Two-stage Multi-objective Analysis in the Assignment of Federal Air Marshals

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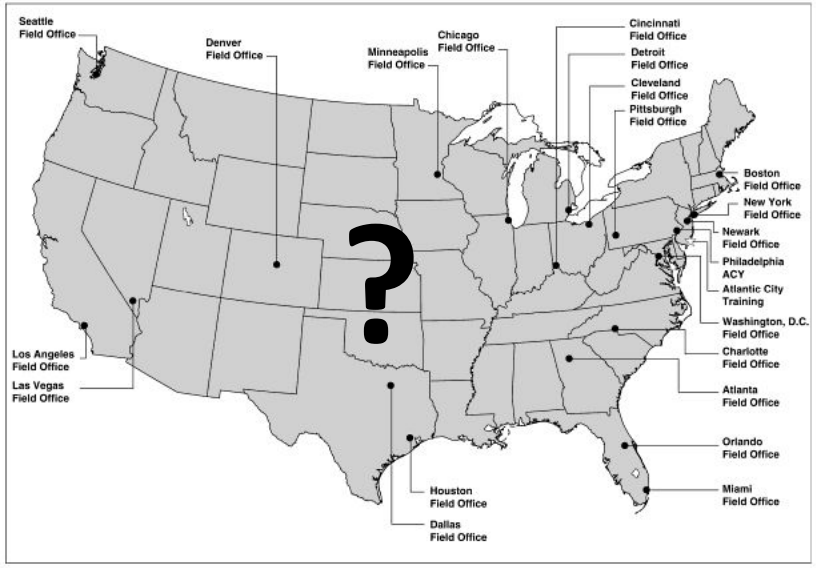
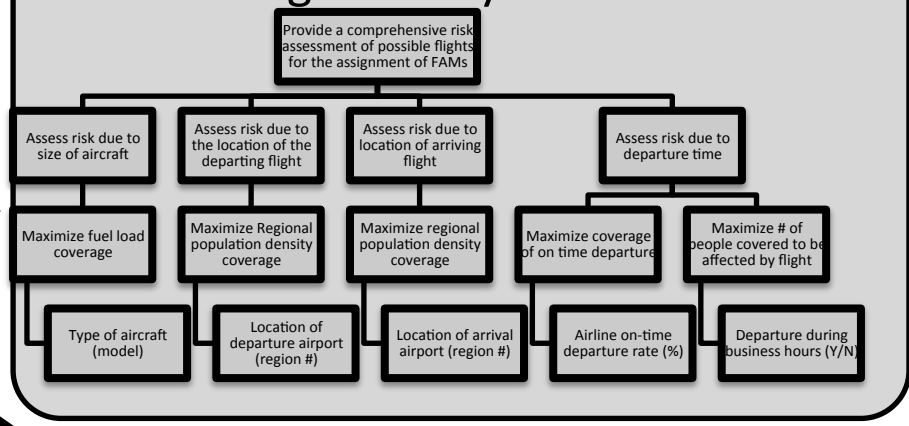
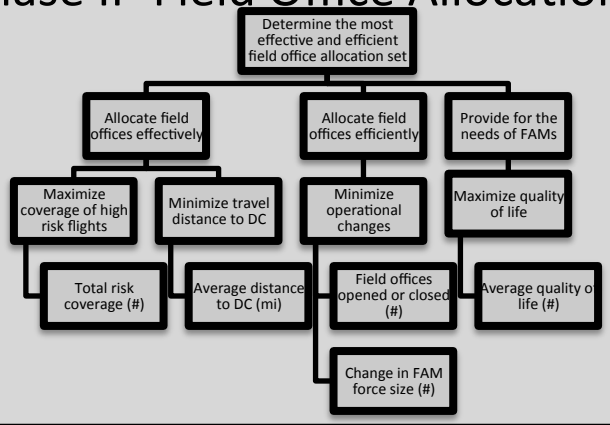
Summary

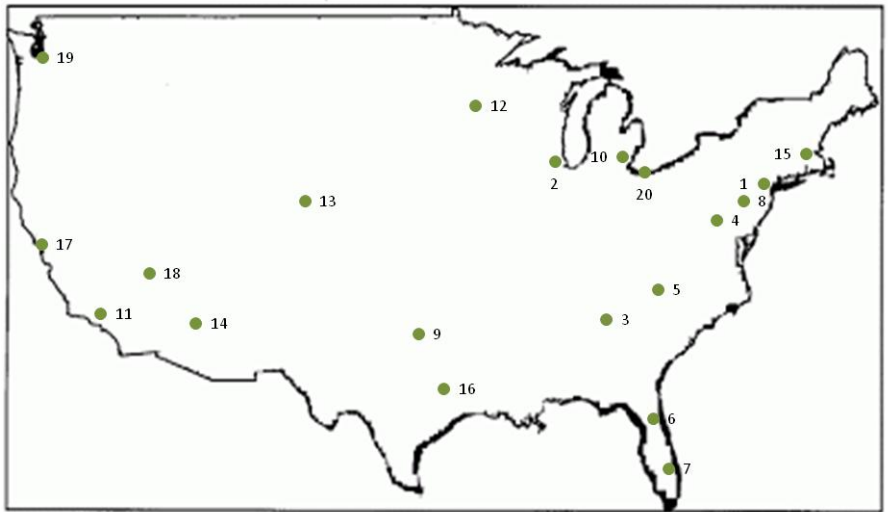


Phase I- Flight & City Risk Assessment



Phase II- Field Office Allocation





Agenda

- Problem Background
- Approach
- Results
- Cost Analysis
- Sensitivity Analysis
- Alternative Generation
- Conclusions
- Questions

Problem Background: The FAMS

- Subset of the Transportation Security Administration and the Department of Homeland Security
- Mission: Promote confidence in the nation's civil aviation system through effective deployment of FAMs to detect, deter, and defeat hostile acts targeting American air carriers, airports, passengers, and crews
- Currently, less than 10,000 FAMs allocated to 21 field offices across the United States needing to cover over 25,000 potential flights per day

Risk and allocation are important to understand in this problem so the FAMS can be effective and efficient in their operations

