AIRPORT SURFACE GRIDLOCK ANALYSIS: A CASE STUDY OF CHICAGO O'HARE 2007

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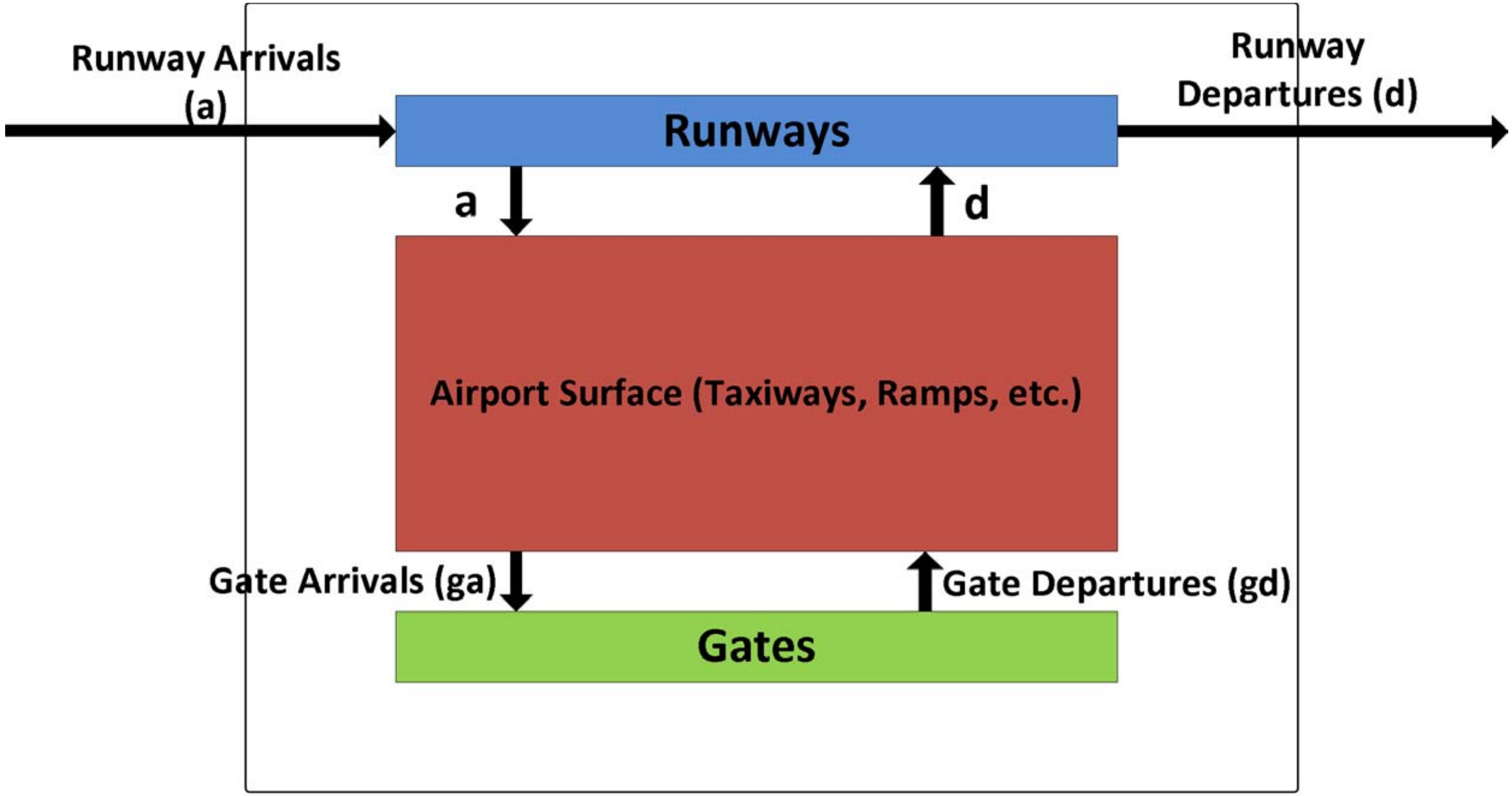
Introduction

- Air Transportation System
- Air Traffic Management and TMIs
  - Ground Delay Program (GDP)
  - Airspace Flow Program (AFP)

Problem Statement

- Note that all aircrafts (arriving and departing) use common resources such as runways, taxiways and gates.
- Air transportation system is a "Closed System", myopic solutions will shift the problem in the system from one point to another.
- If the system gets flooded with arrival flights while no departure is happening, it will overflow which means that it has reached its carrying capacity.
- This problem which is known as grid-lock problem makes the aircrafts movements on the surface difficult and causes more delays.

Airport Surface System



Airport as a system

Grid-Lock: Data Sources (Metron Aviation)

- Metron Aviation has done a research on Grid lock problem.
- They have used various sources of information:
  - Interviews with Command Center specialists
  - Interviews with Air Traffic Managers
- Ways of identifying Grid-Lock
  - The tower calls to report the issue.
  - The ATCSCC specialist notices that departure delays are 45 minutes or greater and calls the tower to see if there is an issue. Sometimes only a few aircraft have large delays, but the ATCSCC specialist cannot reliably determine this.
  - For the NY area airports, the ATCSCC specialist observes large departure delays reported by DSP. Even though DSP shows the delay for each departure, the ATCSCC specialist still must call the tower to determine whether there is a gridlock issue and how to remedy it.

Grid-Lock: Expert views (Metron Aviation)

- Grid-Lock is related to the configuration and the structure of the airport.
- Knowing inbound legs and outbound legs that use the same equipment is useful.
- The term “grid lock” is overused. (Air Traffic Manager)
- GDPs are not very useful, since they take 2-3 hours to affect arrival demand.

Grid-Lock Occurrence (Metron Aviation)

- ATCSCC logs (2004 and 2005) were searched for the term "grid lock":
  - 192 incidents
  - Incidents on 125 distinct days
    - 121 in 2004
    - 71 in 2005
  - 32 different airports had the incident reported
  - Thunderstorms were the contributing factor 80% of the times
  - Next common factor was airport volume, 6% of the times
  - Other factors:
    - Taxiway and runway construction
    - Insufficient deicing capacity
    - A large number of aircrafts diverted from other airports
    - Military restrictions

Grid-Lock: Method and data (Metron Aviation)

- Proposed statistics for identifying grid-lock:
  - The number of aircrafts on the surface
  - The number of aircrafts in the movement area
  - The number of aircrafts on the surface and not parked
  - Taxi delay data
- They used the number of aircrafts on the surface using ETMS DZ and AZ messages.

