Aircraft Arrival Schedule Optimization

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Senior Design Finalist

Senior Design Project

Project Overview

Problem

- Irregular volume flow ➔ Operation delay ➔ ~$3.1 M Excess cost

Methodology

- Optimization of aircraft arrival schedule
- Simulation of volume flow

Deliverables

- Optimal scheduling and validation tools
- Revised schedule based on current parameters

Value

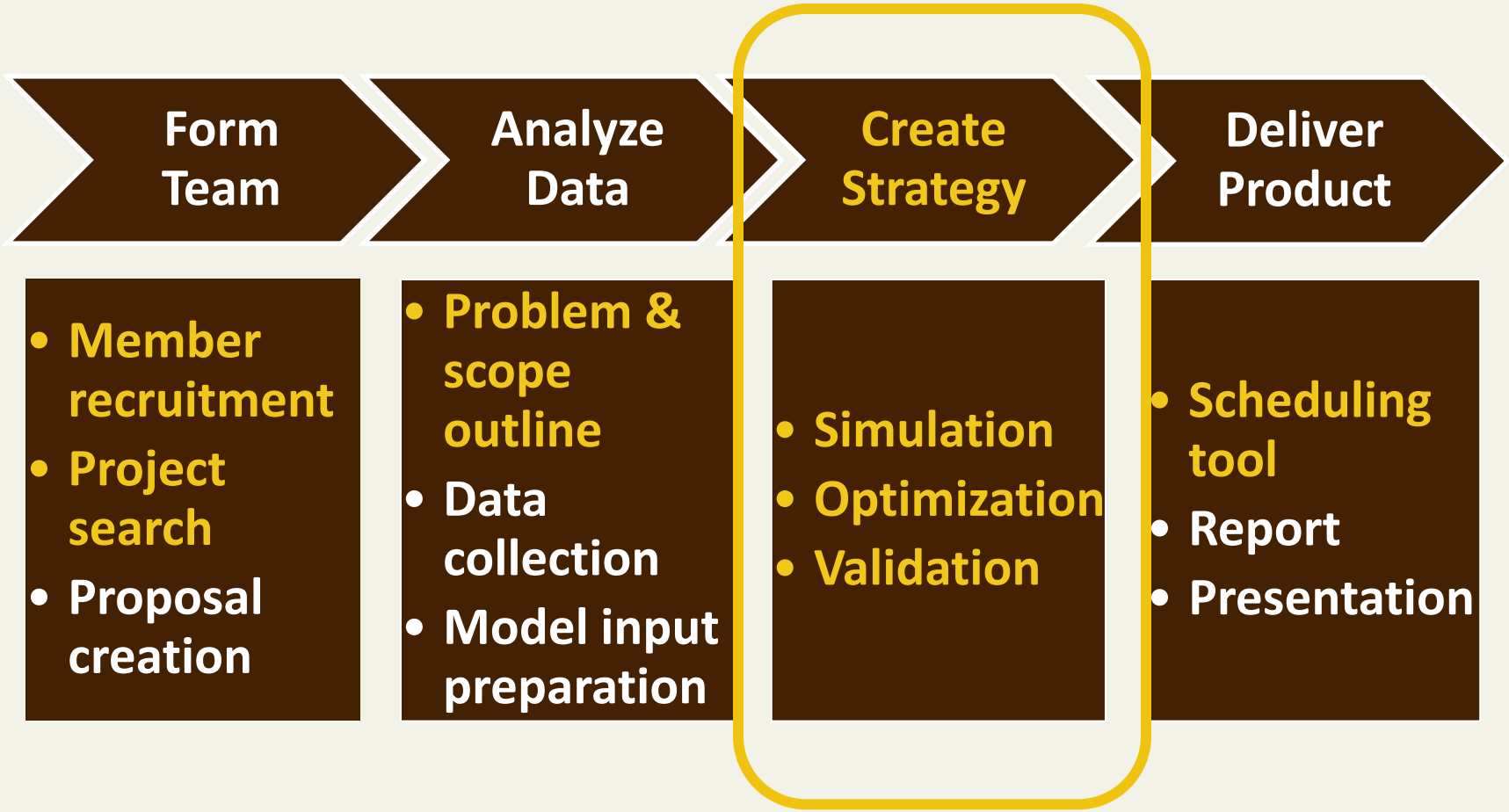
- Approximate annual savings: $1.7 M

Project Roadmap

7 months

Form Team	Analyze Data	Create Strategy	Deliver Product
• Member recruitment • Project search • Proposal creation	• Problem & scope outline • Data collection • Model input preparation	• Simulation • Optimization • Validation	• Scheduling tool • Report • Presentation

My Contribution



Client Description

Over 130 nightly aircraft arrivals

155 miles of conveyors

5.2M sq. ft.