Problem Background: Related Work

- Nassim Taleb's theory of Black Swan Events
  - Highly improbable and unpredictable with enormous effects
  - At the limit of statistics
- Intelligent Randomization in Scheduling – IRIS (Tsai)
  - Separate, but related problem working to optimize the FAM schedule
  - Uses Stackelberg Game Theory and advanced computer algorithms
- General Aircrew Scheduling
  - Set portioning (Ryan 1992), Fuzzy sets (Teodorović and Lučic 1998), Simulated annealing (Lučic and Teodorović 1999), column generation (Gamache et al. 1999).
- OASIS (Castaneda et al. 2007)
  - optimized security infrastructure for airports.
- System of System for border security (Flanigan and Brouse, 2013)

Problem Background: Problem Definition

- Stakeholder analysis
  - The Studies, Research, and Analysis Office of Flight Operations
  - Desire an effective and efficient field office allocation recommendation
  - Increase ingenuity by minimizing access to current operating procedures
  - Deliverables: Number of field offices, location of each field office, and number of FAMs assigned to each field office

Redefined Problem Statement

Determine the best field office allocation set that meets the FAMS' needs by assessing the risk of flights and assigning FAMs to flights to maximize risk coverage

Problem Complexity

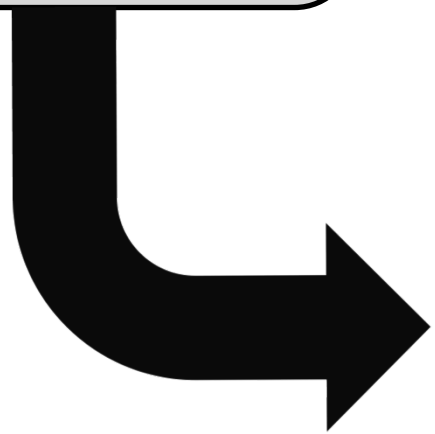
- Assigning a number of agents to an equal number of flights is a linear assignment problem and solvable in polynomial time.
- In the FAM assignment problem, each agent is assigned a different set of tasks; chain of events depends on their first flight of the day, number and length of subsequent connecting flights
- Because the number and length of each agent's flights (tasks) are different, the problem is classified as a generalized assignment problem "Generalized Assignment Problem"
  - Superset of the multiple knapsack problem.
  - NP-hard and not solvable in polynomial time.

Problem complexity prevents solving to optimality in a reasonable amount of time. We need a heuristic-based approach that emphasizes stakeholder value