Grid-Lock: Methodology

- To analyze grid-lock we chose the surface count as our measure
  - Surface count correlates with surface congestion
  - More air crafts on the surface can cause disruption in smooth surface operations
- The reasons for grid-lock can be divided into two categories
  - Local airport operation disruption
    - Reduced runway capacity due to deicing, inclement weather, etc.
    - Couple flights with no confirmed flight plan in front of the departure queue
  - System wide imbalanced operations
    - Weather induced situations like imbalances in ORD-MDW case (Causing congestion in ORD) or PHL-LGA pair conflict

Grid-Lock: Surface Count

- Following information is required to count the number of air crafts on the surface at each time (t):
  - Cumulative count of arrival aircrafts to the airport up to t (not the gate) (A)
  - Cumulative count of departure aircrafts from the airport up to t (not the gate) (D)
  - Initial count of aircrafts on the surface of the airport at the beginning of the day (IC)
- To calculate the surface count schedule data is not enough
  - Using scheduled departures (arrivals) and actual departure (arrival) times is not a good measure to calculate surface count (SC)
  - Scheduled and actual arrivals and departures are the time to arrive or push back from the gate
  - Arrivals flights are on the surface as soon as they land
  - Departure flights are on the surface as long as they have not taken off

Grid-Lock: Surface Count

- Surface Count at each time (SC(t)):
  - $SC(t) = SC(t-1) + a(t) - d(t)$, $SC(0)$=Initial Count (IC)
  - $SC(t) = IC + A(t) – D(t)$
- In the first formula it is stated that the surface count at each time is equal to the surface count at the previous time window plus the number of actual arrivals to the airport at that time (not cumulative) minus the number of aircrafts leaving the airport. Note that the initial surface count, SC(0) is equal to the initial count.
- Second formula is another way to state the surface count which is initial count plus the cumulative arrivals minus the cumulative departures.

Surface Count: Schedule Time vs. Wheel Time

- As mentioned before to count the true number of aircrafts on the surface we need the actual wheel on/off times
- Departure/arrival times are push-back/arriving time from/at the gate.
- Aircrafts can spend much longer time on the surface (taxi times) and not actually leaving the airport (in departure case)
- Also arriving aircrafts can spend long times on the surface away from the gate.

Surface Count: Schedule Time

- If we calculate the surface count using schedule (gate) times we calculate the number aircrafts at the gate at each time (GC)
- Using wheel on/off times will provide us with total number of aircrafts on the surface (gates + taxiways + ramps)
- However gate count (GC) is not what we are worried about, the relationship between gate count and surface count makes this statistic, attractive for comparison studies:

$$GC_t = \lim_{TaxiTime \to 0} SC_t$$

Surface Count: Schedule Time vs. Wheel Time

- Having the following relationship:

$$GC_t = \lim_{TaxiTime \to 0} SC_t$$

  - The above formula means that, if the time used to taxi aircrafts to and from the gates would approach zero, the number of aircrafts on the surface would be equal to the aircrafts at the gates
  - In other words, surface count would be equal to the gate count if aircrafts would take off directly from the gate and land directly at the gate.

Data Sources

- To be able to calculate mentioned statistics we need data sources that include actual operations such as actual gate times as well as taxi times (wheel times)
  - Airline On-Time Performance (AOTP)
    - Includes all the domestic operating airlines with more than 1% traffic
  - Aviation System Performance Metrics (ASPM)
    - Includes all the operations; international, domestic, General Aviation (GA)
- It is obvious that ASPM data has more instances and is more comprehensive and it is expected that the numbers calculated from ASPM be greater than those calculated using AOTP.

Data Processing

- Time (each day) is discretized into 15 minute time intervals
  - Each day has 96 time windows
  - In order to consider the operations that are continued from one day to another, 97^{th} time window is added to accommodate those operations
  - Scheduled and actual gate times are converted to time windows of the day
  - Gate delays , if greater than 15 minutes, are converted to number of time intervals
    - For example , delay of 25 minutes is equal to int(25/15)+1=2
  - Negative delays are assumed to be zero
  - Cancellations and diversions are excluded from the data (AOTP) while calculating the actual operations

Data Processing

- Multiple statistics are calculated to measure the performance of the system
  - Number of arrivals/departures at each time window (gate operations)
  - Number of landings/take-offs at each time window
  - Cumulative delay (gate/taxi) assigned to each time window
  - Number of cancellations and diversions (in case of using AOTP)
  - Initial count of aircrafts on the surface
  - Surface count at each time window
  - Gate count at each time window
- Data mentioned above can be used to assess the performance of the system.

M : Measure of Congestion for a day

- We consider the count of aircrafts on the surface but not at the gates as a measure for surface congestion.

$$m_i = TotalSurf_i - GateCount_i \quad \forall i \in T$$

$$M = \underset{i \in T}{Max}\{m_i\}$$

- M is the maximum surface count in a day!
- To have better understanding of the behavior of the statistic m_i, average value and median of m_i is also calculated

Why M?

- Having aircrafts on the surface is necessary to utilize the runway capacity in the most efficient manner
  - Whenever a runway is free for departure, there has to be a flight ready to depart, or runways will be underutilized.
- Over populated surface will interrupt smooth operations, causing excessive taxi times, fuel burns and possibly grid-locks.

Initial Count of Aircrafts on the surface

- To have an un-biased estimator of the count of aircrafts on the surface of the airport we need to know the ***number of aircrafts at the airport at the beginning of the day***.
- We call this statistic "***Initial Count***"
- To calculate the "Initial Count" we propose a Tail Number matching Algorithm.

Initial Count: Algorithm

- Initial Count =0
- For each DepTail# in Departures
  - Find all matching Tail# with DepTail# in the same list
  - Find the earliest scheduled departure assigned to that Tail#
    - For each Tail# in Arrivals
    - Find all matching Tail# with DepTail#
    - Find earliest scheduled arrival assigned to that Tail#
    - If Earliest Assigned DepTime< Earliest Assigned ArrTime for that Tail#
      - Initial Count= Initial Count + 1

Numerical Results

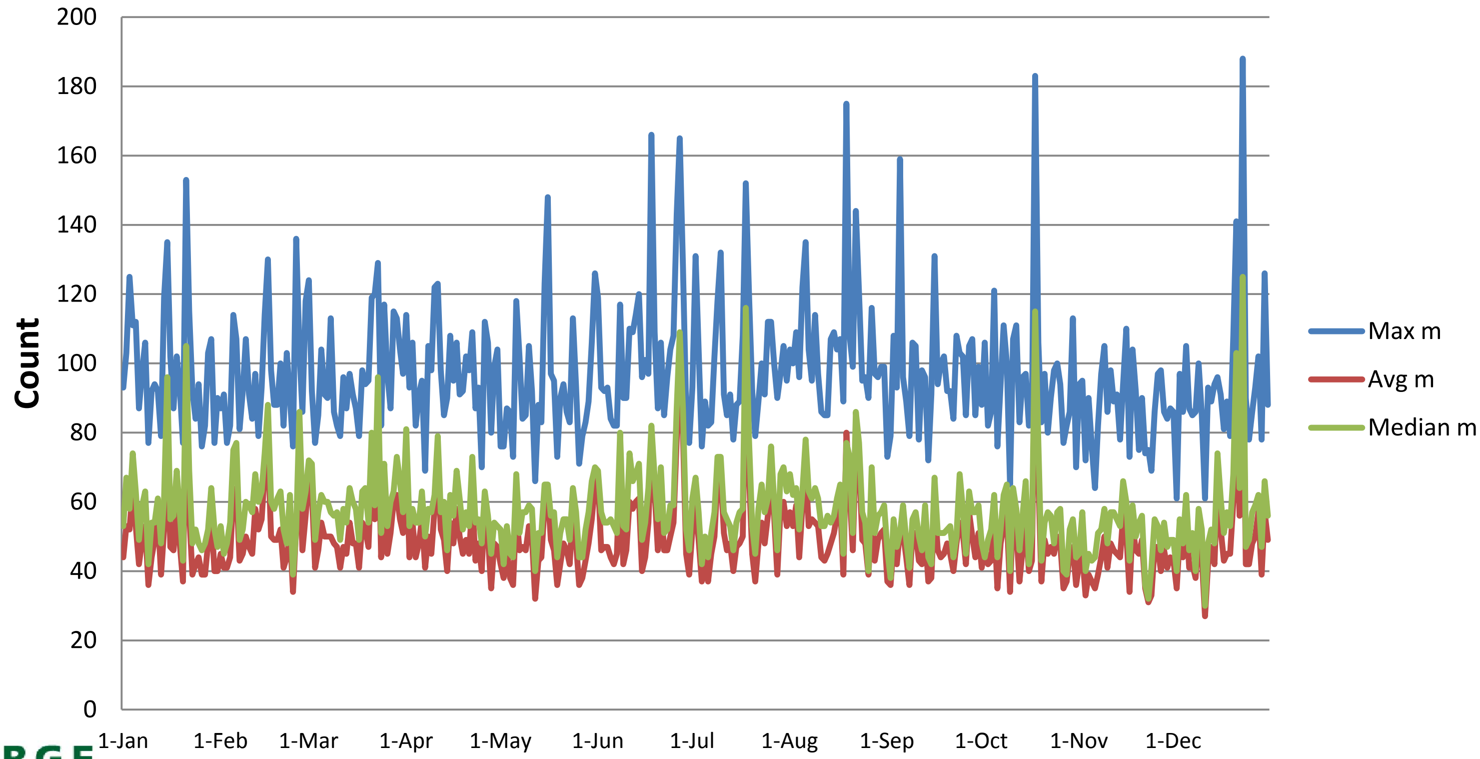
- Test Case:
  - Chicago O'Hare (ORD)
  - Year of 2007
  - ASPM data