1.6M packages sorted daily

400K packages/hr processed

Project Scope

- Westbound Volume
- Monday – Thursday
- 10:00PM – 2:15AM

In 4 hours 15 minutes,

- ~ 100 flights
- ~ 850K packages
- ~ 1600 containers

Problem Statement

Nightly operation delay

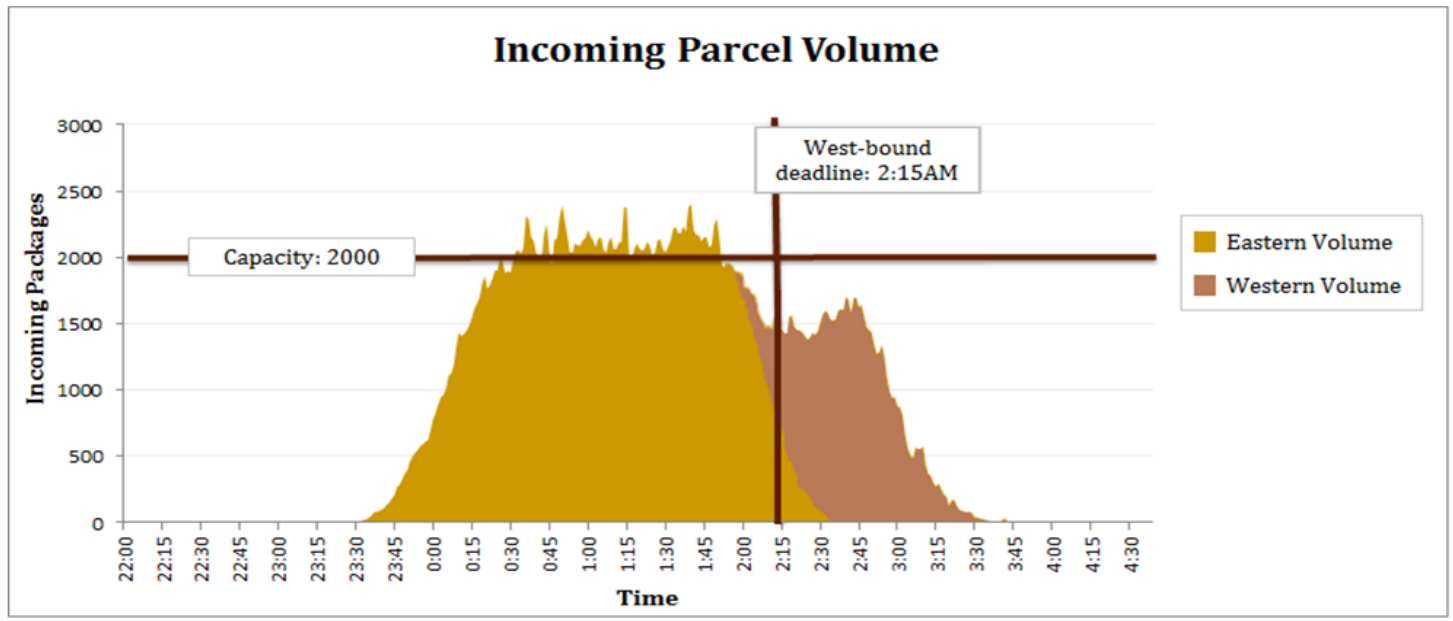
Problem

Cause

Volume flow exceeds capacity limits

Excess costs to Worldport & network

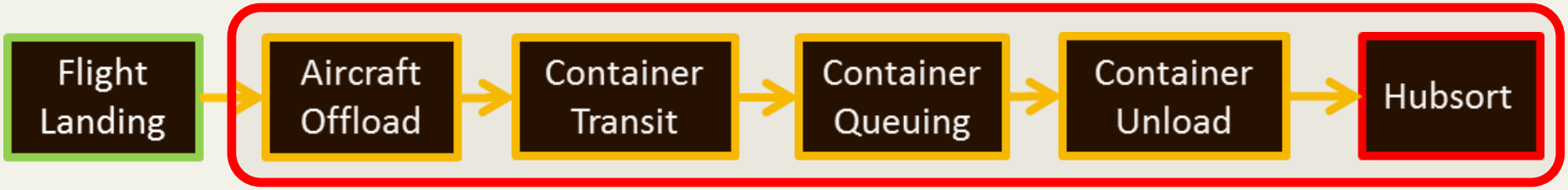
Effect



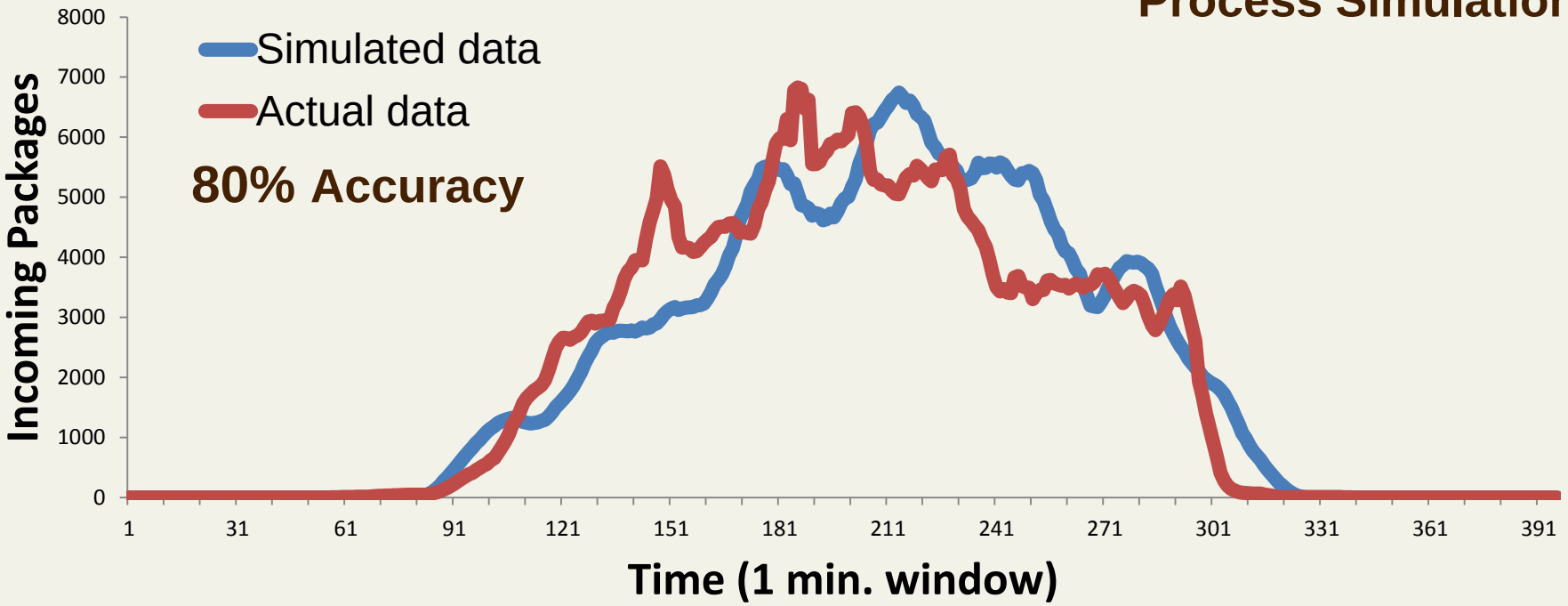
Simulation

Process Flow Simulation

Simulation Validation



Process Simulation



Optimization Model

Strategy

1. Schedule flights as late as possible
2. On-time shift completion

Objective Function

Maximize arrival lateness

Subject to

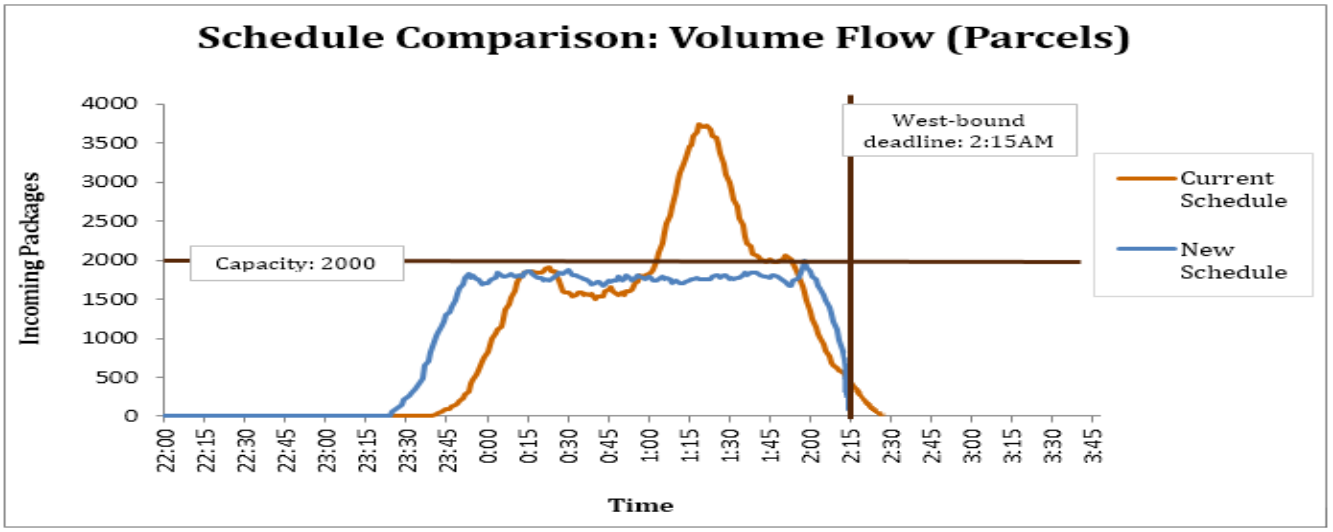
- Capacity constraints
- Deadline constraints
- Business constraints
- Landing constraints

