Aircraft Arrival Schedule Optimization

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Client Contact
Mr. Bob Armstrong
Mr. Jeff Sierota

Advisor
Dr. Doug Bodner

Team Members
Chen, Yuelin (Lyn)
Chow, Diana
Ferguson, Stefan
Kim, Sohyun
Le, Jianing (Jessica)
Shah, Nirmi
Wu, Zhixun (Herman)
Wykoff, Brandon

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Project Overview

Problem
- Irregular volume flow ➔ Operational delay ➔ ~$3.1M 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: $1.7M
Client Background

UPS Worldport Sorting Hub

~ 100 nightly aircraft arrivals
Client Background

~ 1.6M packages sorted nightly

5.2M sq. ft.

155 miles of conveyors
Project Scope

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

In 4 hours 15 minutes,

~ 100 flights
~ 850K packages
~ 1600 containers
Problem Statement

Problem:
Nightly operation delay

Cause:
Volume flow exceeds capacity limits

Effect:
Excess costs to Worldport & network

Overview

Methodology

Deliverables

Valuation

Summary
Design Strategy

Problem Objective

- Schedule flights as late as possible
- On-time shift completion

Objective Function

- Maximize arrival lateness

Subject to

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

Overview Methodology Deliverables Valuation Summary
Design Strategy

Process Flow Simulation

- Flight Landing
- Remote Ramp
- Parking Location
- Parking Wing
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Hubsort

Overview  Methodology  Deliverables  Valuation  Summary
Simulation

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

Landing & taxi time
Delay tendency
Simulation

Location

Hub Wing
Remote Ramp

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

Overview
Methodology
Deliverables
Valuation
Summary
Simulation

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

Overview
Methodology
Deliverables
Valuation
Summary

Aircraft type
Number of containers
Simulation

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

Parking location to hub
Wing = shorter transit
Ramp = longer transit
Process Flow

1. Flight Landing
2. Parking Location
3. Aircraft Offload
4. Container Transit
5. Container Queuing
6. Container Unload
7. Package Sorting

Overview
Methodology
Deliverables
Valuation
Summary
Simulation

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

More volume = more workers
So, constant unload time
Simulation

Process Flow

- Flight Landing
- Parking Location
- Aircraft Offload
- Container Transit
- Container Queuing
- Container Unload
- Package Sorting

Three package types: smalls, parcels, irregulars

Subject to capacity constraints by package type
Simulation Validation

Flight Landing ➔ Aircraft Offload ➔ Container Transit ➔ Container Queuing ➔ Container Unload ➔ Hubsort

Process Simulation

Incoming Packages

80% Accuracy

Time (1 min. window)

0 1 31 61 91 121 151 181 211 241 271 301 331 361 391

Simulated data

Actual data

80% Accuracy

Overview Methodology Deliverables Valuation Summary
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
# Model Run: Example

## Flight Assignment Matrix

<table>
<thead>
<tr>
<th>Flight</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>...</th>
<th>254</th>
<th>255</th>
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<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>1</td>
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<tr>
<td>4</td>
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<td>1</td>
<td></td>
<td></td>
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<tr>
<td>...</td>
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<td></td>
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<td>99</td>
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<tr>
<td>100</td>
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<td></td>
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<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Time Window**: Represents the time slots available for flight assignments.
- **Flight Assignment**: Indicated with numbers 1 to 100.
Model Run: Example

Volume Flow Profile

- Memphis
- Atlanta
- Chicago
- Orlando
- New York

Overview  Methodology  Deliverables  Valuation  Summary
Model Run: Example

Assignment Matrix:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Volume Flow Profile:

Total Volume Inflow:

Deadline

Capacity

Volume

Time

Flight

Volume

Time
Model Run: Example

Assignment Matrix:

Total Volume Inflow:

Volume Flow Profile:
Model Run: Example

Assignment Matrix:

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td></td>
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</tr>
</tbody>
</table>

Volume Flow Profile:

Total Volume Inflow:

Overview  Methodology  Deliverables  Valuation  Summary
# Results & Validation

## Schedule Comparison: Volume Flow (Parcels)

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

**West-bound deadline: 2:15 AM**

**Capacity: 2000**
Methodology Recap

Optimization strategy
Process time simulation
Xpress & Excel package

3.6M variables
2.4M constraints
~ 15 minute runtime
Deliverables

**Scheduling Package**
- Xpress model
- Excel user interface
- Excel validation tools

**Revised Schedule**
- Worldport parameters
- Aircraft delay report
- Parking strategy
## Deliverables

### Aircraft Arrival Scheduling Tool

**Calculations - Do Not Edit**

<table>
<thead>
<tr>
<th>User Input</th>
<th>Calculations - Do Not Edit</th>
<th>Xpress Output</th>
<th>User Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Fill - Can Override</td>
<td>Aircraft Arrival Scheduling Tool</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Aircraft Arrival Scheduling Tool Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expected Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Volume Deadline (Use/1)</td>
<td>21:00 AM</td>
</tr>
<tr>
<td>Window Precision to the minute</td>
<td>10</td>
</tr>
<tr>
<td>Hourly Landing Cap</td>
<td>53</td>
</tr>
<tr>
<td>Capacity Smalls (per min)</td>
<td>3185</td>
</tr>
<tr>
<td>Capacity Parcels (per min)</td>
<td>2000</td>
</tr>
<tr>
<td>Capacity Irregulars (per min)</td>
<td>80</td>
</tr>
<tr>
<td>Yard Wait Time (Minutes, integer)</td>
<td>14</td>
</tr>
<tr>
<td>ULD Unload Time (Minutes, integer)</td>
<td>17</td>
</tr>
<tr>
<td>Print Model Log [Y, E, D, P, O]</td>
<td>1</td>
</tr>
</tbody>
</table>

### Xpress Output

<table>
<thead>
<tr>
<th>Flight Number</th>
<th>Origin</th>
<th>Current Schedule</th>
<th>E/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS31369</td>
<td>ATL</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31351</td>
<td>PIT</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31291</td>
<td>CLE</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31275</td>
<td>RDU</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31337</td>
<td>MIA</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31381</td>
<td>MEM</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>AC1255</td>
<td>BKN</td>
<td>11:00:00 PM</td>
<td>E</td>
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<tr>
<td>UPS1057</td>
<td>MHT</td>
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<td>E</td>
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<td>UPS10467</td>
<td>SBN FWA</td>
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<td>E</td>
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<tr>
<td>UPS1021</td>
<td>JAX</td>
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<td>E</td>
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<td>UPS31171</td>
<td>BOS</td>
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<td>E</td>
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<td>UPS31481</td>
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<td>E</td>
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<td>UPS31283</td>
<td>CLT</td>
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<td>E</td>
</tr>
<tr>
<td>UPS31231</td>
<td>RIC</td>
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<td>E</td>
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<tr>
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<tr>
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<td>PHL</td>
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<td>E</td>
</tr>
<tr>
<td>UPS30781</td>
<td>MSN</td>
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<td>E</td>
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<td>UPS30785</td>
<td>YHM</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31063</td>
<td>BDL</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31201</td>
<td>ATL</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31287</td>
<td>BWI</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS30214</td>
<td>CQN</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31325</td>
<td>MCO</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS30991</td>
<td>ORL</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
<tr>
<td>UPS31333</td>
<td>PBI</td>
<td>11:00:00 PM</td>
<td>E</td>
</tr>
</tbody>
</table>

### FICO Xpress 7.3

**64-bit**

**IVE**
Valuation

Cost Reductions

Worldport operations

Labor overtime

Downstream UPS network

Planning, fuel, and maintenance

Current Costs Estimate

Revised Cost Estimate

Project Savings Estimate
## Valuation

<table>
<thead>
<tr>
<th>Current Costs</th>
<th>Estimated New Costs</th>
<th>Project Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.1M</td>
<td>$1.9M</td>
<td>Conservatively: $1.2M</td>
</tr>
<tr>
<td></td>
<td>$1.4M</td>
<td>Likely: $1.7M</td>
</tr>
<tr>
<td></td>
<td>$1.2M</td>
<td>Ideally: $1.9M</td>
</tr>
</tbody>
</table>

