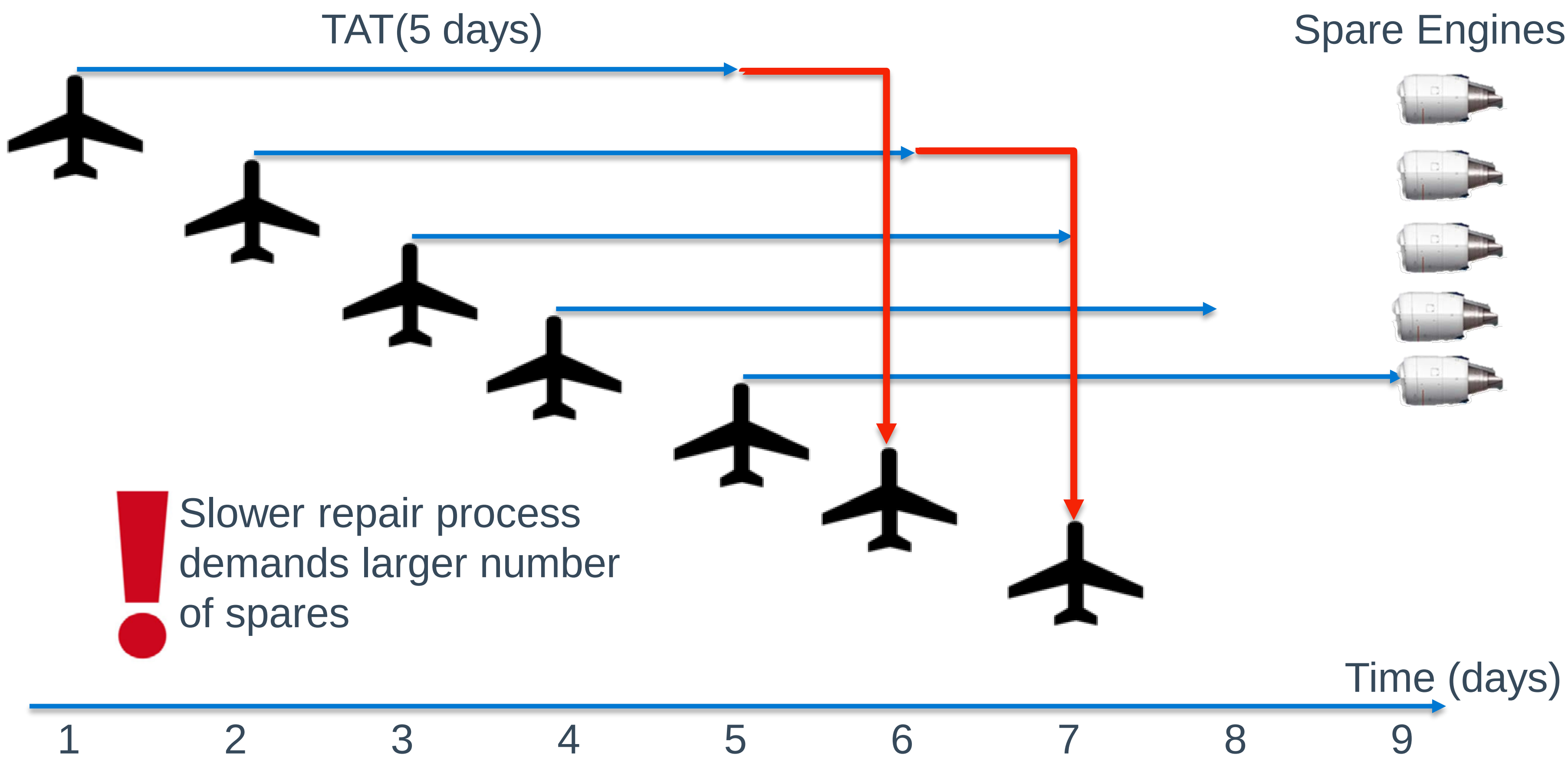

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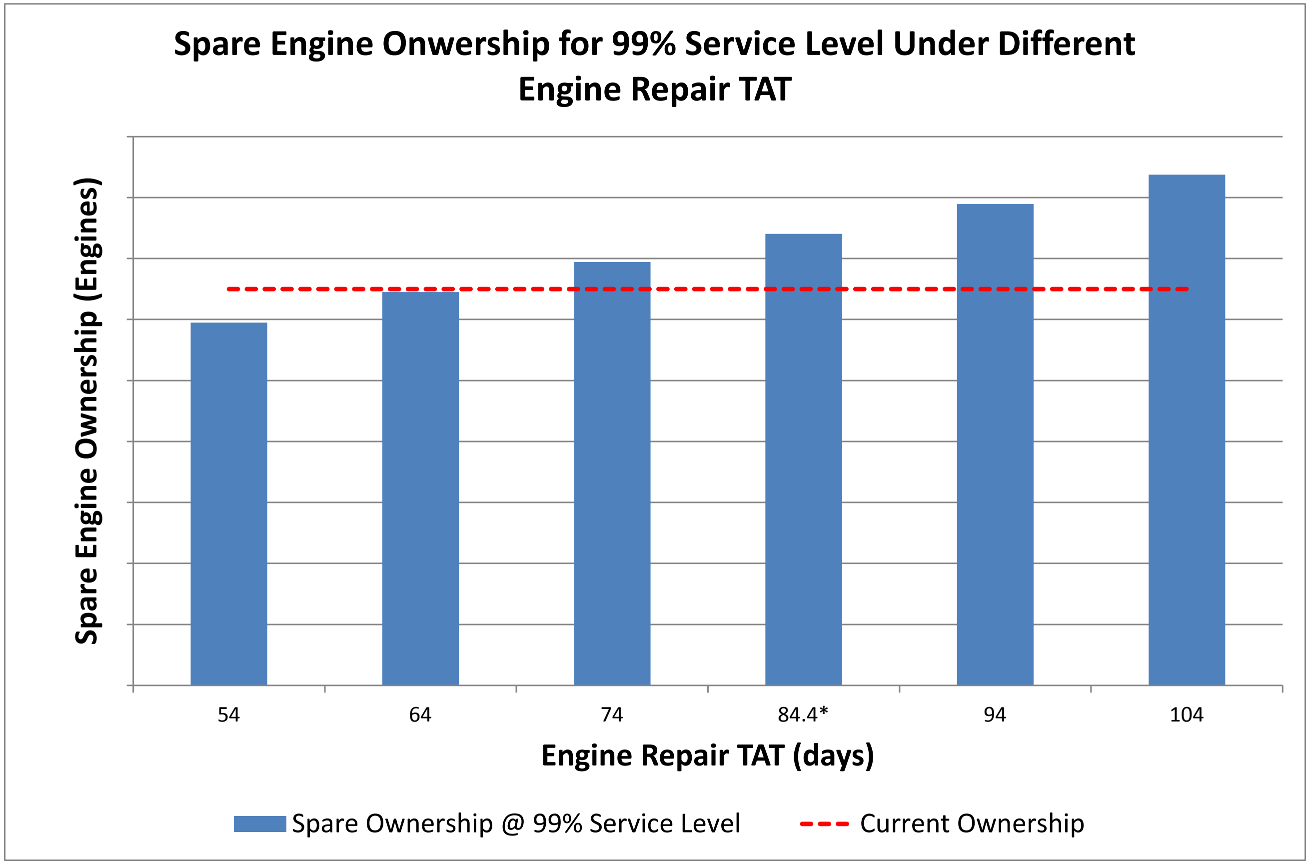

- Our models were used here to plan for the spare engine requirements at 99% service level as the airline planned to shorten the engine repair turn-around-time (TAT), leading to a lower number of spare engines requirement