Model Input

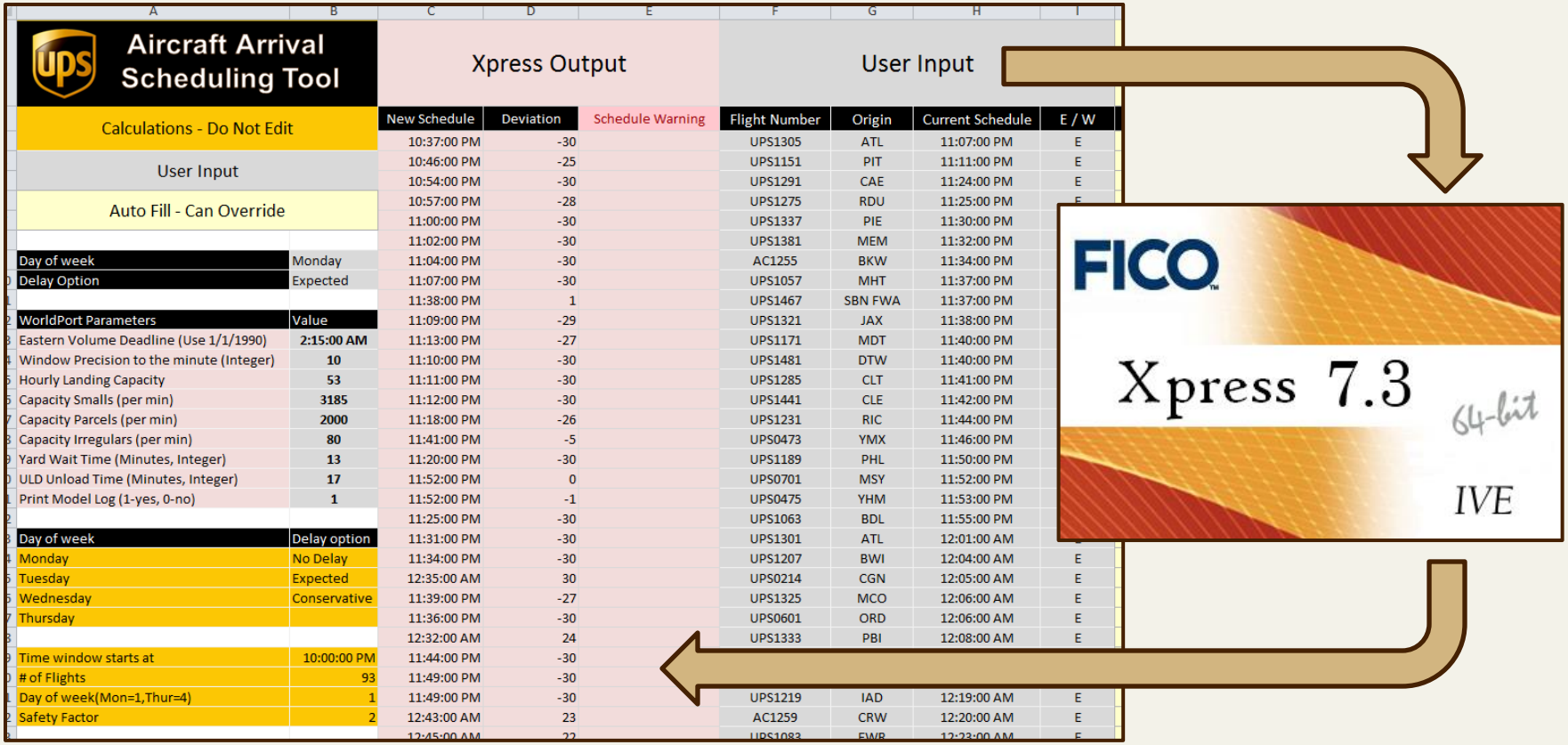
- Worldport parameters
- Flight arrival information
- Expected volume
- Flight specifics

Optimization Validation

Origin	Flight Number	Original Time	Proposed Time	Reschedule (mins)
ATL	UPS1305	11:07 PM	**10:52 PM**	-15
PIT	UPS1151	11:11 PM	**11:07 PM**	-4
PIE	UPS1337	11:30 PM	**11:22 PM**	-8
MEM	UPS1381	11:32 PM	**12:02 AM**	30
BKW	AC1255	11:34 PM	**11:26 PM**	-8
SBN FWA	UPS1467	11:37 PM	**11:07 PM**	-30
MHT	UPS1057	11:37 PM	**11:16 PM**	-21



Deliverables



Aircraft Arrival Scheduling Tool

Calculations - Do Not Edit

User Input

Auto Fill - Can Override

Day of week	Monday
Delay Option	Expected
WorldPort Parameters	Value
Eastern Volume Deadline (Use 1/1/1990)	2:15:00 AM
Window Precision to the minute (Integer)	10
Hourly Landing Capacity	53
Capacity Smalls (per min)	3185
Capacity Parcels (per min)	2000
Capacity Irregulars (per min)	80
Yard Wait Time (Minutes, Integer)	13
ULD Unload Time (Minutes, Integer)	17
Print Model Log (1-yes, 0-no)	1
Day of week	Delay option
Monday	No Delay
Tuesday	Expected
Wednesday	Conservative
Thursday	
Time window starts at	10:00:00 PM
# of Flights	93
Day of week(Mon=1,Thur=4)	1
Safety Factor	2