Approach

Phase I-

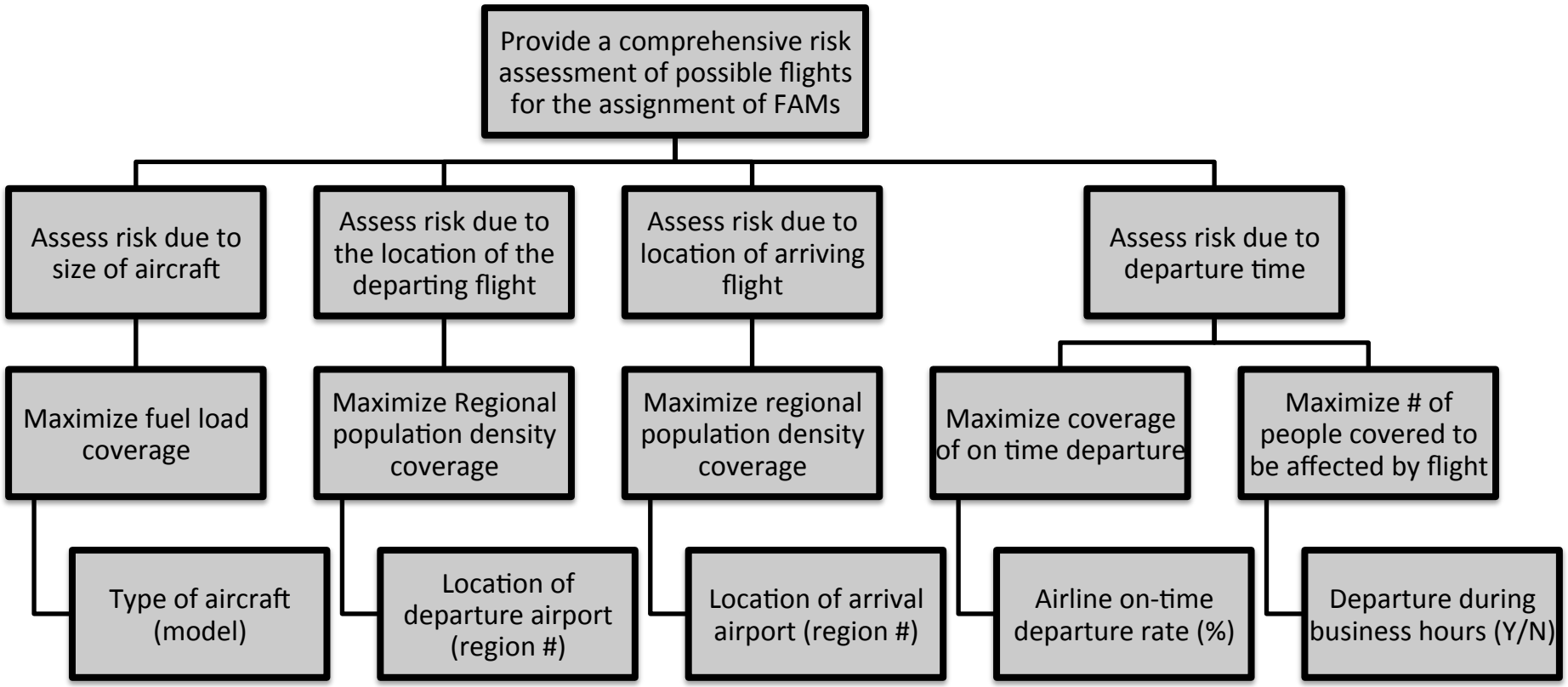
Flight & City-level Risk Assessment



Phase II-

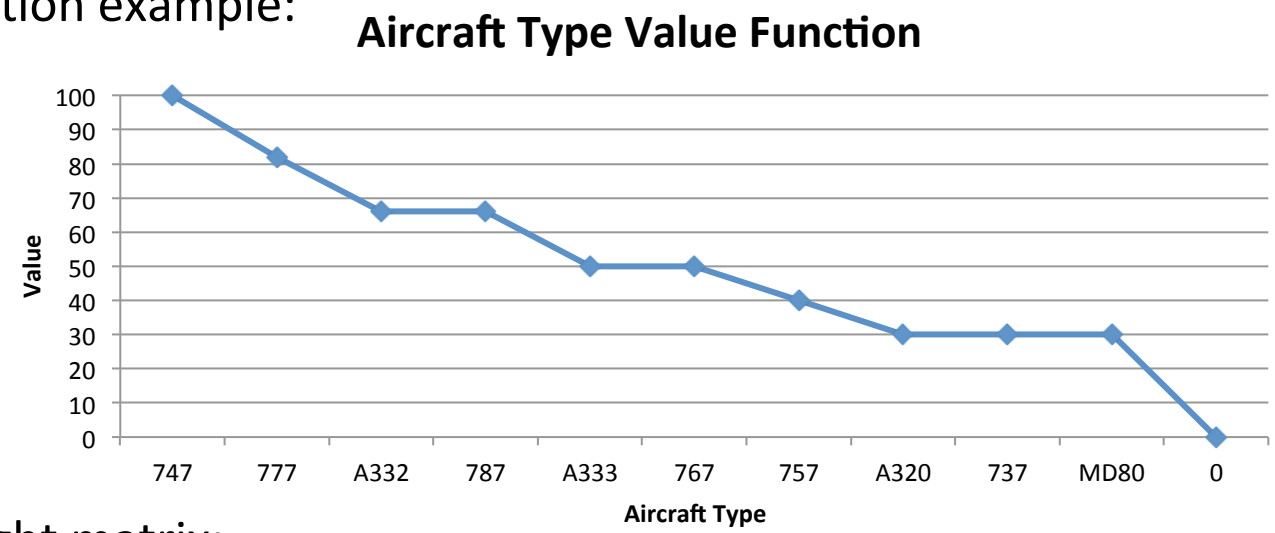
Field Office Allocation

Phase I-Value Hierarchy



Phase I-Value Functions

- Value function example:



- Swing weight matrix:

		Level of importance of the value measure								
		Very Important	Swt	Mwt	Important	Swt	Mwt	Less Important	Swt	Mwt
Variation in measure range	High	Type of Aircraft	100	0.308	Arrival Airport Region	70	0.215	Departure Time Flight	25	0.077
		Departure Airport Region	80	0.246						
	Medium									
	Low				On Time Departure Rate	50	0.154			

Phase I-Resulting Top 30 Airport Cities

Airport City	Airport 1	Risk 1	Ratio 1	Aiport 2	Risk 2	Ratio 2	Airport 3	Risk 3	Ratio 3	Total Risk	Total Ratio
NEW YORK	LGA	901768	0.366	EWR	832149	0.338	JFK	727055	0.295	2460972	0.100
CHICAGO	ORD	1694481	0.788	MDW	456712	0.212				2151194	0.087
ATLANTA	ATL	2147503	1							2147503	0.087
WASHINGTON	DCA	732576	0.388	BWI	597545	0.317	IAD	556445	0.295	1886566	0.077
CHARLOTTE	CLT	1228585	1							1228585	0.050
ORLANDO	MCO	693439	0.622	TPA	421467	0.378				1114905	0.045
MIAMI	MIA	559255	0.520	FLL	517114	0.480				1076369	0.044
PHILADELPHIA	PHL	1025136	1							1025136	0.042
DALLAS-FORT WORTH	DFW	989116	1							989116	0.040
DETROIT	DTW	954034	1							954034	0.039
LOS ANGELES	LAX	870729	1							870729	0.035
MINNEAPOLIS	MSP	847967	1							847967	0.034
DENVER	DEN	781077	1							781077	0.032
PHOENIX	PHX	761982	1							761982	0.031
BOSTON	BOS	658341	1							658341	0.027
HOUSTON	IAH	651500	1							651500	0.026
SAN FRANCISCO	SFO	640321	1							640321	0.026
LAS VEGAS	LAS	622548	1							622548	0.025
SEATTLE	SEA	499633	1							499633	0.020
CLEVELAND	CLE	365211	1							365211	0.015
SALT LAKE CITY	SLC	358792	1							358792	0.015
ST LOUIS	STL	341233	1							341233	0.014
NASHVILLE	BNA	307998	1							307998	0.013
SAN DIEGO	SAN	306790	1							306790	0.012
RALEIGH/DURHAM	RDU	276058	1							276058	0.011
PITTSBURGH	PIT	268748	1							268748	0.011
PORTLAND	PDX	264592	1							264592	0.011
KANSAS CITY	MCI	258280	1							258280	0.010
FORT MYERS	RSW	252790	1							252790	0.010
COVINGTON	CVG	243531	1							243531	0.010