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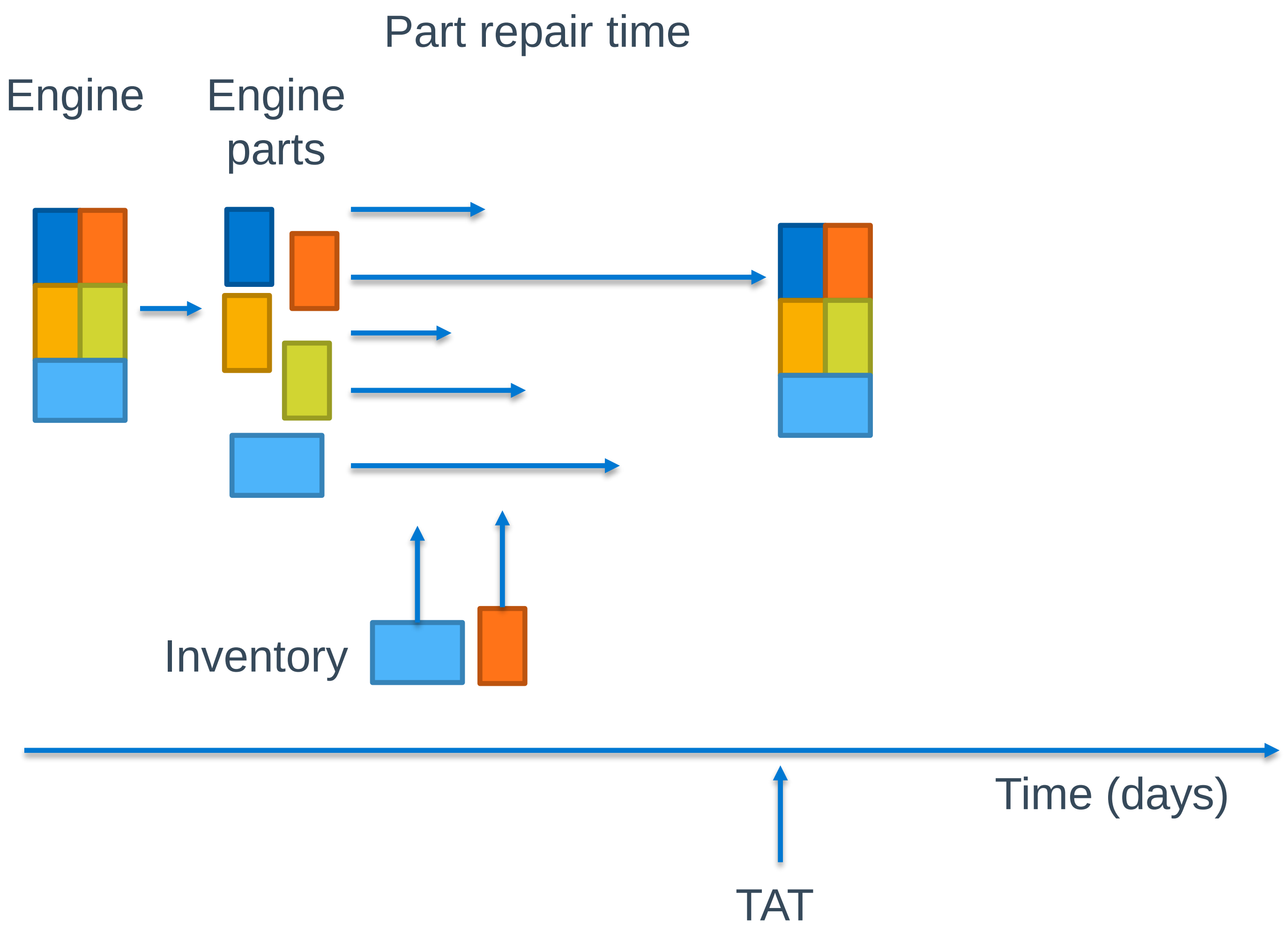
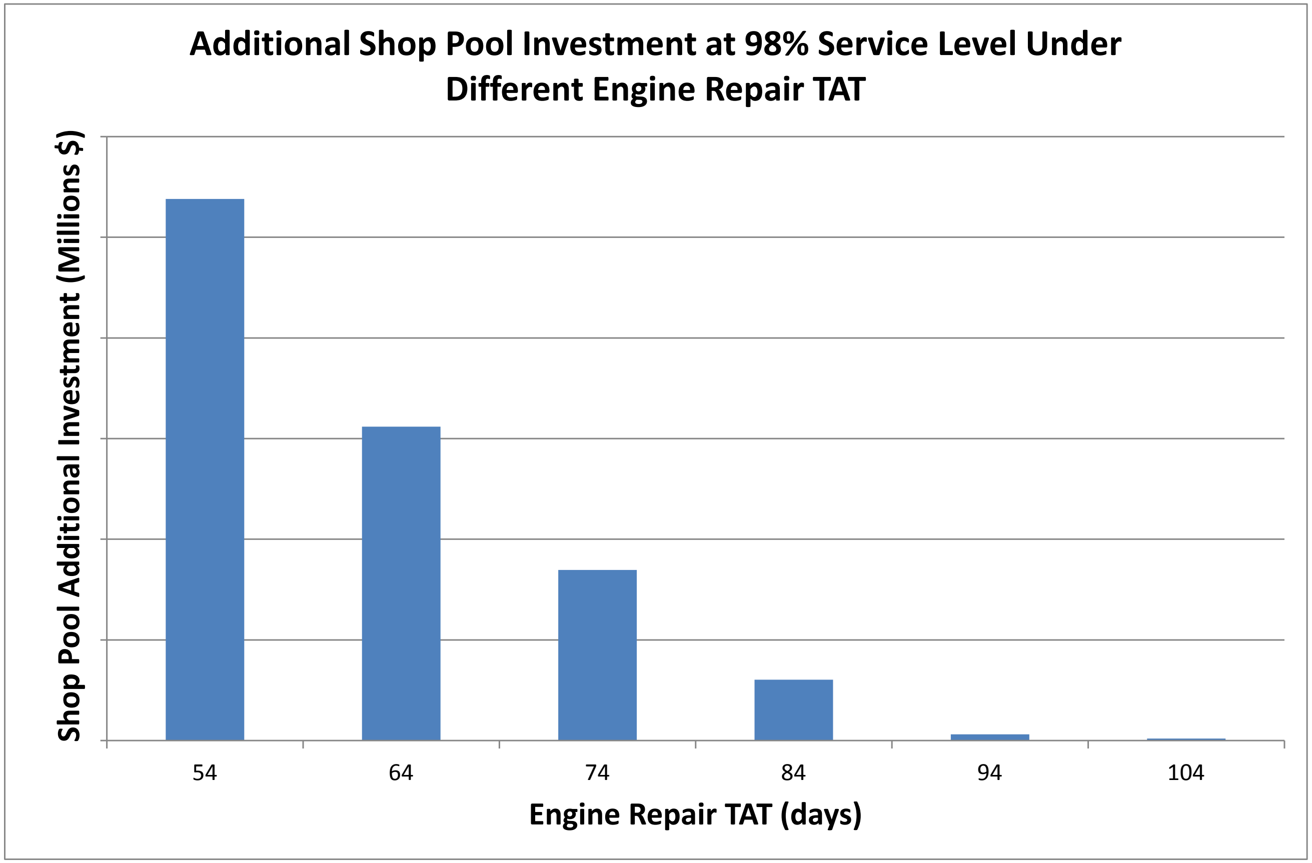
Case Study:
Impact of Engine Repair TAT in Shop Pool Investment