Xpress Output

User Input

New Schedule	Deviation	Schedule Warning	Flight Number	Origin	Current Schedule	E / W
10:37:00 PM	-30		UPS1305	ATL	11:07:00 PM	E
10:46:00 PM	-25		UPS1151	PIT	11:11:00 PM	E
10:54:00 PM	-30		UPS1291	CAE	11:24:00 PM	E
10:57:00 PM	-28		UPS1275	RDU	11:25:00 PM	E
11:00:00 PM	-30		UPS1337	PIE	11:30:00 PM	
11:02:00 PM	-30		UPS1381	MEM	11:32:00 PM	
11:04:00 PM	-30		AC1255	BKW	11:34:00 PM	
11:07:00 PM	-30		UPS1057	MHT	11:37:00 PM	
11:38:00 PM	1		UPS1467	SBN FWA	11:37:00 PM	
11:09:00 PM	-29		UPS1321	JAX	11:38:00 PM	
11:13:00 PM	-27		UPS1171	MDT	11:40:00 PM	
11:10:00 PM	-30		UPS1481	DTW	11:40:00 PM	
11:11:00 PM	-30		UPS1285	CLT	11:41:00 PM	
11:12:00 PM	-30		UPS1441	CLE	11:42:00 PM	
11:18:00 PM	-26		UPS1231	RIC	11:44:00 PM	
11:41:00 PM	-5		UPS0473	YMX	11:46:00 PM	
11:20:00 PM	-30		UPS1189	PHL	11:50:00 PM	
11:52:00 PM	0		UPS0701	MSY	11:52:00 PM	
11:52:00 PM	-1		UPS0475	YHM	11:53:00 PM	
11:25:00 PM	-30		UPS1063	BDL	11:55:00 PM	
11:31:00 PM	-30		UPS1301	ATL	12:01:00 AM	
11:34:00 PM	-30		UPS1207	BWI	12:04:00 AM	E
12:35:00 AM	30		UPS0214	CGN	12:05:00 AM	E
11:39:00 PM	-27		UPS1325	MCO	12:06:00 AM	E
11:36:00 PM	-30		UPS0601	ORD	12:06:00 AM	E
12:32:00 AM	24		UPS1333	PBI	12:08:00 AM	E
11:44:00 PM	-30					
11:49:00 PM	-30					
11:49:00 PM	-30		UPS1219	IAD	12:19:00 AM	E
12:43:00 AM	23		AC1259	CRW	12:20:00 AM	E
12:45:00 AM	22		UPS1083	EWR	12:23:00 AM	E

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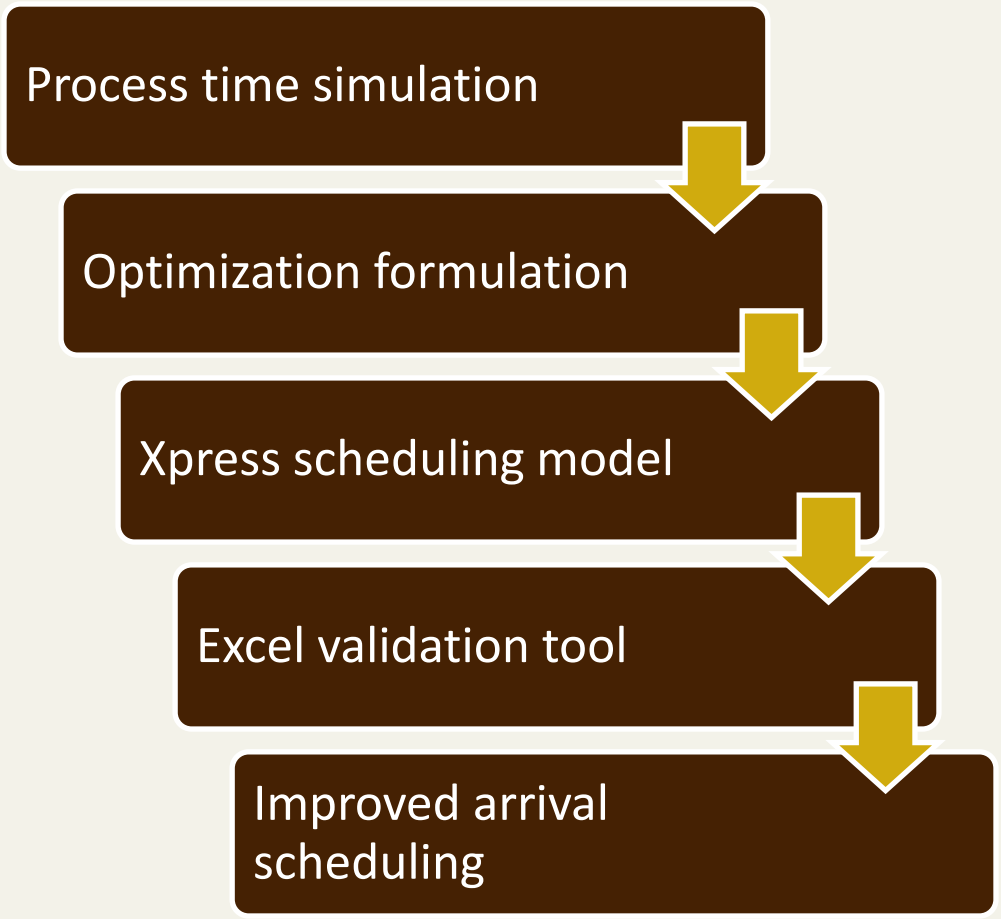
Summary



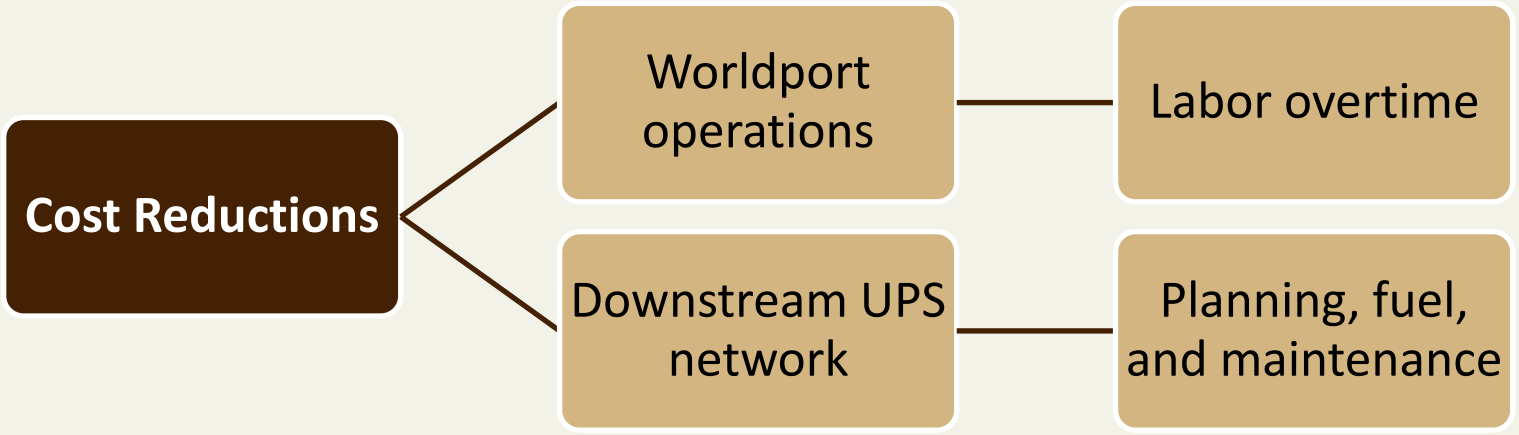
3.6M variables

2.4M constraints

<15 minute runtime

Project Results

- **Senior Design Finalist**: top 4 among 28 teams
- **Client Satisfaction**: attended our final presentation
- **Valid Results**: same as UPS internal team's
- **Cost Reductions**: $1.7 M annually