Results

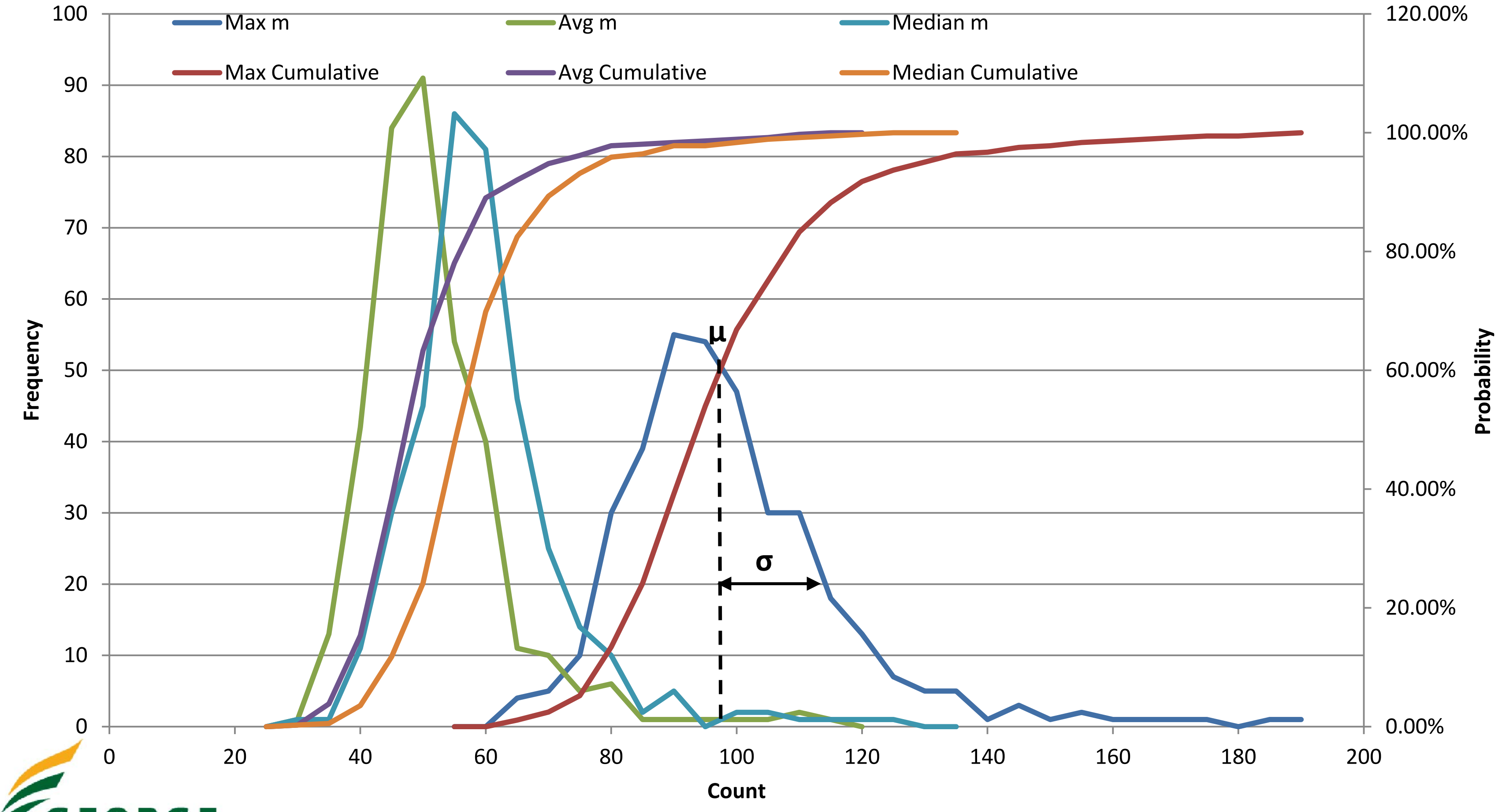
ORD	Departure Count	Delay Min	Delay TW	DepTaxi Min	Arrival Count	Delay Min	Delay TW	ArrTaxi Min
Jan	47470	984220	106276	953495	47674	1115263	114875	474695
Feb	40861	1130577	108407	848275	40942	1133763	109211	460697
Mar	47717	1112397	114622	968206	47703	1339406	129401	428142
Apr	46232	919325	101336	908628	46205	1083985	112124	402835
May	49007	612461	85112	959165	49010	685841	89805	421170
Jun	46655	977167	105301	995435	46674	1098032	113429	421281
Jul	48300	878272	100781	965572	48326	927258	104268	445706
Aug	48393	1052452	111349	1049485	48458	1092251	114263	467015
Sep	46048	574535	80064	912144	46189	592429	81438	423555
Oct	48179	631301	85412	966298	48389	671798	88288	427680
Nov	45651	659483	84584	850409	45698	683115	86348	401820
Dec	42828	1417239	128333	945526	42700	1521641	135234	457243
Sum	557341	10949429	1211577	11322638	557968	11944782	1278684	5231839

How functions of m_i are distributed throughout 2007?