Estimated annual savings from reduced operations delay
Summary

Problem & Approach
- Operation delays
- Improved aircraft arrival schedule

Methodology
- Optimization model
- Process simulation

Validation & Results
- Simulation accuracy
- Rescheduling effects

Valuation
- Reduced Worldport & network costs
- ~ $1.7 M annual savings
Thank You

Questions?
Appendix – Model

Parameters:
\( i \) – Flight \((1 - \# \text{Flights})\)
\( j \) – Time window \((1 - 300)\) \((10:00 \text{PM} - 3:00 \text{AM}, 1 \text{minute intervals})\)
\( u \) – \#th ULD \((1 - 40)\)
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:
\( \text{CSA}_i \) – Current Scheduled Arrival for \( i \)
\( V_{ik} \) – 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 \( i \)
\( TT_i = \begin{cases} 8.5 \text{ minutes} & \text{if flight i parks at Wing} \\ 13 \text{ minutes} & \text{if flight i parks at Ramp} \end{cases} \)
\( DT_i \) – Delay Tendency for flight \( i \)
\( \text{EAST,WEST}_i \) – Flights Origin Direction \( \begin{cases} 1 & \text{East Coast} \\ 0 & \text{West Coast} \end{cases} \)

Hub Details:
\( \text{UUX}_{iu,j} \) – ULD \( u \) of flight \( i \) entering in the sorting system in time \( j \)
\( \text{UUX}_{iu} = \begin{cases} 1 & \text{ULD entering} \\ 0 & \text{Otherwise} \end{cases} \)
\( \text{UUU}_{iu,j} \) – Volume of ULD \( u \) of flight \( i \) entering in the sorting system in time \( j \)
\( \text{UUU}_{iu,j} = \text{UUX}_{iu} \times \text{UR}_i \forall i,u,j \)
\( YQ = \text{Average Queuing Time at Yard} \)
\( UT = \text{Average Unload Time for ULD at Spot} \)
\( \text{EASTERN DEADLINE} = \text{Deadline set by client for when eastern flight volume must enter the system} \)

ULD Details:
\( \text{NULD}_i \) – Number of ULDs in flight \( i \)
\( U_{iu} \) – ULD Matrix
\( U_{iu} = \begin{cases} 1 & \text{if } i \text{th ULD exists in flight } i \\ 0 & \text{else} \end{cases} \)
\( U_{ik} \) – Average Package Volume in ULD of flight \( i \)
\( U_{ik} = V_{ik} / \text{NULD}_i \)
Appendix – Model (cont.)

Decision Variables:
\( X_{ij} \): Assignment of flight \( i \) to window \( j \)
\( X_{ij} = \begin{cases} 1 & \text{Landing Assigned} \\ 0 & \text{Not Assigned} \end{cases} \)

Landing Time of flight \( i \), \( L_i = \sum_{j=1}^{Total\_Windows} j \times X_{ij} \quad \forall i \)

ULD Yard Arrival Time = Landing Time + Setup Time + \( u \times \) offload Rate + Transit Time

Objective Function:
\[ \text{max} \sum_{i=1}^{\# \text{of Flights}} L_i \]

Subject To:
1. Each flight is only assigned one landing time:
\[ \sum_{j=1}^{Total\_Windows} X_{ij} = 1 \quad \forall i \]

2. No more than two flights assigned in two time windows:
\[ \sum_{t} \sum_{j=1}^{Flights} X_{ij} \leq 2 \quad \forall t, 1 \leq t \leq TOTAL\_WINDOWS - 1 \]

3. Maximum 53 flights can land in one hour:
\[ \sum_{j=t}^{t+60} \sum_{i=1}^{Flights} X_{ij} \leq 53 \quad \forall t, 1 \leq t \leq TOTAL\_WINDOWS - 60 \]

4. Flight cannot be scheduled beyond lower bound:
\[ L_i \geq CSA_i - SCHEDULE\_BACK_i \quad \forall i \]

5. Flight cannot be scheduled beyond upper bound:
\[ L_i \leq CSA_i + SCHEDULE\_FORWARD_i \quad \forall i \]
Appendix – Model (cont.)