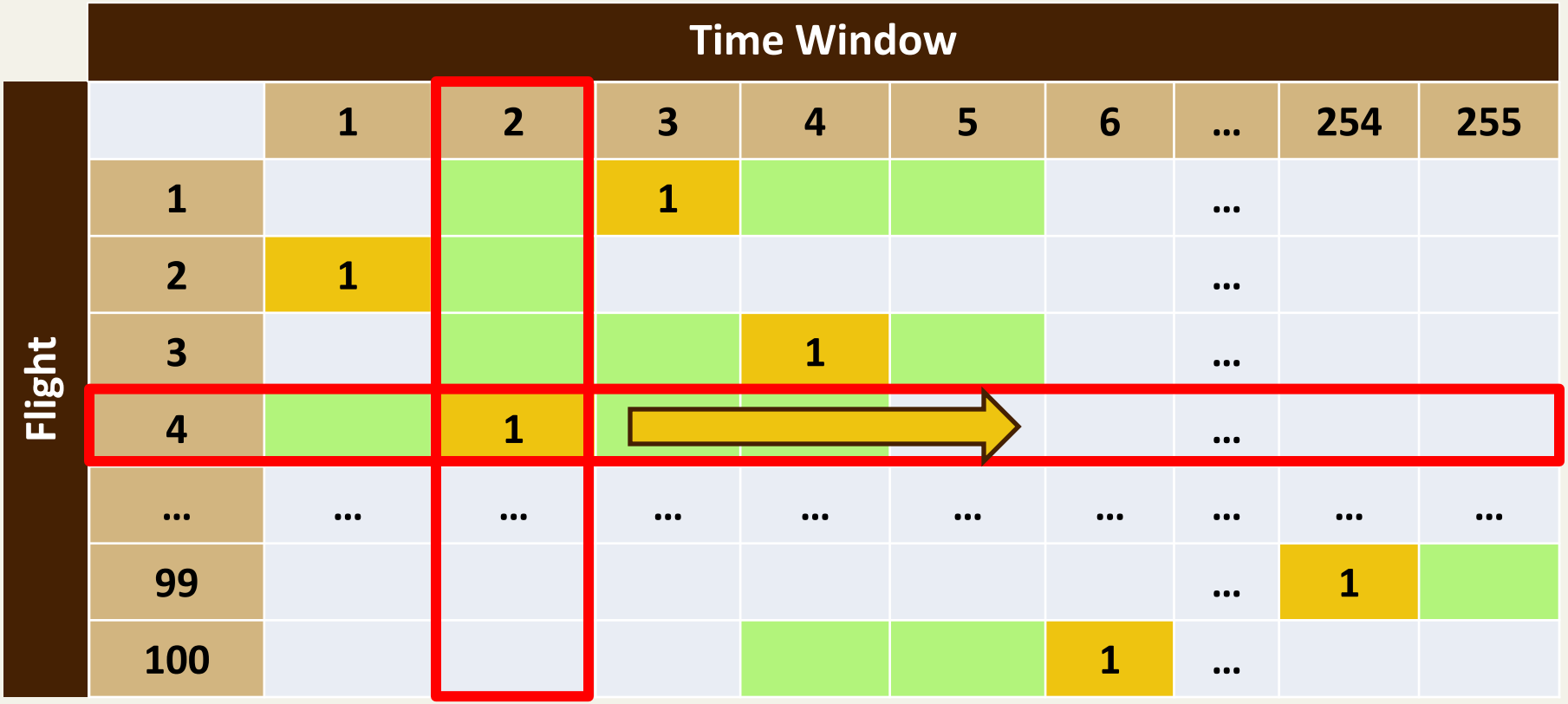


Thank You

Also Attached: Model Run Example & Appendix

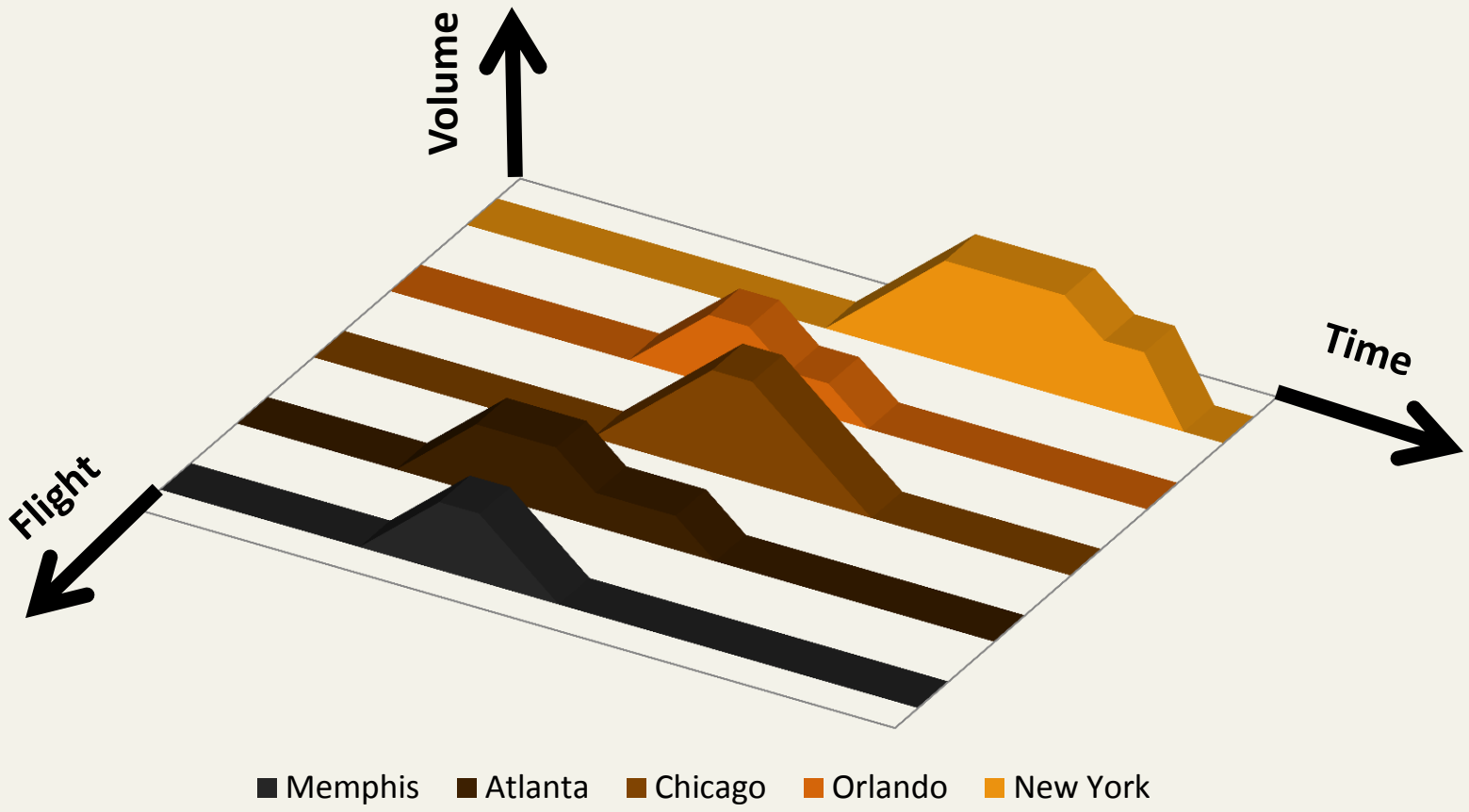
Model Run: Example

Flight Assignment Matrix



Model Run: Example

Volume Flow Profile

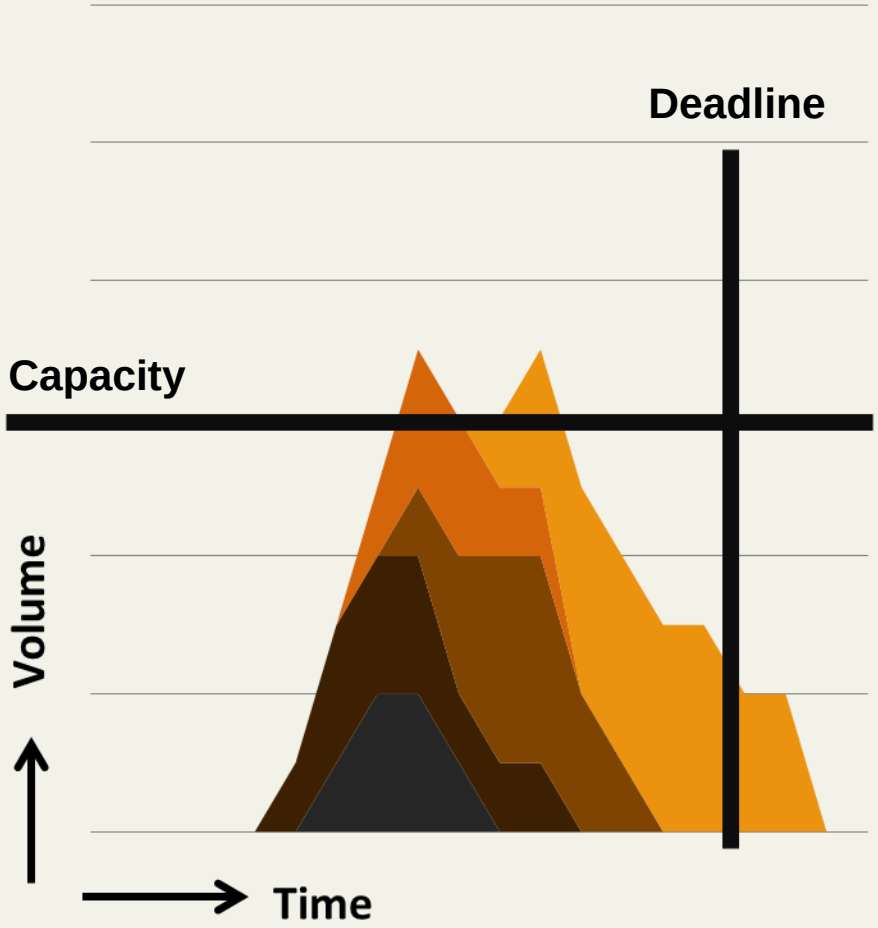


Model Run: Example

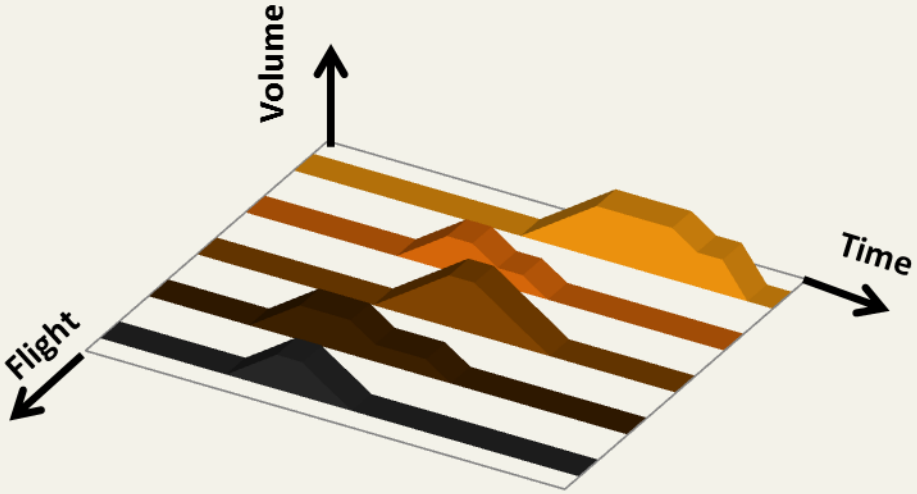