ORD	Max(mi)	Avg(mi)	Med(mi)
Average	97.16	49.94	57.6
Min	61	27	30
Max	188	113	125
Std Dev	18.24	11.65	12.33



Distributions for functions of m_i



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Bad Days at ORD

ORD	M>125 (μ+1.5σ)	M>134 (μ+2σ)	M>150 (μ+3σ)	Day-M>125	Day-M>134	Day-M>150
Jan	3	2	1	3,15,21,	15,21,	21,
Feb	2	1	0	16,25,	25,	N/A
Mar	1	0	0	23,	N/A	N/A
Apr	0	0	0	N/A	N/A	N/A
May	2	1	0	16,31,	16,	N/A
Jun	4	3	2	18,26,27,28,	18,26,27,	18,27,
Jul	3	1	1	2,10,18,	18,	18,
Aug	3	3	1	6,19,22,	6,19,22,	19,
Sep	2	1	1	5,16,	5,	5,
Oct	1	1	1	18,	18,	18,
Nov	0	0	0	N/A	N/A	N/A
Dec	3	2	1	21,23,30,	21,23,	23,
Sum	24	15	8			

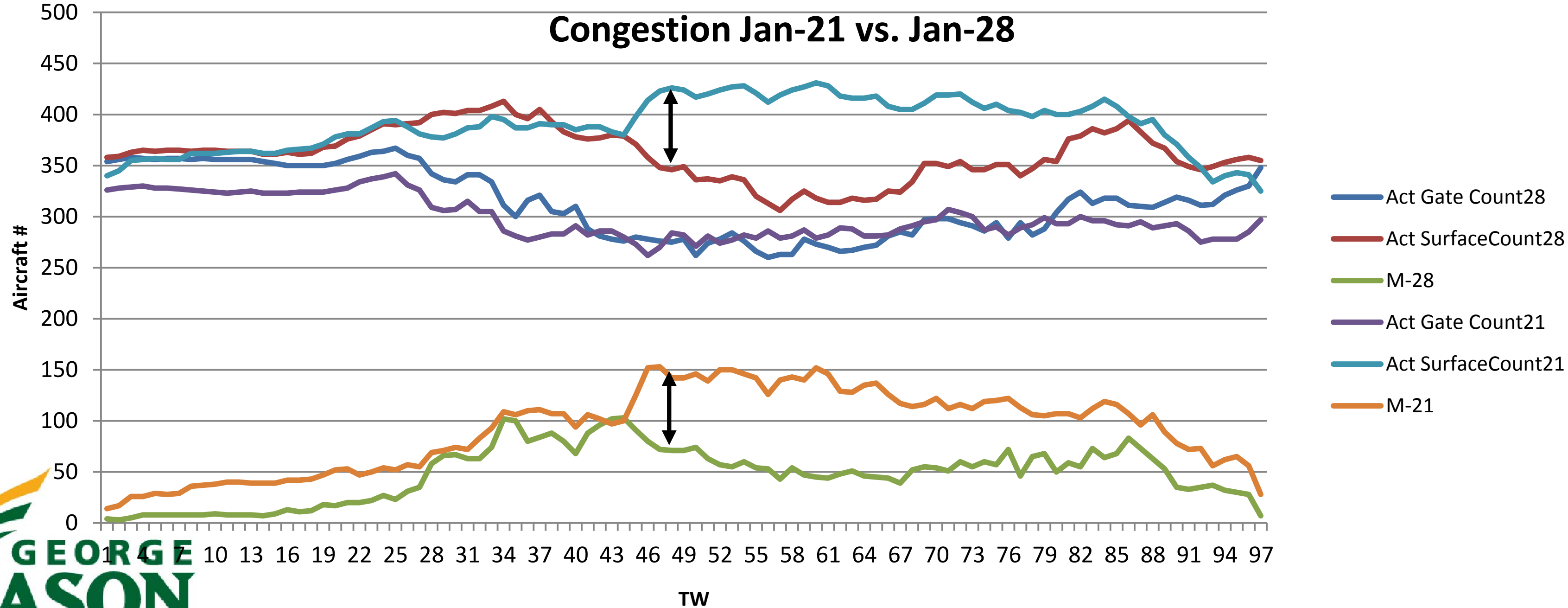
Discussion

- There has been 8 days with congestion (surface count) greater than $\mu+3\sigma$
  - January 21st , 2007 is chosen for a closer look
  - The results are compared to operations on January 28th, 2007
  - These days are the same day of the week and are expected to have almost similar operations!

Operation Summary

- Summary of operations, 21st vs. 28th

ORD	Departure Count	Delay Min	DepTaxi Min	Arrival Count	Delay Min	ArrTaxi Min	Initial Count
21-Jan	1200	83403	41939	1199	96726	32507	326
28-Jan	1512	49499	31289	1513	53440	16981	354



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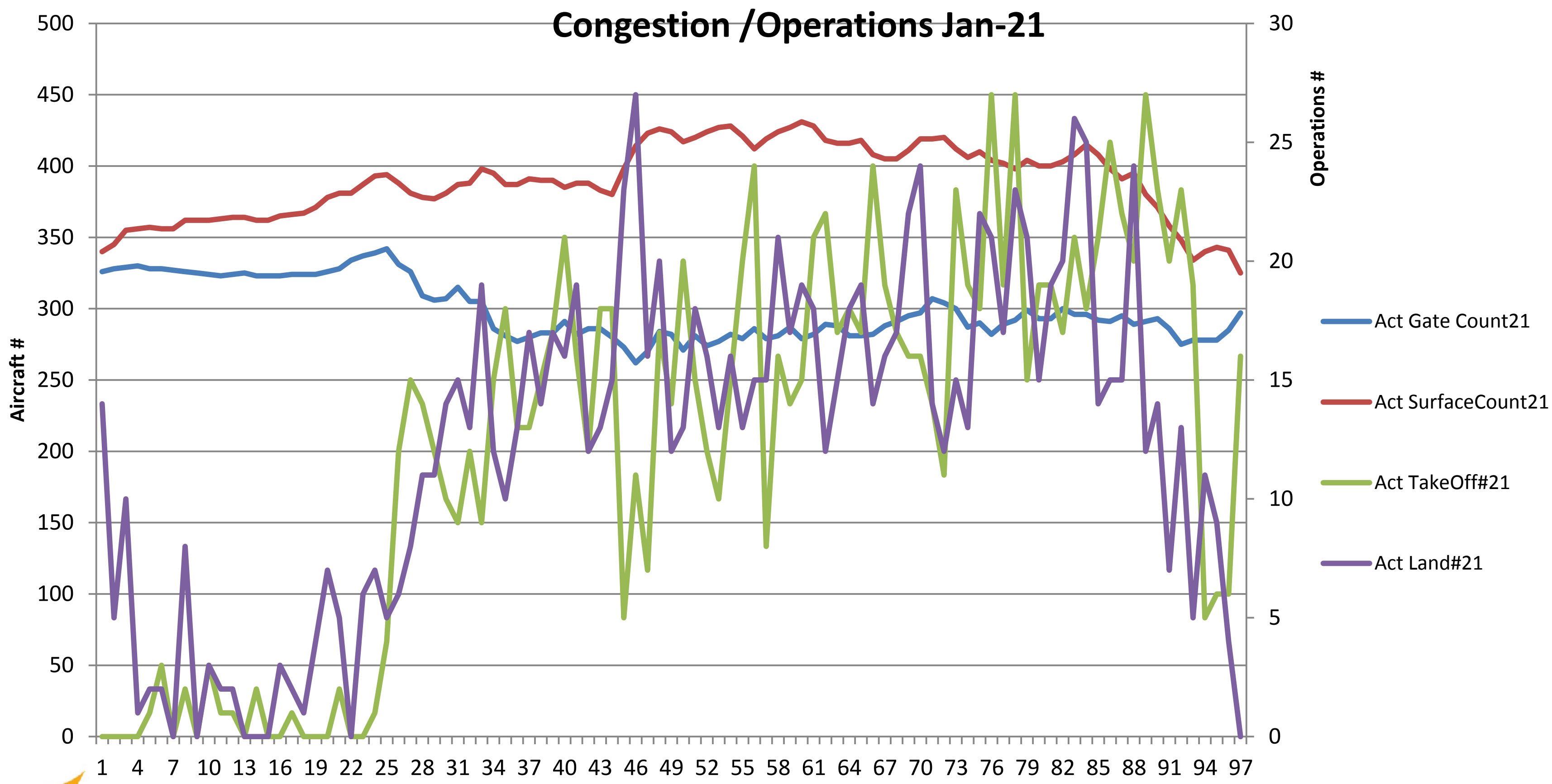
Weather Conditions (Jan-21)