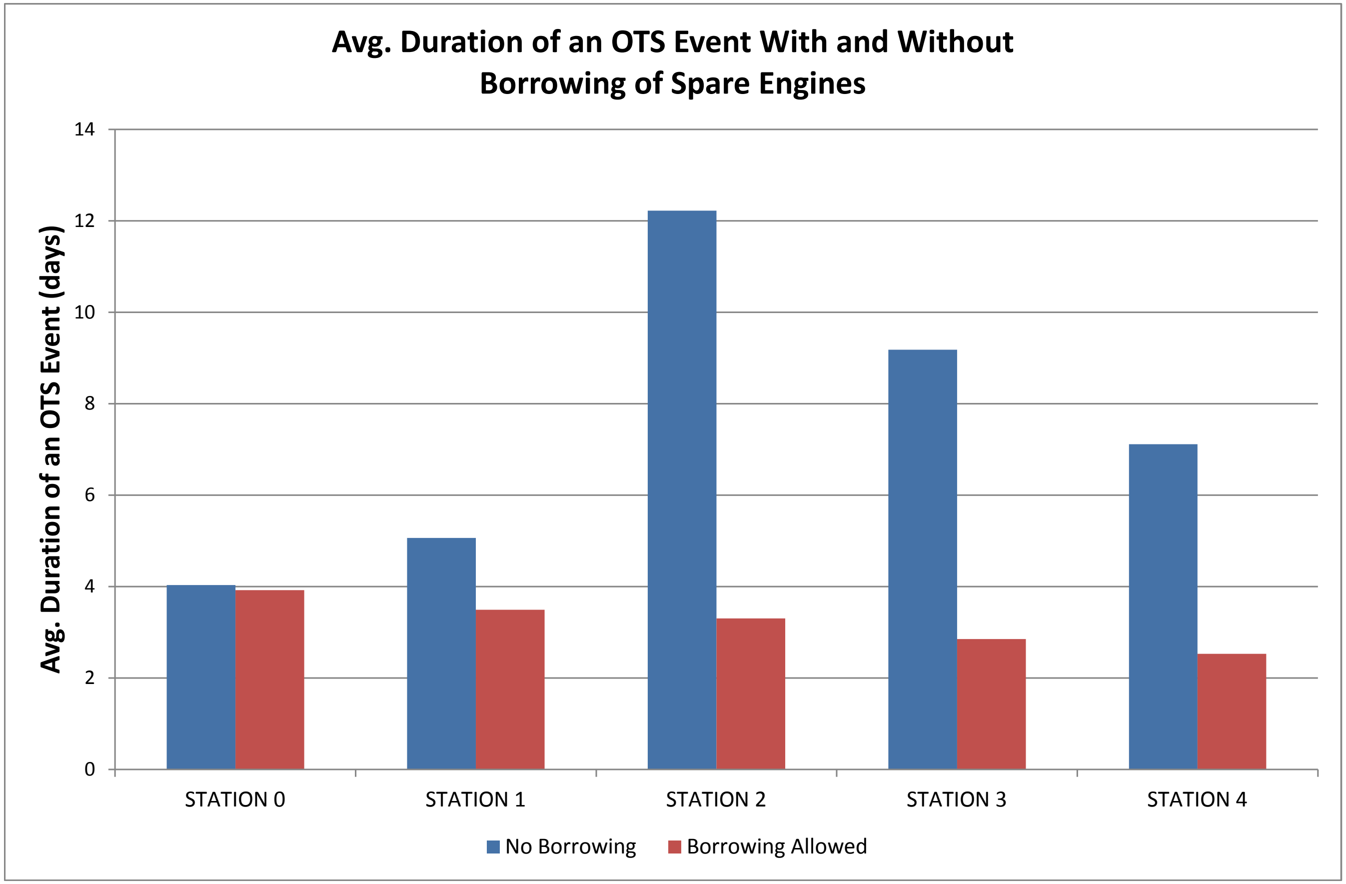
Case Study:
Impact of Engine Repair TAT in Shop Pool Investment