Assignment Matrix:

1										1
2							1			
3								1		
4					1					
5						1				

Total Volume Inflow:



Volume Flow Profile:



Model Run: Example

Assignment Matrix:

1								1		
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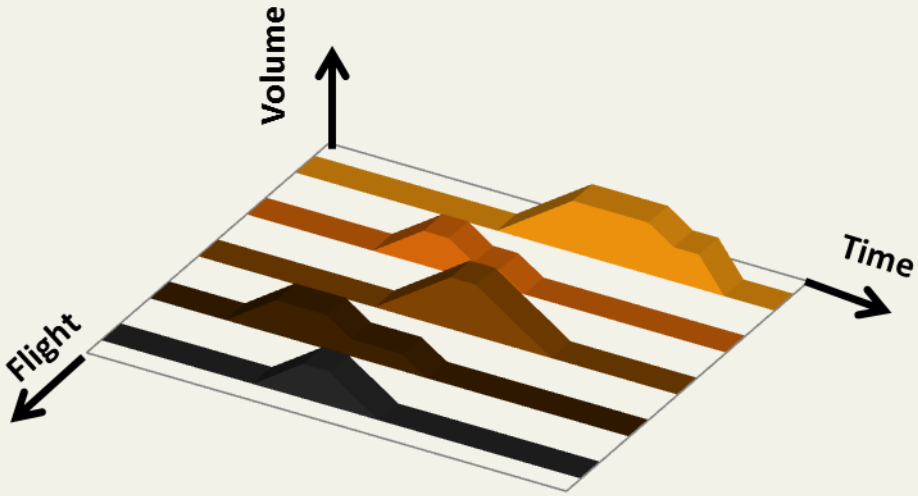
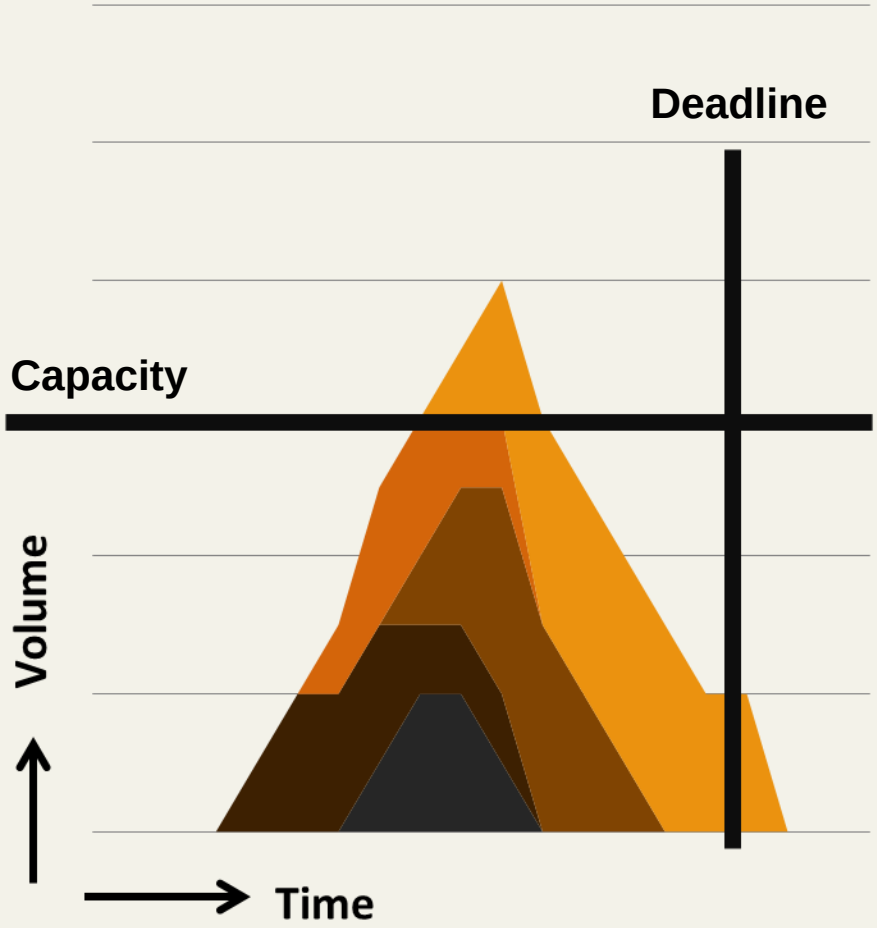
5							1			