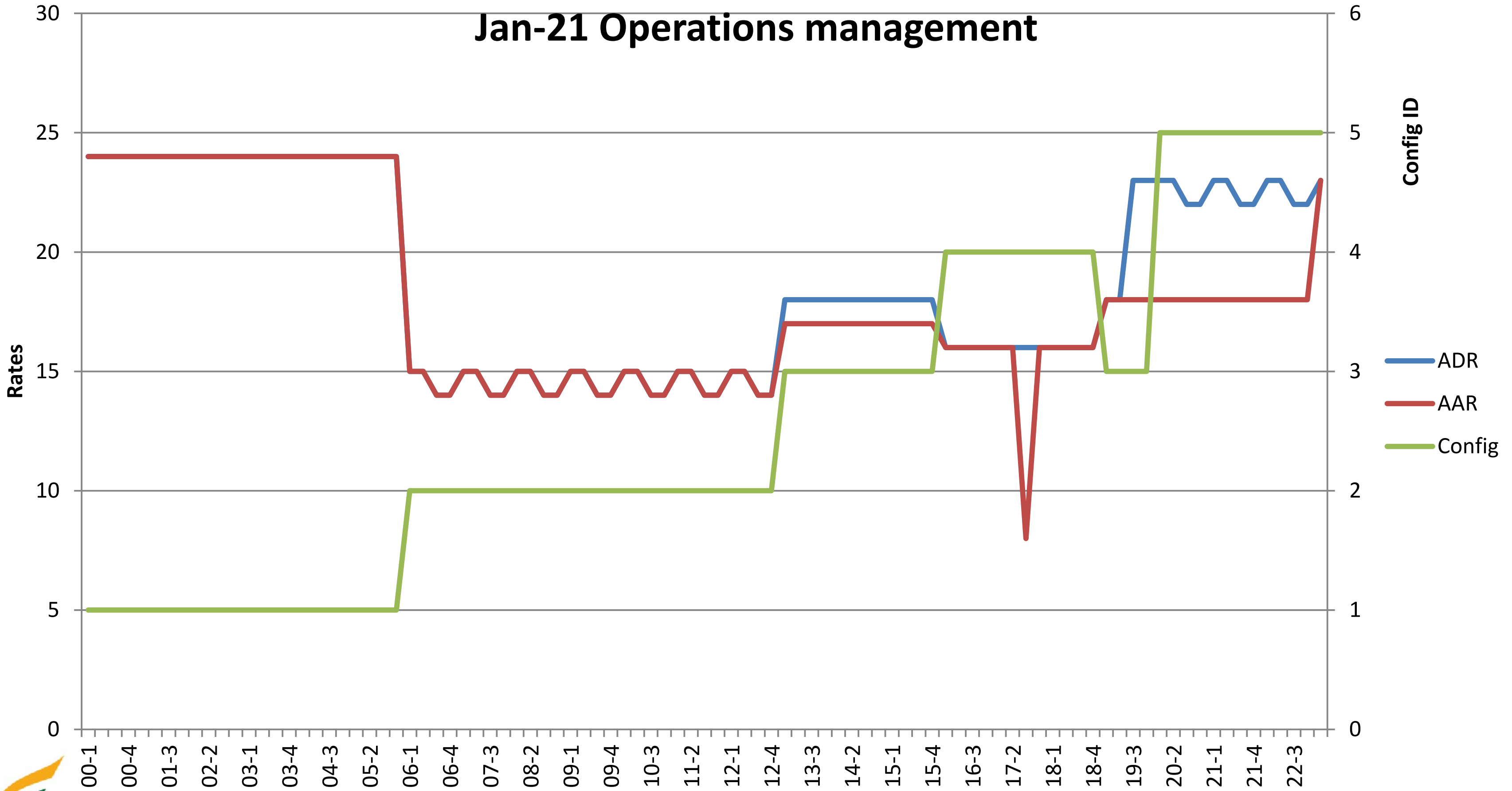
- Runway Configurations

ID	Configuration
1	14R, 22L, 22R | 9L, 22L, 27L
2	9L, 9R | 4L, 9R, 32R
3	4R, 9R | 4L, 9L, 32L, 32R
4	9L, 9R | 4R, 22L, 32R
5	4R, 9L, 9R | 4L, 9L, 32L, 32R