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											34
											32
											31
											27
											26
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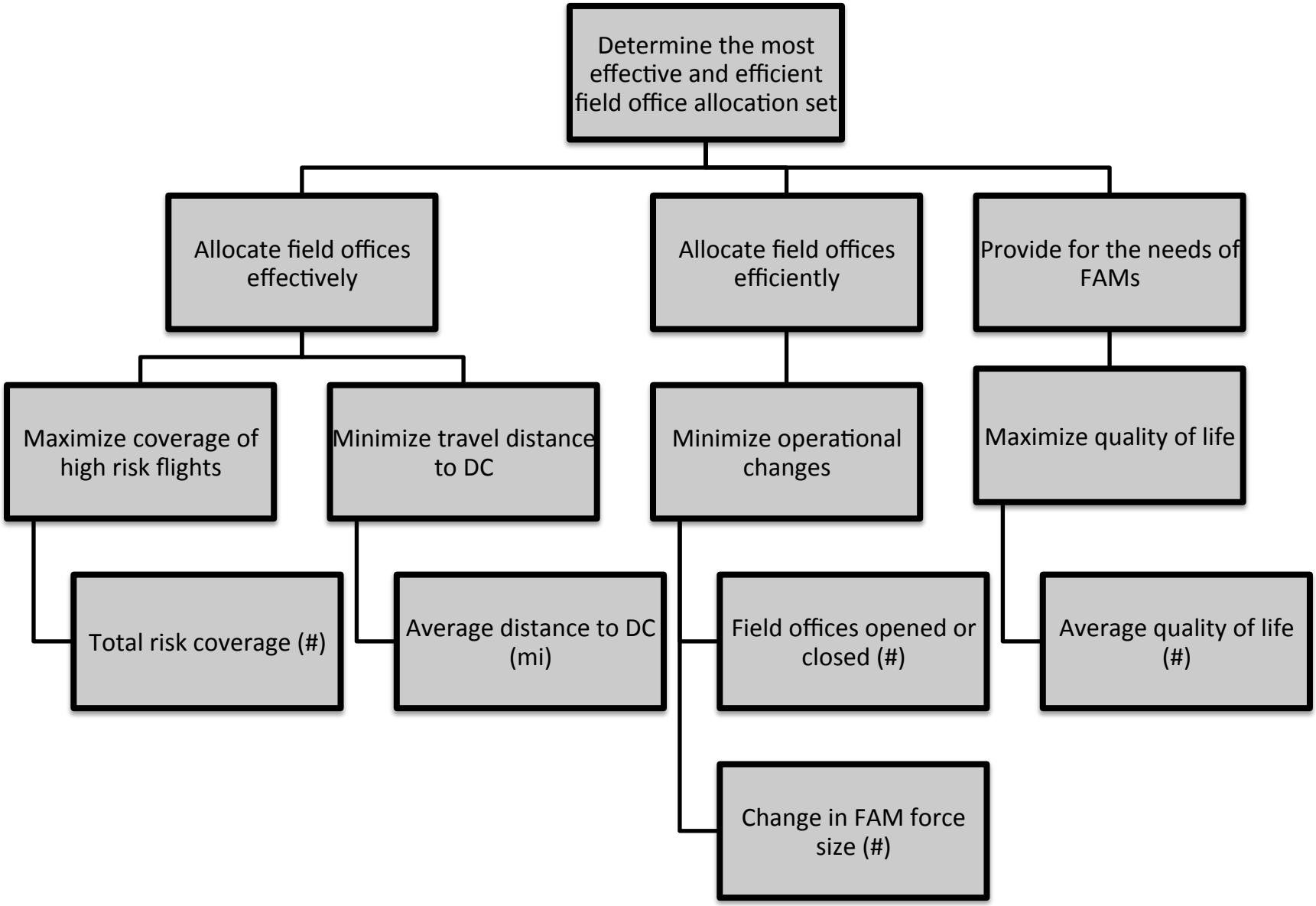
FORT MYERS	RSW	252790	1							252790	0.010
COVINGTON	CVG	243531	1							243531	0.010

How many agents to assign to which flight?
To which field offices are they stationed?

Phase II-Value Hierarchy



Phase II-Value Functions

Swing weight matrix:

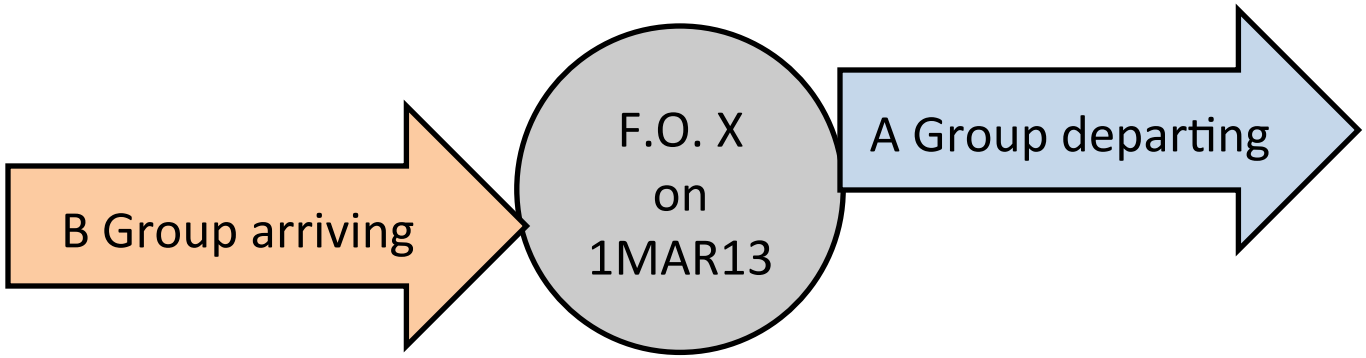
		Level of importance of the value measure							
		Very Important	Swt	Mwt	Important	Swt	Mwt	Less Important	Swt	Mwt
Variation in measure range	High	Total Risk Coverage	100	0.290						
	Medium	Average Distance to DC	75	0.217	# of FO # of FAMs	70 60	0.203 0.174	Average Quality of Life	40	0.116
	Low									

FAM Flight Assignment

- Crux of the problem
- Relates Phases I and II by determining total risk coverage

Phase II-FAM Flight Assignment

- Greedy algorithm
- Assumptions and Constraints
  - Based on 181.5 FAM mission days per year with 2 day long trips
  - Maximum duty day 10 hours (90 minutes for pre-flight and 15 minutes for post-flight)
  - Flights cannot be covered more than once
  - FAMs scheduled over one day (1 March 2013 with 22614 flights)
  - A Group: Depart field office between 0600 and 1200 hours
  - B Group: Arrive at field office between 1800 and 2400 hours
  - Number of FAMs scaled by factor of 50 (i.e. 20,000 -> 400)



Phase II-FAM Flight Assignment

Station	Group	Slot	Day
LGA	A	1	1
EWR	A	1	1
JFK	A	1	1
ORD	A	1	1
ORD	B	1	1
MDW	A	1	1
ATL	A	1	1
ATL	B	1	1
DCA	A	1	1
BWI	A	1	1
IAD	A	1	1
CLT	A	1	1

Input

Flight ID	Departure Airport	Departure Date	Departure Time	Arrival Airport	Arrival Date	Arrival Time	Flight Time	Risk	FAM ID
589017	CLT	3/1/2013	16:30	PHL	3/1/2013	18:08	1:38	79.23	
449559	BOS	3/1/2013	13:00	BWI	3/1/2013	14:30	1:30	75.38	
450795	BWI	3/1/2013	7:10	BOS	3/1/2013	8:31	1:21	75.38	
450807	BWI	3/1/2013	11:00	BOS	3/1/2013	12:20	1:20	75.38	
452307	BWI	3/1/2013	8:45	PWM	3/1/2013	10:06	1:21	75.38	
453311	BWI	3/1/2013	12:45	ROC	3/1/2013	13:54	1:09	75.38	

