Resource Allocation in Flow-Constrained Areas with Stochastic Termination Times Considering Both Optimistic and Pessimistic Reroutes

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Abstract

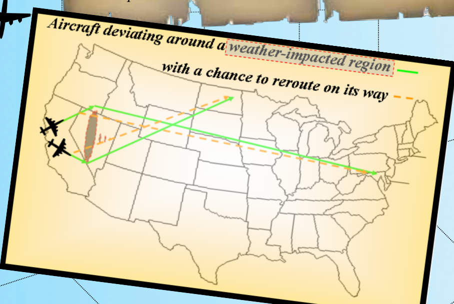
In this project we formulate an optimization problem for the assignment of dispositions to flights whose preferred flight plans pass through a flow-constrained area. For each flight, the disposition can be either to depart as scheduled but via a secondary route that avoids the flow-constrained area, or to use the originally intended route but to depart with a controlled departure time and accompanying ground delay. We anticipate that the capacity through the flow-constrained area will increase at some future time once the weather activity clears. The model is a two-stage stochastic program that represents the time of this capacity windfall as a random variable, and determines expected costs given a second-stage decision, conditioning on that time. The goal is to minimize the expected cost over the entire distribution of possible capacity increase times.

Model Inputs

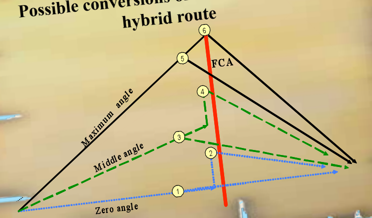
- Location of the FCA (Flow Constrained Area)
- Nominal (good weather) capacity of the FCA
- Reduced FCA (bad weather) capacity of the FCA
- Start time of the AFP (Airspace Flow Program)
- Planned end time of the AFP

Model Outputs

- An initial plan that designates whether a flight is assigned to its primary route or secondary route;
- A recourse action for each flight under each possible early clearance time.



Possible conversions of a secondary into hybrid route



Decision Variables Definitions

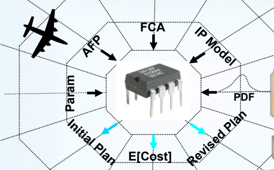
$x^p_{f,t}$ = 1, if flight f uses its primary route and has an appointment time t at the FCA; 0, otherwise

$x^s_{f,r}$ = 1, if flight f is assigned to its secondary route that has a directional angle r; 0, otherwise

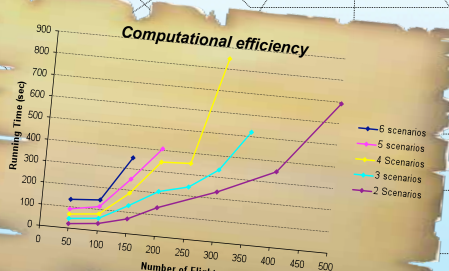
$y^p_{f,t}|u$ = 1, if at the time $U-u$ of the capacity windfall, flight f is assigned to its primary route with appointment slot t at the FCA; 0, otherwise

$y^h_{f,t,r}|u$ = 1, if flight f was originally assigned to its secondary route with directional angle r, but under capacity clearing time u has been assigned an FCA appointment slot t; 0, otherwise

$y^s_{f,r}|u$ = 1, if flight f was originally assigned to its secondary route with directional angle r, and if, under AFP stop time u, that decision remains unchanged; 0 otherwise



Computational efficiency



Case Study

	Reroute (RR)	Ground Delay (GD)
Plan	none/static/recourse	none/static/recourse
Execute	none/static/recourse	none/static/recourse

Case		RR	GD
Case 1:	Plan	RR: none	GD: recourse
	Execute	RR: none	GD: recourse
Case 2:	Plan	RR: static	GD: static
	Execute	RR: static	GD: static
Case 3:	Plan	RR: static	GD: static
	Execute	RR: static	GD: recourse
Case 4:	Plan	RR: static	GD: recourse
	Execute	RR: static	GD: recourse
Case 5:	Plan	RR: recourse	GD: recourse
	Execute	RR: static	GD: recourse
Case 6:	Plan	RR: recourse	GD: static
	Execute	RR: recourse	GD: recourse
Case 7:	Plan	RR: recourse	GD: recourse
	Execute	RR: recourse	GD: recourse
Case 8-13:	Plan	RR: recourse	GD: recourse
	Execute		GD: recourse