Process Time Calculations

a. Process Time by Flight, ULD

\[ \text{PROCESS\_TIME}_{j,i,u} = (ST_i + DT_i + (u \times UR_i) + TT_i + YQ) \times U_{i,u} \quad \forall i, \forall u \]

b. ULD Spot Arrivals

\[ \text{ULD\_SpotArrival}_{j,i,u} = \lambda \left( i, \left( j - \text{PROCESS\_TIME}_{j,i,u} \right) \right) \times U_{i,u} \quad \forall i, \forall u, \forall j \]

c. ULD Spot Departures

\[ \text{ULD\_SpotDeparture}_{j,i,u} = \text{ULD\_SpotArrival}_{j,i,u} \left( i, \left( j - UT \right) \right) \times U_{i,u} \quad \forall i, \forall u, \forall j \]

d. ULDs Unloading from Flight \( j \)

\[ \text{ULD\_UNLOADING}_{j,i} = \text{ULD\_UNLOADING}_{j-1,i} + \sum_{u=1}^{40} \text{ULD\_SpotArrival}_{j,i,u} - \sum_{u=1}^{40} \text{ULD\_SpotDeparture}_{j,i,u} \quad \forall i, \forall j \geq 2 \]

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

\[ \text{TEV}_{j,k} = \sum_{i=1}^{\# \text{Flights}} \text{ULD\_UNLOADING}_{j,i} \times UV_{i,k} \quad \forall j, \forall k \]

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

\[ \sum_{j=1}^{\# \text{Flights}} \text{TEV}_{j,k} \leq (\text{Process\_Capacity}_{k} \times \text{WindowPrecision}) \quad \forall k, \forall j, 1 \leq j \leq (\text{TOTAL\_WINDOWS} - \text{WindowPrecision}) \]

g. Limiting Volume from Eastern Origin Flights after Deadline

\[ \text{TEV\_EASTERN}_{j,k} = \sum_{i=1}^{\# \text{Flights}} \text{ULD\_UNLOADING}_{j,i} \times UV_{i,k} \times \text{EAST\_WEST}_{i} \quad \forall j, \forall k \]

\[ \text{TEV\_EASTERN}_{j,k} \leq 0 \quad \forall k, \forall j \geq \text{EASTERN\_DEADLINE} \]
Appendix - Valuation

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

<table>
<thead>
<tr>
<th>Operation Delay</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>6</td>
<td>10</td>
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<tr>
<td>10</td>
<td>18</td>
<td>25</td>
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<table>
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<tr>
<th>Reduced Delay</th>
<th>Current Costs w/o Special Conditions</th>
<th>Revised Costs</th>
<th>Project Savings</th>
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<tbody>
<tr>
<td>Likely</td>
<td>10 min.</td>
<td>3145000</td>
<td>1400000</td>
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<tr>
<td>Conservative</td>
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<td>1945000</td>
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<td>Ideal</td>
<td>15 min.</td>
<td>3145000</td>
<td>1151000</td>
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<table>
<thead>
<tr>
<th>Operation Delay</th>
<th>Marginal Cost per Minute ($)</th>
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</thead>
<tbody>
<tr>
<td>[0 min, 15 min]</td>
<td>1000</td>
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<tr>
<td>[20 min, 30 min]</td>
<td>10000</td>
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<tr>
<td>≥35 min</td>
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<table>
<thead>
<tr>
<th>Operation Delay</th>
<th>Marginal % Caused by Bad Scheduling</th>
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<tr>
<td>[0 min, 10 min]</td>
<td>80%</td>
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<tr>
<td>[15 min, 20 min]</td>
<td>60%</td>
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<tr>
<td>≥25 min</td>
<td>Special Conditions, Not Applicable</td>
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