Volatility in operations on21st



Traffic Management



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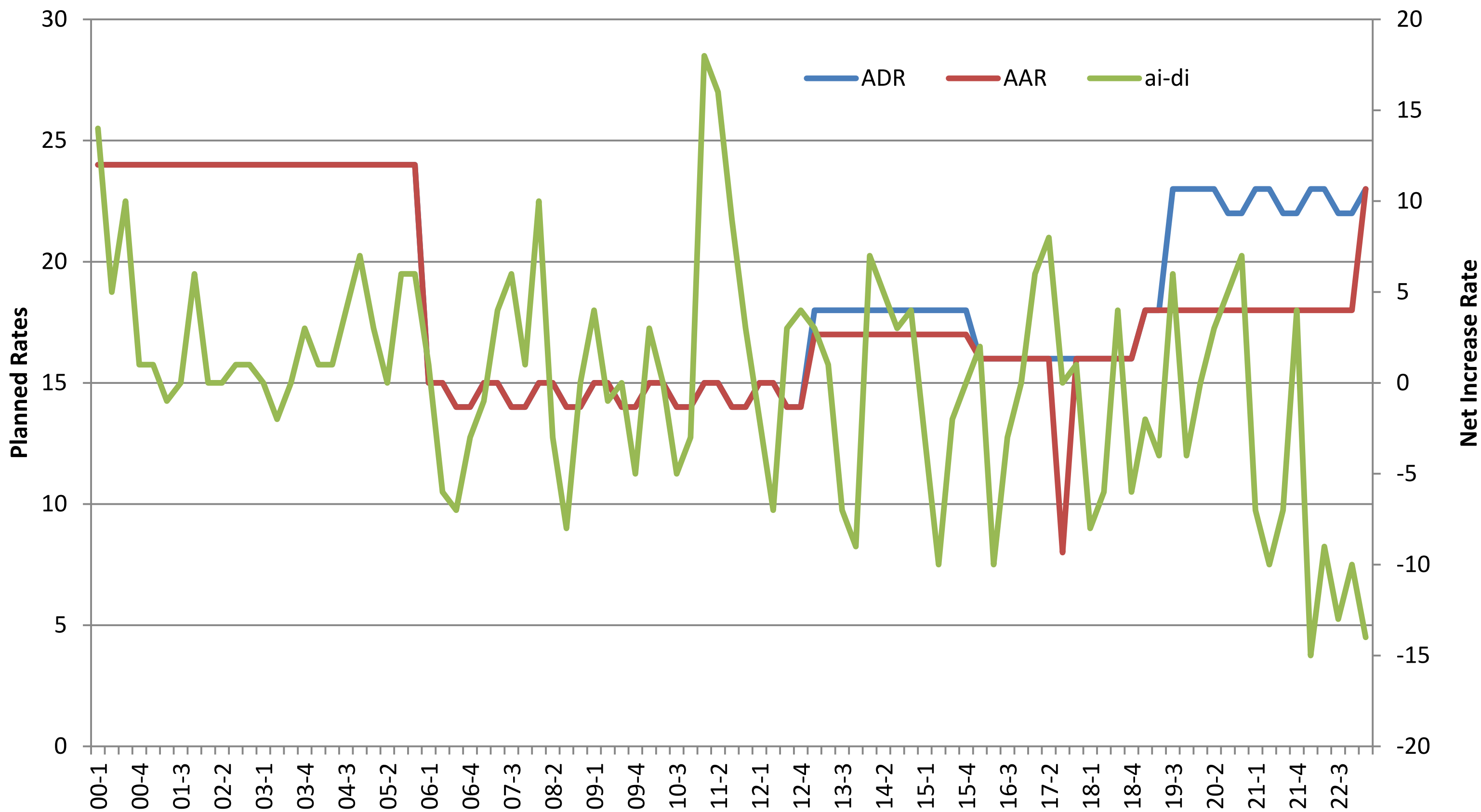
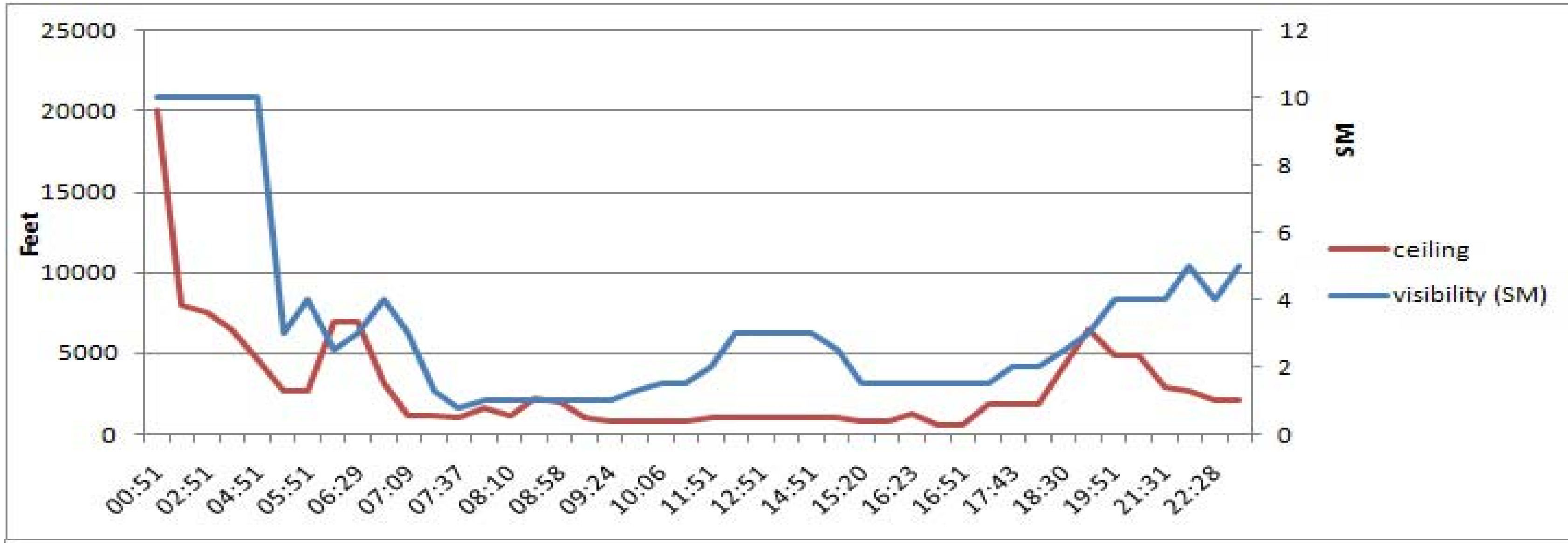
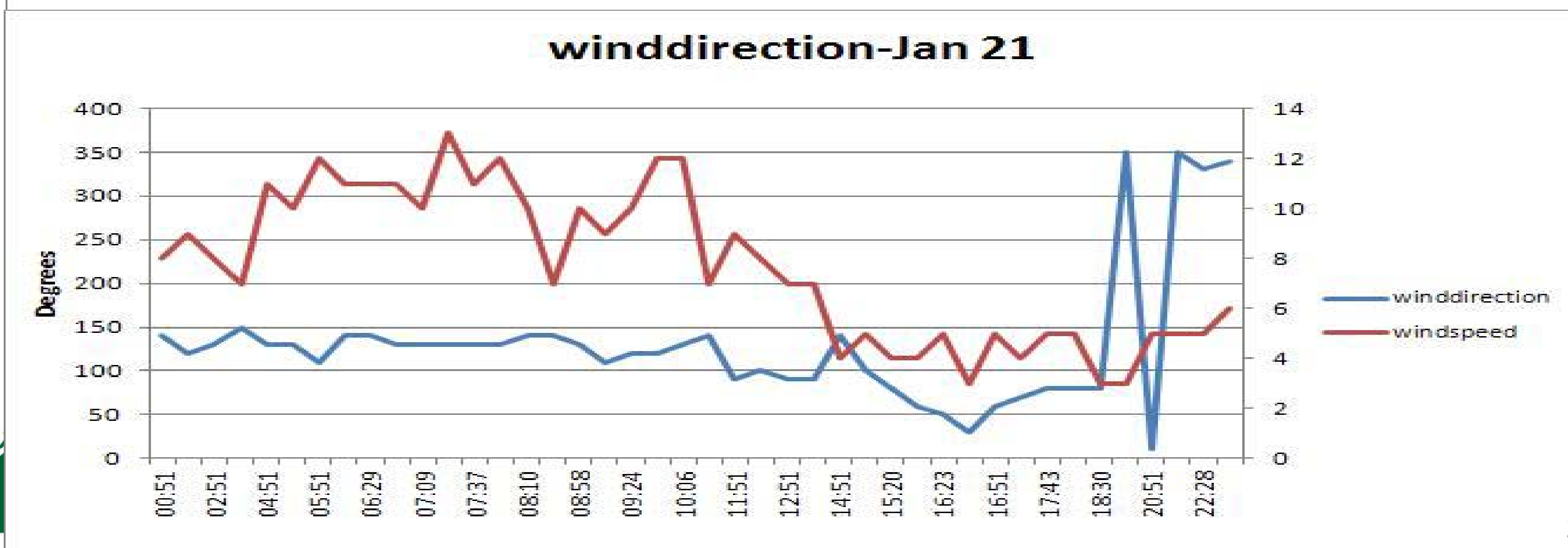
Operations: Actual vs. Planned