Output

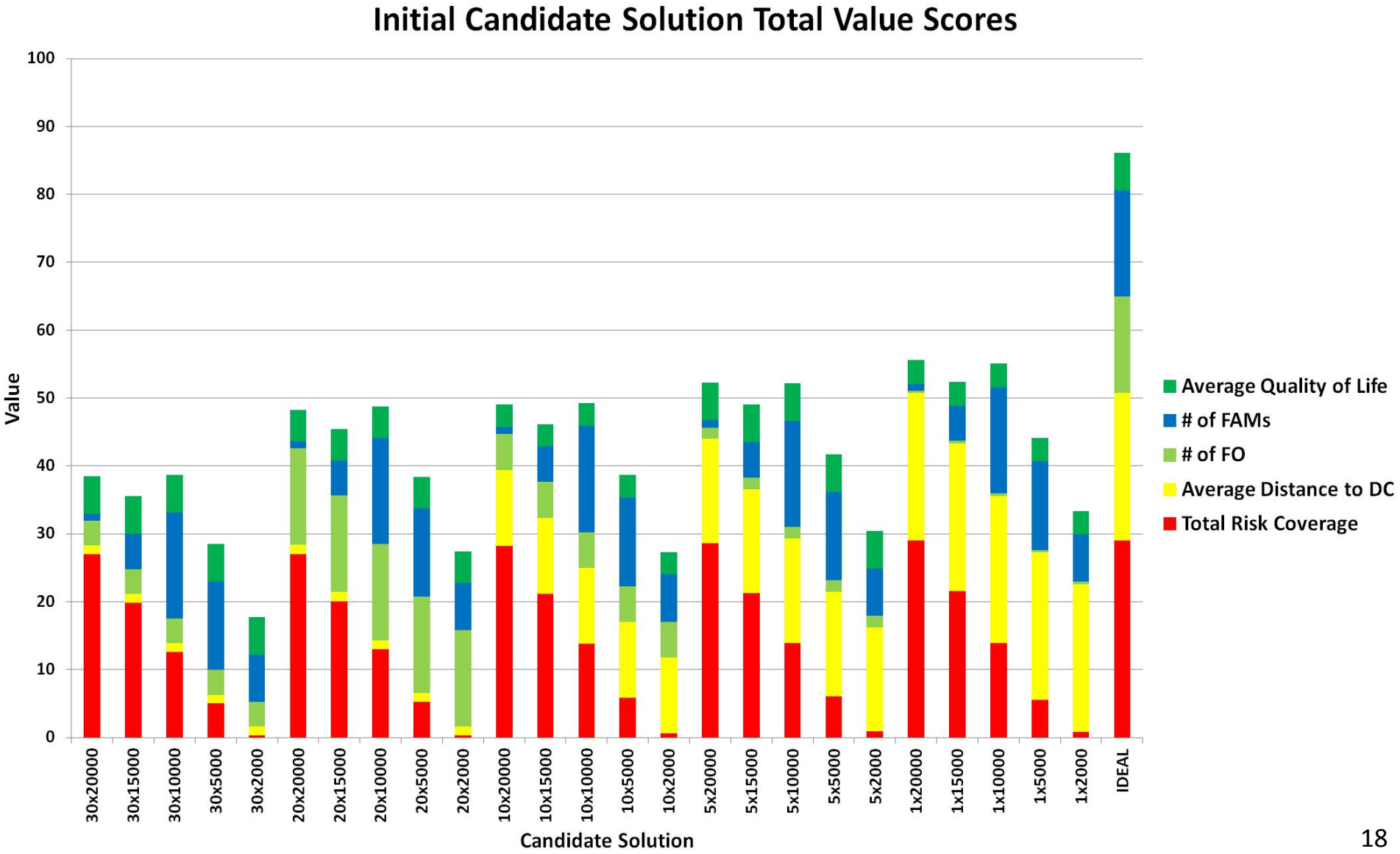
Field Office Airport	FAM ID	Leg	Flight ID	Departure Airport	Departure Date	Departure Time	Arrival Airport	Arrival Date	Arrival Time	Flight Time	Risk	Duty Day Remaining
LGA	LGA_A_1	0	162537	LGA	3/1/2013	7:00	DCA	3/1/2013	8:07	1:07	73.1	7:08
LGA	LGA_A_1	1	156389	DCA	3/1/2013	10:30	BOS	3/1/2013	11:53	1:23	73.1	4:00
LGA	LGA_A_1	2	53477	BOS	3/1/2013	14:15	BWI	3/1/2013	15:50	1:35	73.1	0:40
EWR	EWR_A_1	0	9562	EWR	3/1/2013	8:30	BOS	3/1/2013	9:39	1:09	69.2	7:06
EWR	EWR_A_1	1	449559	BOS	3/1/2013	13:00	BWI	3/1/2013	14:30	1:30	75.4	3:51
EWR	EWR_A_1	2	651305	BWI	3/1/2013	16:30	CLT	3/1/2013	17:50	1:20	71.1	0:46
JFK	JFK_A_1	0	306028	JFK	3/1/2013	7:30	SYR	3/1/2013	8:47	1:17	69.2	6:58
JFK	JFK_A_1	1	37616	SYR	3/1/2013	11:55	DCA	3/1/2013	13:19	1:24	63.8	3:49
JFK	JFK_A_1	2	157610	DCA	3/1/2013	15:30	BOS	3/1/2013	16:59	1:29	73.1	0:35
ORD	ORD_A_1	0	545663	ORD	3/1/2013	7:20	PHL	3/1/2013	10:20	2:00	68.2	6:15
ORD	ORD_A_1	1	534482	PHL	3/1/2013	15:55	MCO	3/1/2013	18:28	2:33	74.9	1:57