Objective Function

$$Min\left[C(X) - \sum_u p_u S(Y_u)\right]$$

Initial plan cost –possible saving under each scenario U

Main Constraints

Under original plan each flight must either be assigned to a secondary route or to its primary routes – possibly with a delay

$$\sum_t x^p_{f,t} + \sum_r x^s_{f,r} = 1 \quad \forall f$$

FCA capacity constraints under original plan:

$$\sum_f x^p_{f,t} \le C^0_t \quad \forall t$$

under revision, flight can only arrive earlier than u + E(f) if it has already departed

$$y^p_{f,t}\,|\,u = x^p_{f,t} \quad \forall f,u, \quad \forall t \in \{1,\ldots,u+E_f\}$$

Under revision, flight originally assigned to its secondary route can go on primary route if it has not departed yet

$$\sum_t y^p_{f,t}\,|\,u \le 1 - \sum_r x^s_{f,r} \quad \forall u, \forall f \ni D_f < u$$

Under revision flight on primary route can only arrive earlier at FCA

$$y^p_{f,t}\,|\,u \le \sum_{q \ge t} x^p_{f,q} + \sum_r x^s_{f,r} \quad \forall u,f,t$$

Flight on hybrid route cannot arrive at FCA at time t unless u plus the revision time is less than t

$$y^h_{f,t,r}\,\big|\,u = 0 \quad \forall f,r,u \quad \forall t \,\big|\, t^d_{f,t} \le u$$

Flight cannot use a hybrid route unless it was originally assigned to its secondary route

$$\sum y^h_{f,t,r}\,|\,u + y^s_{f,r}\,|\,u \le x^s_{f,r} \quad \forall u,f,r$$

Under all scenarios each flight must either be assigned to a time slot at FCA or complete its secondary route:

$$\sum_t y^p_{f,t}\,|\,u + \sum_r \sum_t y^h_{f,t}\,|\,u + \sum_r y^s_f\,|\,u = 1 \quad \forall u,f$$

FCA capacity constraints under scenario u:

$$\sum_f y^p_{f,t}\,|\,u + \sum_r \sum_f y^h_{f,t,r}\,|\,u \le C^u_t \quad \forall u,t$$

Results

Case	q	p[q]	c(xp=1)	c(xs=1)	sv(yp=1)	sv(yh=1)	c(q)	Objective
1	15	0.5	12821	0	11079	0	1742	3619
	30	0.3			9511	0	3310	
	45	0.1			8096	0	4725	
2	15	0.5	355	1444	0	0	4686	4686
	30	0.3			0	0	4686	
	45	0.1			0	0	4686	
3	15	0.5	355	1444	56	0	4630	4658
	30	0.3			0	0	4686	
	45	0.1			0	0	4686	
4	15	0.5	8805	357	7764	0	2113	3423
	30	0.3			6675	0	3202	
	45	0.1			5692	0	4184	
5	15	0.5	8805	357	7652	298	1330	2837
	30	0.3			6570	216	2659	
	45	0.1			5537	158	3867	
6	15	0.5	355	1444	56	1035	1526	2373
	30	0.3			0	690	2615	
	45	0.1			0	371	3573	
7	15	0.5	1551	1318	1169	1104	1025	2021
	30	0.3			914	829	2105	
	45	0.1			728	504	3264	
8	15	0.5	927	2433	690	2340	519	1676
	30	0.3			522	2207	1084	
	45	0.1			398	1712	2692	
9	15	0.5	788	2380	566	2273	543	1638
	30	0.3			425	2162	1017	
	45	0.1			300	1647	2686	
10	15	0.5	1162	3286	839	3230	490	1834
	30	0.3			594	3174	903	
	45	0.1			424	2812	2159	
11	15	0.5	455	2655	360	2602	253	1342
	30	0.3			300	2484	669	
	45	0.1			240	2152	1723	
12	15	0.5	455	2618	360	2562	265	1341
	30	0.3			300	2443	681	
	45	0.1			240	2111	1735	
13	15	0.5	1075	3570	906	3561	195	1340
	30	0.3			751	3551	381	
	45	0.1			601	3404	971	

Conclusions and future work

we have defined the basics of a stochastic optimization model for simultaneously making ground delay and reroute decisions in response to en route airspace congestion. a weather impacted area anticipating future clearance can produce the lowest expected cost. What is more important to note is that our model can determine when this represent an optimal strategy.

In case 9 we add a third option with a directional angle equal to the average of the optimistic and pessimistic cases (the average of the zero-angle and the max angle). Our results show that this produces very little additional benefit. For case 10, we pre-compute the optimal directional angle of each flight independent of capacity constraints (here optimal is relative to the weather clearance time probability distribution and the geometry of the flight path). Note that the costs here are worse than in case 8 indicating the importance of considering the capacity constraints.

Cases 11, 12 and 13 are similar to cases 8, 9 and 10 respectively except that the capacity of the second stage was set to infinity (un-capacitated). In the absence of second stage capacity constraints, as one can expect, the approach that employs the optimal unconstrained directional angle (case 13) provides the lowest cost

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