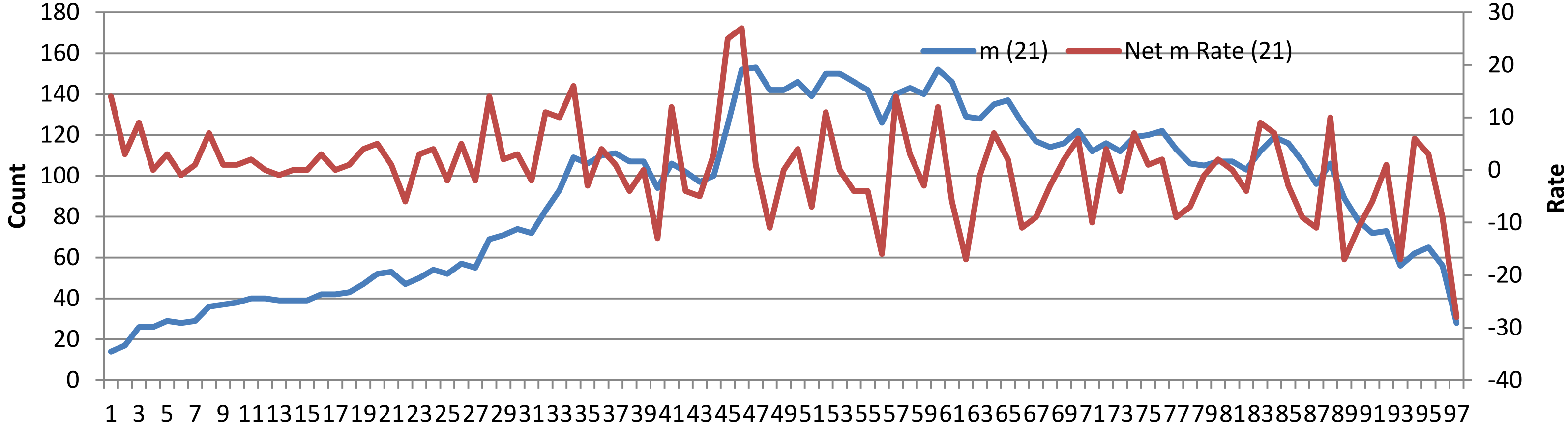


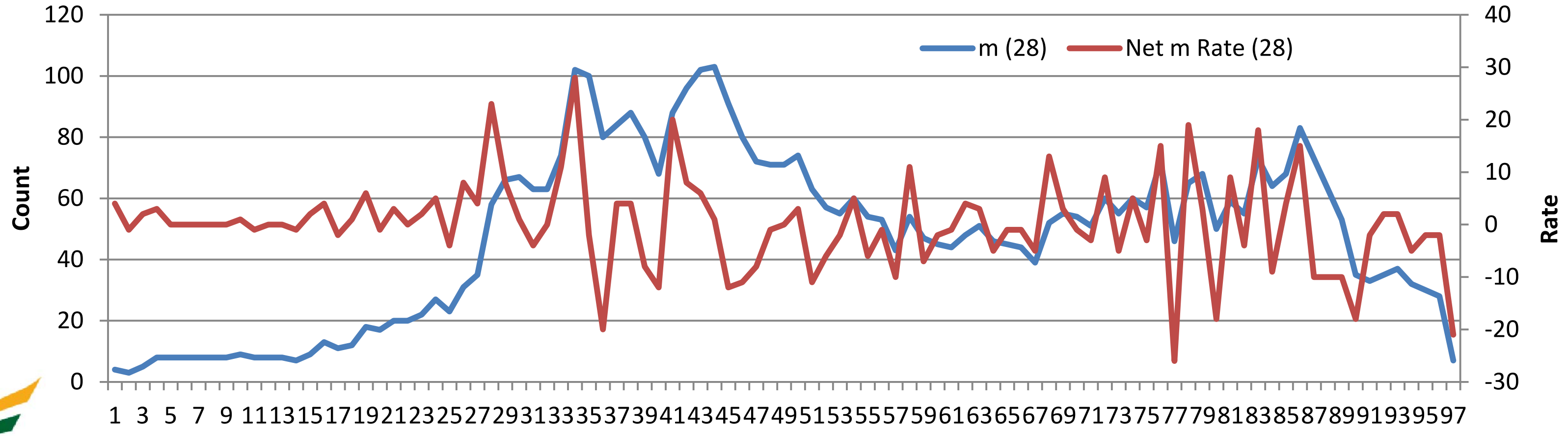
Weather Conditions





Actual Ops: 21st vs. 28th





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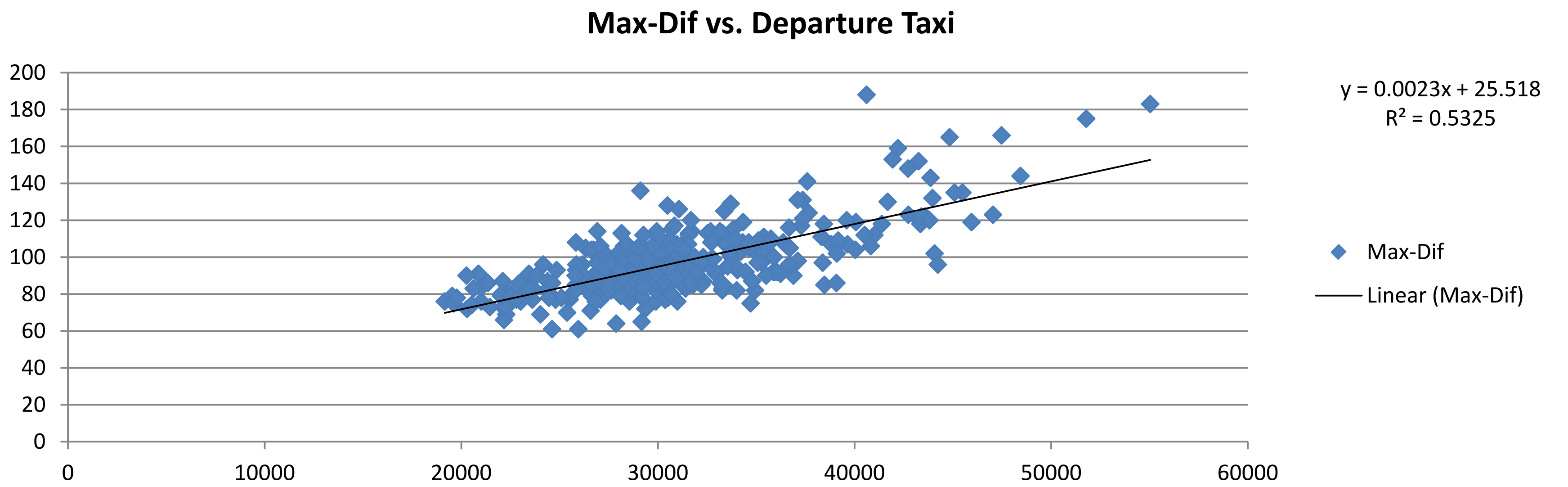
Summary of 3σ days : Weather