Volume Flow Profile:



Total Volume Inflow:

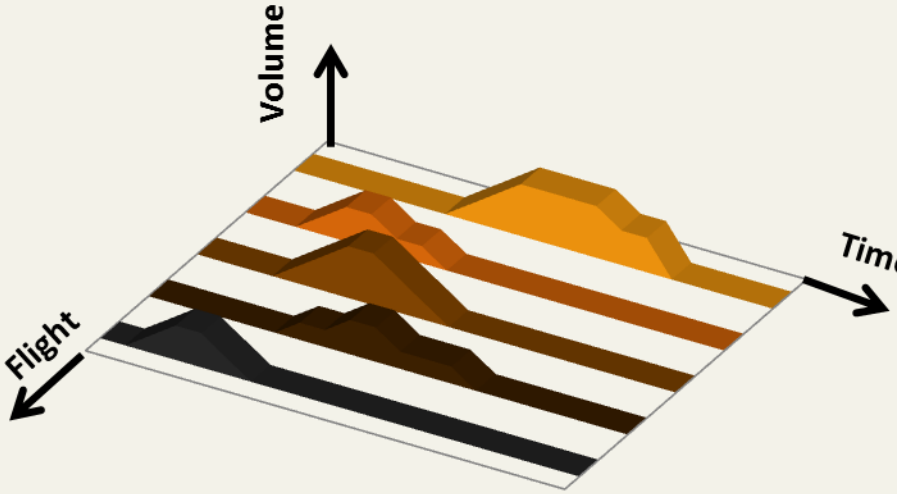


Model Run: Example

Assignment Matrix:

1							1				
2			1								
3				1							
4						1					
5		1									

Volume Flow Profile:



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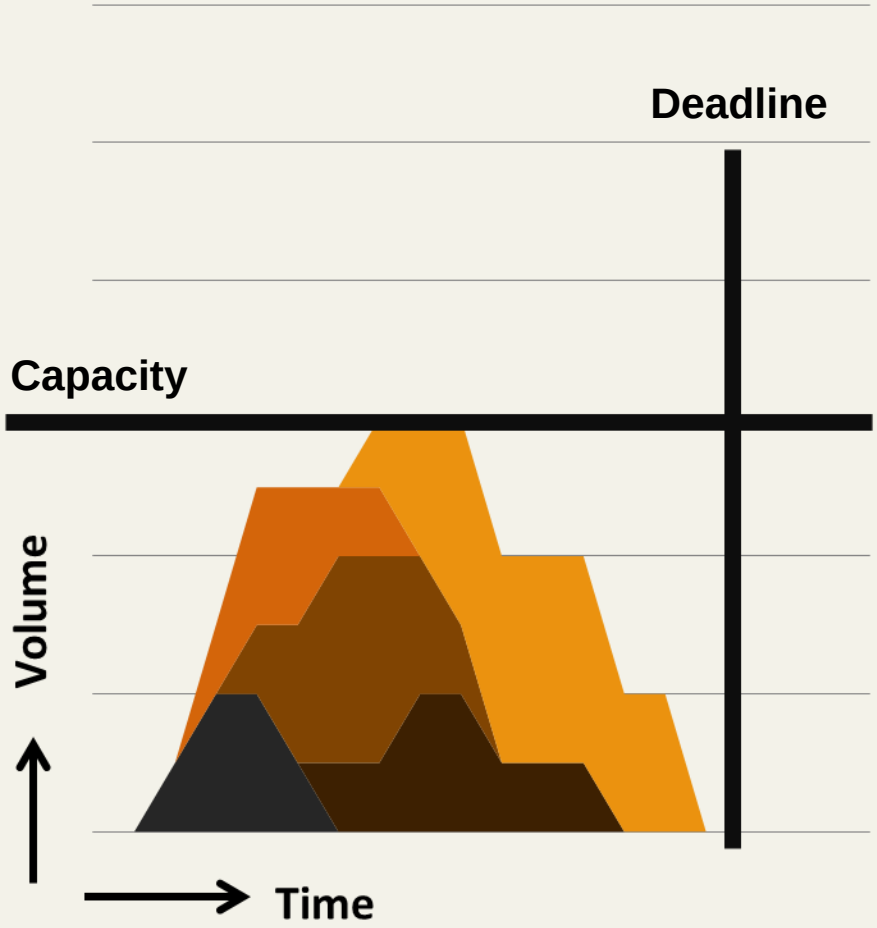

Appendix – Model

Parameters:

$i - Flight \quad (1 - \#\ Flights)$

$j - Time\ window \quad (1 - 300) \quad (10{:}00PM - 3{:}00AM, 1\ minute\ intervals)$

$u - \#th\ ULD \quad (1 - 40)$

$Package\ type - (1 - small, 2 - parcel, 3 - irregular):$

Note: All calculations related to ULD will be calculated three times for the three package types.