Phase II-Field Office Allocation

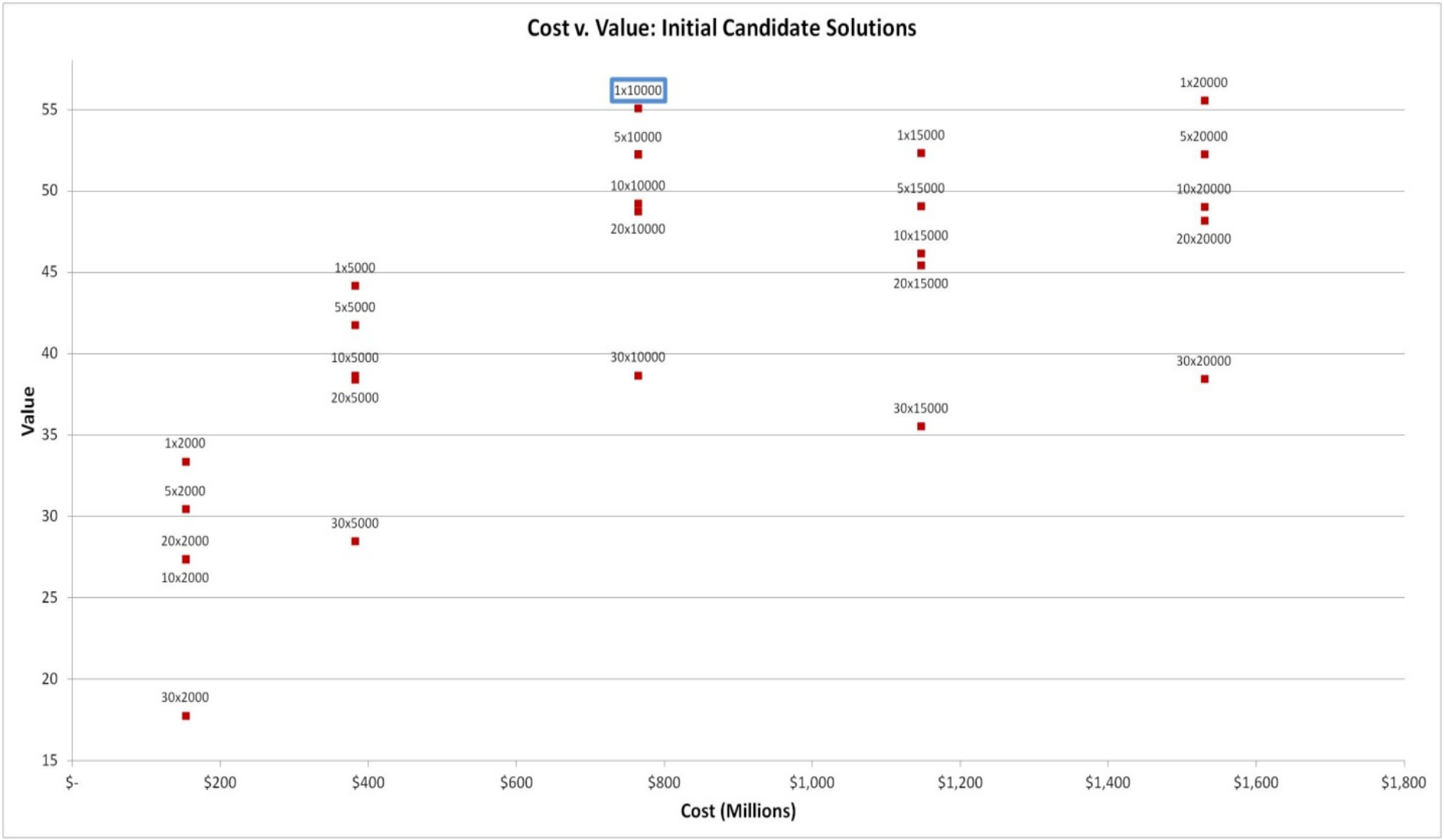
- 25 initial candidate solutions
  - Top 30/20/10/5/1 airport cities (must include Washington)
  - Decision space involved *n* offices x *m* agents
    (e.g. 20 x 5000 is 5000 agents distributed among 20 offices)
  - 20k/15k/10k/5k /2k FAMs distributed by risk