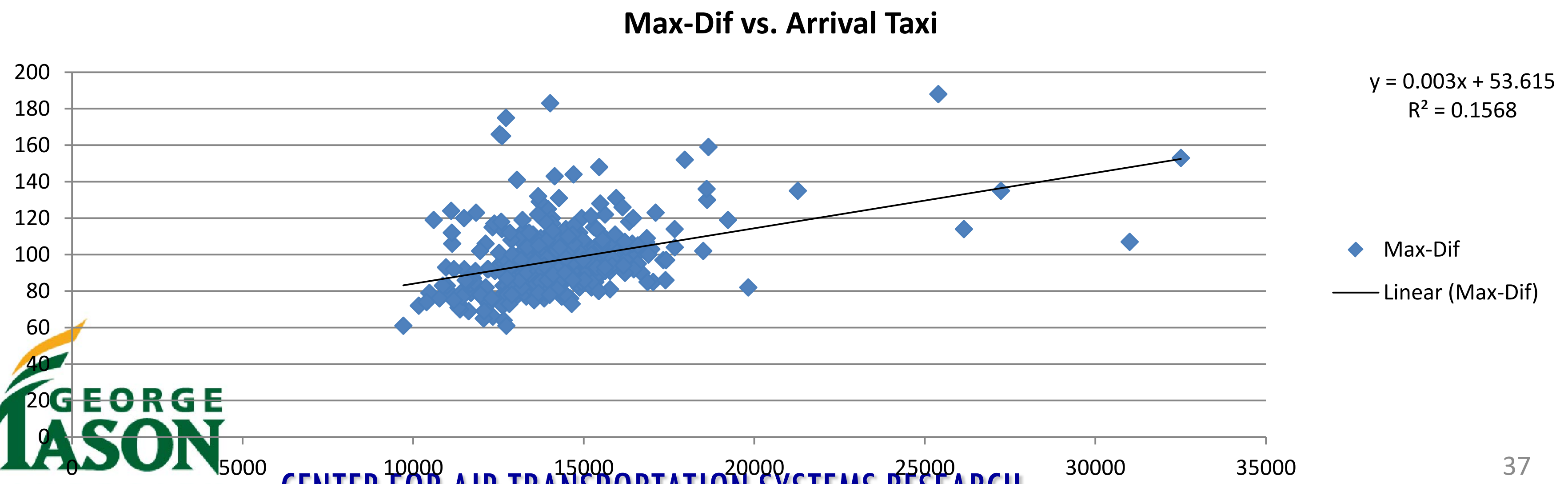
ORD-2007	Ceiling			Wind Speed		Visibility		#Config.
	No.Ceil.%	Avg.	Min	Avg.	Max	Avg.	Min	
21-Jan	0	3963.5	600	7	13	5	1	6
18-Jun	40.6	13475.5	2200	12.1	22	8.2	3	6
27-Jun	28.1	15072.5	3500	7.8	18	8.9	3	3
18-Jul	12.5	7376	2600	10.2	23	9.4	0.8	7
19-Aug	0	2765.6	400	7.8	15	5.8	1.5	3
5-Sep	79.1	13350	10000	6.9	26	8.4	6	5
18-Oct	37.5	4822	1300	18.7	28	9.3	3	3
23-Dec	0	2044.8	900	24.9	34	4.2	0.5	3

Summary of 3σ days : Operations

ORD-2007	Airport Departure Rate			Departure Demand			Airport Acceptance Rate			Arrival Demand		
	Average	Sum	Max	Average	Sum	Max	Average	Sum	Max	Average	Sum	Max
21-Jan	19.1	1832	24	22.1	2124	48	18.2	1748	24	28.6	2744	67
18-Jun	20.7	1990	25	23.4	2250	77	19.6	1884	25	41.6	3993	120
27-Jun	22.3	2144	24	22.5	2158	60	20.4	1961	24	35.8	3437	105
18-Jul	20.8	2000	24	20.3	1952	46	20.8	2000	24	19.7	1894	48
19-Aug	19.9	1907	25	25.9	2487	94	19.7	1888	25	47.4	4553	101
5-Sep	22.8	2186	24	21.5	2066	71	22.8	2186	24	16.7	1599	46
18-Oct	19.3	1851	22	24.9	2395	83	18.7	1797	22	47.9	4601	117
23-Dec	16.1	1543	18	19.5	1874	49	15.8	1515	18	41.2	3954	102

Congestion vs. Taxi times





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Correlation Tests

- We performed correlation test using Excel:

	Total Taxi	*M*
Total Taxi	**1**	
M	**0.744543**	**1**

	Dep Taxi	*M*
Dep Taxi	**1**	
M	**0.729702**	**1**

	Arr Taxi	*M*
Arr Taxi	**1**	
M	**0.396008**	**1**

Network of Airports

- Statistics for different functions of mi at different airports:

Airport	Max(mi)			Avg(mi)			Median(mi)		
	Average	St. Dev.	Range	Average	St. Dev.	Range	Average	St. Dev.	Range
ORD	97.16	18.24	[61,188]	49.94	11.65	[27,113]	57.6	12.33	[30,125]
ATL	113.4	21.68	[75,241]	54.51	13.7	[33,121]	62.91	15.25	[33,130]
BOS	51.57	13.33	[22,131]	26.08	10.42	[9,85]	27.58	11.42	[8,93]
EWR	72.67	19.87	[35,130]	37.55	16.19	[13,92]	38.75	17.28	[12,101]
PHL	65.91	16.59	[36,148]	30.92	11.95	[11,88]	30.86	12.72	[9,87]
LAX	65.86	9.43	[49,102]	34.1	7.34	[21,75]	37.81	7.96	[23,82]
SFO	45.48	8.53	[26,83]	21.41	6.43	[10,63]	21.92	6.83	[10,66]

Network Effects (2 Sigma days)

Network Effects	2 sigma days ATL	2 sigma days BOS	2 sigma days EWR	2 sigma days PHL	2 sigma days LAX	2 sigma days SFO	2 sigma days ORD
Jan					5,	21,	15,21,
Feb		15,26,					25,
Mar	1,	2,					
Apr	3,	4,17,	15,18,		3,		
May		16,	10,16,				16,
Jun	8,11,12,14,25,28,	5,8,12,19,21,27,28,29	1,12,21,28,	12,13,14,27,28,	1,8,19,27,28,	24,27,	18,26,27,
Jul	1,9,10,18,19,20,29,	27,	10,27,	10,29,	19,27,29,	16,29,	18,
Aug	5,16,24,	3,	3,9,17,	6,9,10,20,	9,17,20,	3,5,31,	6,19,22,
Sep				27,	27,	21,27,	5,
Oct		19,	9,19,	9,18,19,		4,9,	18,
Nov	25,		26,	14,26,	30,		
Dec		20,21,	23,		20,21,23,27,28,	6,21,22,23,27,	21,23,

Network Effects (3 Sigma days)

Network Effects	3 sigma days ATL	3 sigma days BOS	3 sigma days EWR	3 sigma days PHL	3 sigma days LAX	3 sigma days SFO	3 sigma days ORD
Jan			N/A		5,		21,
Feb			N/A				
Mar			N/A				
Apr		17,	N/A				
May			N/A				
Jun	8,11,12,25,	27,28,	N/A		8,27,		18,27,
Jul	10,18,	27,	N/A	29,	29,		18,
Aug	16,		N/A				19,
Sep			N/A	27,			5,
Oct			N/A	9,			18,
Nov			N/A				
Dec		20,	N/A			6,27,	23,

Important Notes

- Correlation can be due to the way operations are managed.
- Priorities and preferences in performing operations can cause correlation.
- In all of the days there has been excessive demand for arrivals and departures compared to existing capacity while , arrival demand has always been greater.
- Weather is the contributing factor in most cases.

Conclusions and Future Directions

- Currently, Traffic Management Initiatives (TMIs) only consider one problem at the time and ignore the effects of decisions on other components of the system, for example:
  - GDP, focuses on arrival flights only, creating priority for arrival flights over departures which in turn causes greater departure delays, taxi times and ultimately grid-locks.
  - AFP, focuses on one flow constrained area, flights from one airport get priority over another airport in close proximity causing delays. (ORD, MDW) and (LGA, PHL) are examples for such airports.

Questions?

Future Directions

- To propose a methodology to integrate all surface operations for both arrivals and departures.
- Taking surface congestion into considerations in decision making process.
- The process should comply with the current practice of Collaborative Decision Making (CDM).