Flight Details:

$CSA_i - Current\ Scheduled\ Arrival\ for\ i$

$V_{i,k} - Volume\ of\ packages\ in\ flight\ i\ of\ type\ k$

$ST_i - Setup\ Time\ for\ flight\ i$

$UR_i - ULD\ unload\ Rate\ for\ flight\ i$

$TT_i - Transit\ time\ for\ ULDs\ for\ flight\ i$

$$TT_i = \begin{cases} 8.5\ minutes\ if\ flight\ i\ parks\ at\ Wing \\ 13\ \ minutes\ if\ flight\ i\ parks\ at\ Ramp \end{cases}$$

$DT_i - Delay\ Tendency\ for\ flight\ i$

$$EAST\_WEST_i - Flights\ Origin\ Direction \begin{cases} 1 & East\ Coast \\ 0 & West\ Coast \end{cases}$$

Hub Details:

$UUX_{i,u,j} - ULD\ u\ of\ flight\ i\ entering\ in\ the\ sorting\ system\ in\ time\ j$

$$UUX_{i,u} = \begin{cases} 1 & ULD\ entering \\ 0 & Otherwise \end{cases}$$

$UUV_{i,u,j} - Volume\ of\ ULD\ u\ of\ flight\ i\ entering\ in\ the\ sorting\ system\ in\ time\ j$

$$UUV_{i,u,j} = UUX_{i,u,j} \times UUR_i \quad \forall i,u,j$$

$YQ = Average\ Queuing\ Time\ at\ Yard$

$UT = Average\ Unload\ Time\ for\ ULD\ at\ Spot$

$EASTERN\ DEADLINE = Deadline\ set\ by\ client\ for\ when\ eastern\ flight\ volume\ must\ enter\ the\ system.$

ULD Details:

$NULD_i - Number\ of\ ULDs\ in\ flight\ i$

$U_{i,u} - ULD\ Matrix$

$$U_{i,u} = \begin{cases} 1 & if\ uth\ ULDs\ exists\ in\ flight\ i \\ 0 & else \end{cases}$$

$UV_{i,k} - Average\ Package\ Volume\ in\ ULD\ of\ flight\ i$

$$UV_{i,k} = V_{i,k} / NULD_i$$

Appendix – Model (cont.)

Decision Variables:

$X_{i,j=}$ *Assignment of flight i to window j*

$$X_{i,j} = \begin{cases} 1 & \text{Landing Assigned} \\ 0 & \text{Not Assigned} \end{cases}$$

$$\text{Landing Time of flight } i, L_i = \sum_{j=1}^{Total\_Windows} j \times X_{i,j} \qquad \forall i$$

ULD Yard Arrival Time = Landing Time + Setup Time + u × offload Rate + Transit Time

Objective Function:

$$max \sum_{i=1}^{\#\ of\ flights} L_i$$

Subject To:

1. Each flight is only assigned one landing time:

$$\sum_{j=1}^{Total\ Windows} X_{i,j} = 1 \qquad \forall i$$

2. No more than two flights assigned in two time windows:

$$\sum_{i}^{\#\ Flights} \sum_{j=t}^{t+1} X_{i,j} \leq 2 \qquad \forall t, 1 \leq t \leq TOTAL\ WINDOWS - 1$$

3. Maximum 53 flights can land in one hour:

$$\sum_{j=t}^{t+60} \sum_{i=1}^{\#\ Flights} X_{i,j} \leq 53 \qquad \forall t\ s.t. 1 \leq t \leq TOTAL\ WINDOWS - 60$$

$_{i,j}$

4. Flight cannot be scheduled beyond lower bound:

$$L_i \geq CSA_i - SCHEDULE\_BACK_i \qquad \forall i$$

5. Flight cannot be scheduled beyond upper bound:

$$L_i \leq CSA_i + SCHEDULE\_FORWARD_i \qquad \forall i$$

Appendix – Model (cont.)

Process Time Calculations

a. Process Time by Flight, ULD

$$PROCESS\_TIME_{i,u} = (ST_i + DT_i + (u * UR_i) + TT_i + YQ) * U_{i,u} \qquad \forall i, \forall u$$

b. ULD Spot Arrivals

$$ULD\_SpotArrival_{j,i,u} = X\left(i, \left(j - PROCESS\_TIME_{i,u}\right)\right) * U_{i,u} \qquad \forall i, \forall u, \forall j$$

c. ULD Spot Departures

$$ULD\_SpotDeparture_{j,i,u} = ULD\_SpotArrival_{j,i,u}\left(i, (j - UT)\right) * U_{i,u} \qquad \forall i, \forall u, \forall j$$

d. ULDs Unloading from Flight i

$$ULD\_UNLOADING_{j,i} = ULD\_UNLOADING_{j-1,i} + \sum_{u=1}^{40} ULD\_SpotArrival_{j,i,u} - \sum_{u=1}^{40} ULD\_SpotDeparture_{j,i,u} \qquad \forall i, \forall j \; st \; j \geq 2$$

e. Total Entering Volume in time j from all flights, by package type k

$$TEV_{j,k} = \sum_{i=1}^{\#\,Flights} ULD\_UNLOADING_{j,i} * UV_{i,k} \qquad \forall j, \forall k$$

f. Cumulative Volume up to 'Process Capacity Window Precision' Limited to Process Capacity Constraint

$$\sum_{j=t}^{t+WindowPrecision} TEV_{j,k} \leq (Process\_Capacity_k * WindowPrecision) \qquad \forall k, \forall j \; st. \; 1 \leq j \leq (TOTAL_{WINDOWS} - WindowPrecision)$$

g. Limiting Volume from Eastern Origin Flights after Deadline

$$TEV\_EASTERN_{j,k} = \sum_{i=1}^{\#\,Flights} ULD\_UNLOADING_{j,i} * UV_{i,k} * EAST\_WEST_i \qquad \forall j, \forall k$$

$$TEV\_EASTERN_{j,k} \leq 0 \qquad \forall k, \forall j \; st. \; j > EASTERN\_DEADLINE$$

Appendix - Valuation

- Operation delay decisions are in 5 min. increments
- For estimating the new costs and project savings: 2012 actual delay data (Mon. – Thurs.)

	Reduced Delay	Current Costs w/o Special Conditions	Revised Costs	Project Savings
Realistic	10 min.	3145000	1400000	1745000
Pessimistic	5 min.	3145000	1945000	1200000
Optimistic	15 min.	3145000	1151000	1994000

Operation Delay	Monday	Tuesday	Wednesday	Thursday	Total
0	3	2	2	2	9
5	4	6	10	2	22
10	18	25	19	12	74
15	18	13	15	16	62
20	2	4	3	12	21
25	2	1	1	5	9
30	1	2	0	1	4
40	0	0	0	2	2
45	0	0	2	0	2
55	1	0	0	0	1
60	0	1	0	0	1
68	1	0	0	0	1
135	0	0	0	1	1
Total	50	54	52	53	209

Operation Delay	Marginal Cost per Minute ($)
[0 min, 15 min]	1000
[20 min, 30 min]	10000
≥35 min	12500

Operation Delay	Marginal % Caused by Bad Scheduling
[0 min, 10 min]	80%
[15 min, 20 min]	60%
≥25 min	Special Conditions, Not Applicable