- Conduct cost and sensitivity analysis to refine solutions

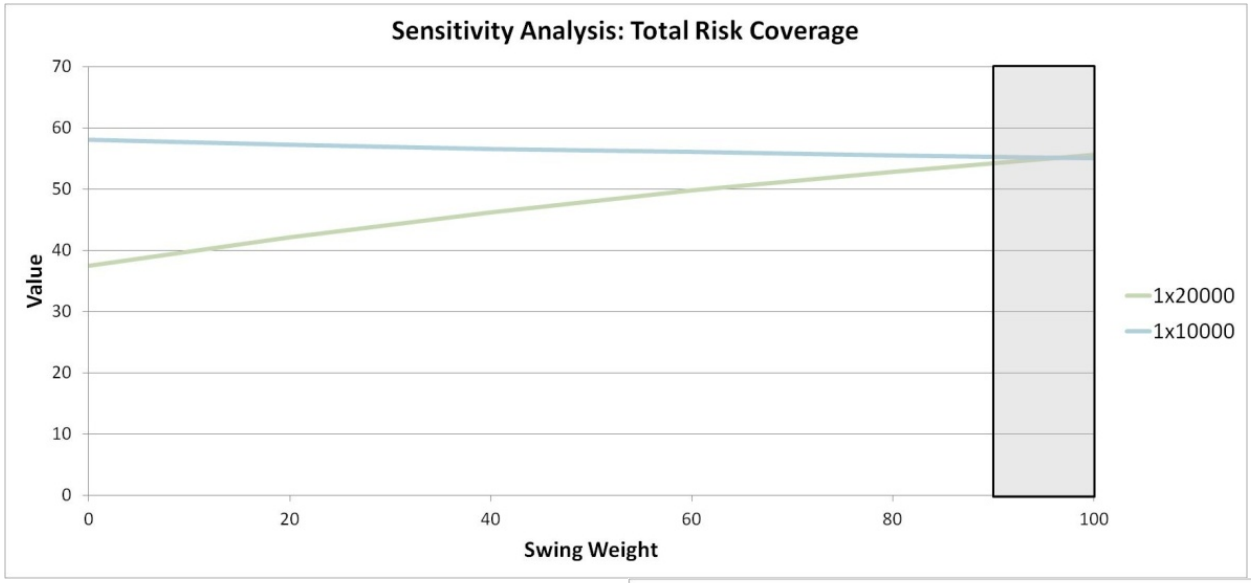
Results

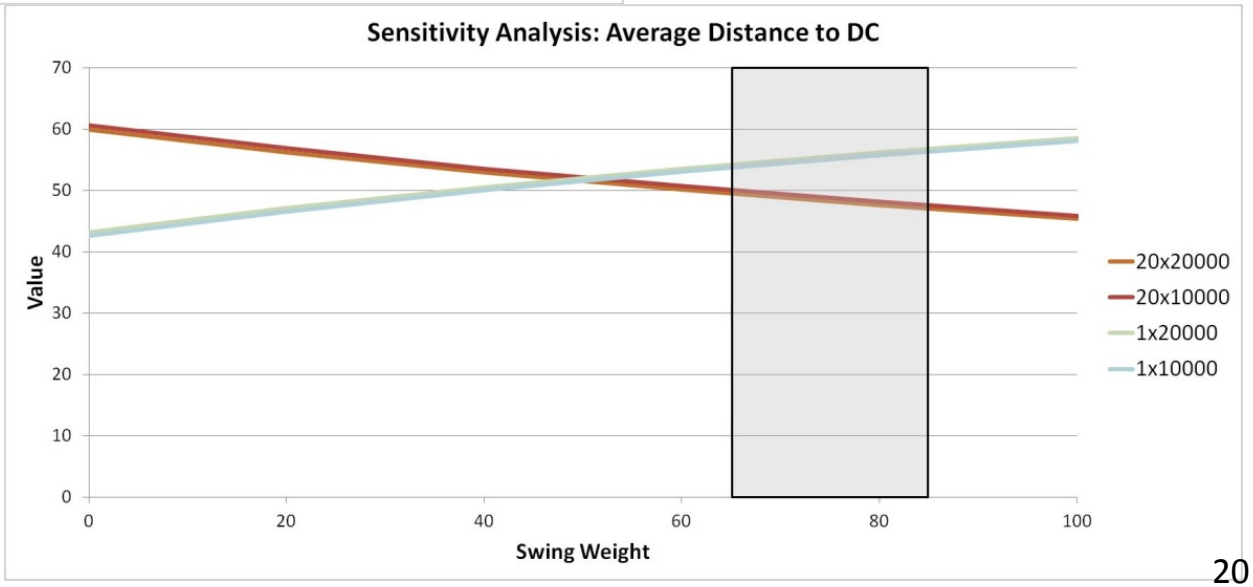

Initial Candidate Solution Total Value Scores
Value
100
90
80
70
60
50
40
30
20
10
0
30x20000
30x15000
30x10000
30x5000
30x2000
20x20000
20x15000
20x10000
20x5000
20x2000
10x20000
10x15000
10x10000
10x5000
10x2000
5x20000
5x15000
5x10000
5x5000
5x2000
1x20000
1x15000
1x10000
1x5000
1x2000
IDEAL
Candidate Solution
Average Quality of Life
# of FAMs
# of FO
Average Distance to DC
Total Risk Coverage