- Once the engine repair TAT goal was set, a second part of the planning process was to determine the level of shop pool investment required to achieve such goal. In general, decreasing the engine repair TAT leads to an increase in the shop pool investment

Operations Research

Case Study: Impact of Engine Spare Borrowing Between Stations on the Duration of OTS Events



- Measuring the duration of Out-of-Service Aircraft (OTS) events allowed us to develop borrowing rates in such way that hubs are better covered

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Impact to AA

- Better spare ownership planning

- Significant savings vs. previous manual methodologies
  - As AA upgrades the fleets, the more accurate planning methodology provides benefits
    - Retiring fleets
    - Growing fleets
  - Millions of dollars (e.g., 15%-27%) in shop pool parts

- Application is currently patent-pending

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Conclusions

- Simulation is the preferred approach due to the complex features of the repair processes and variability
- The simulation approach provides the necessary level of accuracy to plan for spare engines and engine parts given the financial and operational significance of the problem
- Simulation allow us to measure the service level in a more relevant way in terms of OTS related metrics
- Current extension to other key assets, e.g., Auxiliary Power Units

Operations Research

Acknowledgements

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    - Jim Diamond, Managing Director of Operations Research & Advanced Analytics in American Airlines
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- Finally, our thanks to the organization and judges of the INFORMS Innovation in Analytics Award competition for taking the time to review and evaluate our work, we really appreciate it