Cost Analysis



Sensitivity Analysis



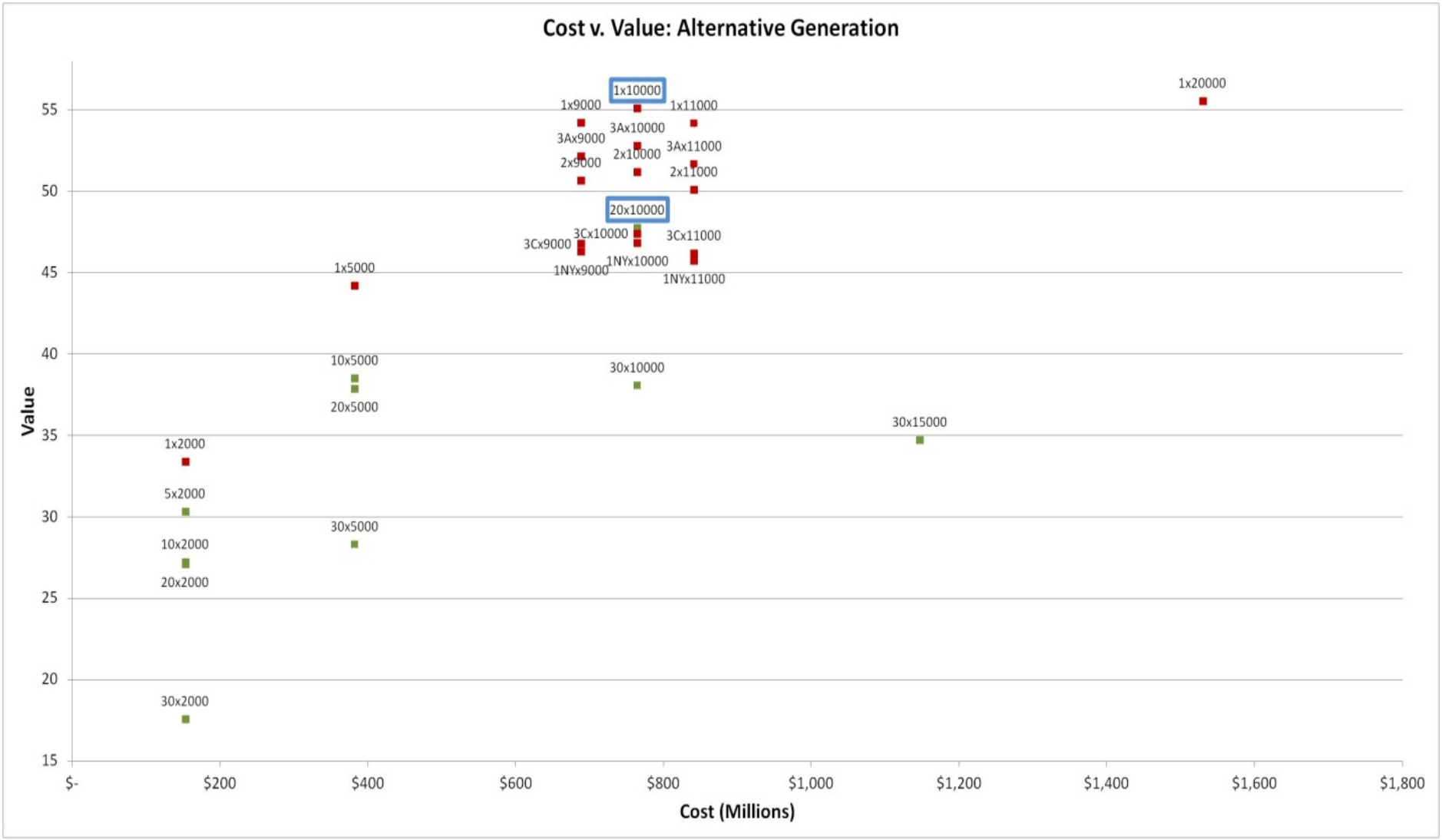


Alternative Generation

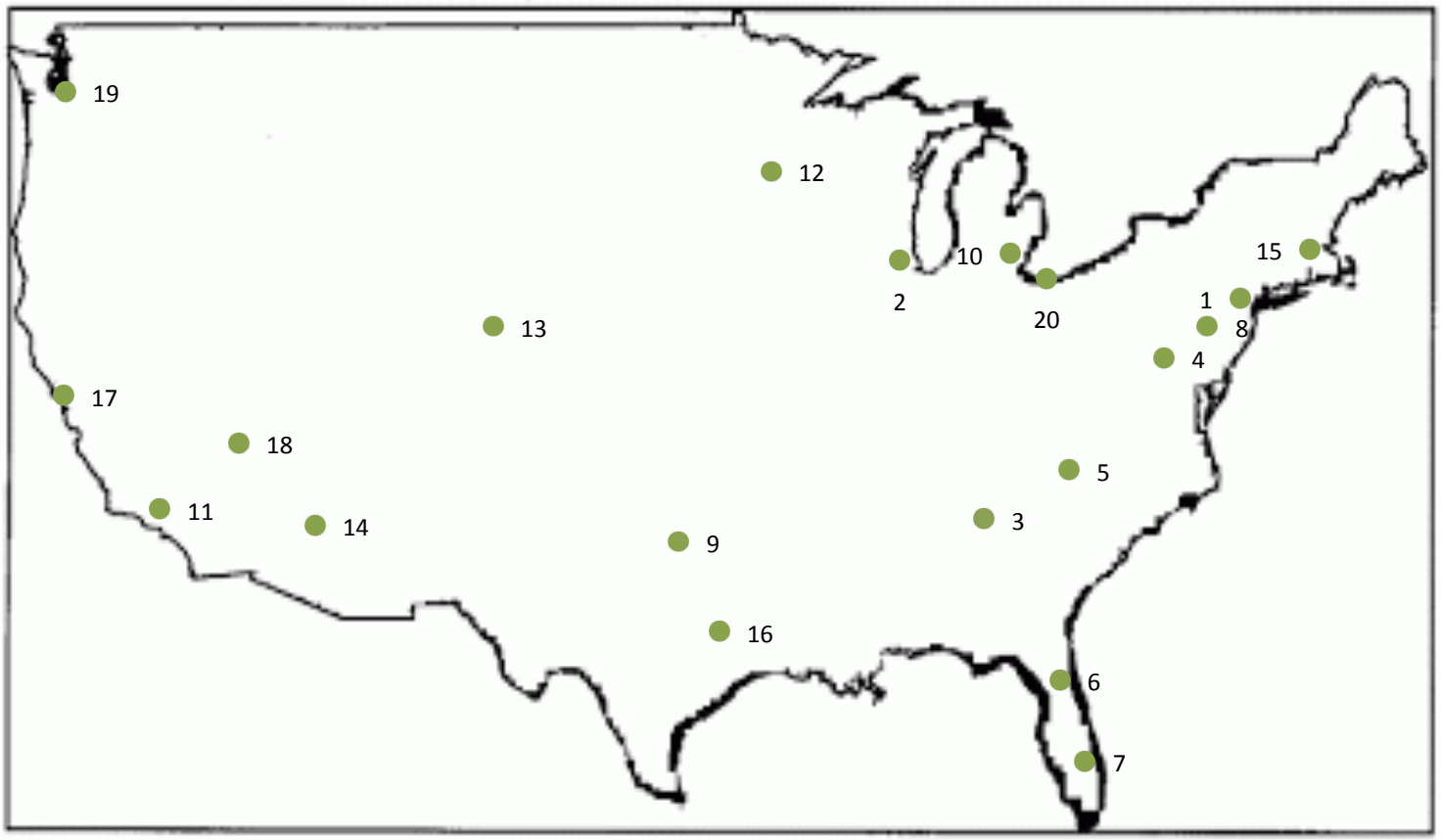
- 14 new alternative candidate solutions ( )
  - Top 3(with Chicago)*/ 3(with Atlanta)*/2*/1/1* airport cities (*must include Washington)
  - 11k/10k/9k FAMs distributed by risk

- 10 new alternative candidate solutions with additional operational constraint ( )
  - 500 FAMs maximum per field office
  - Applicable initial candidate solution set with equally distributed FAMs

Alternative Generation



20x10000 Solution



1. NEW YORK
2. CHICAGO
3. ATLANTA
4. WASHINGTON
5. CHARLOTTE
6. ORLANDO
7. MIAMI
8. PHILADELPHIA
9. DALLAS
10. DETROIT
11. LOS ANGELES
12. MINNEAPOLIS
13. DENVER
14. PHOENIX
15. BOSTON
16. HOUSTON
17. SAN FRANCISCO
18. LAS VEGAS
19. SEATTLE
20. CLEVELAND

Conclusion

- Recommendation
  - 20 Field Offices with 10,000 total FAMs (500 each)
  - 1 Year Cost: $765 M
  - Different Field Offices
    - Close: Newark, Pittsburgh, and Cincinnati
    - Open: Phoenix and San Francisco

- Future work
  - Improve FAM flight assignment algorithm to increase the amount of days and number of FAMs scheduled
  - The FAMS inputs their own data to validate approach

Questions?

Backup Slides

Phase I-Risk Assessment