Miami Beach

- Annual INFORMS Fall 2001 Aviation Applications Track
  - Revenue Management
  - Airline Strategic and Schedule Planning
  - Crew Management
  - and many more.
- Miami Beach
  - November 4-7, 2001
  - www.informs.org/Conf/Miami2001
- Send email to klabjan@uiuc.edu

Robust Crew Scheduling: Move-up Crews

Diego Klabjan
Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign

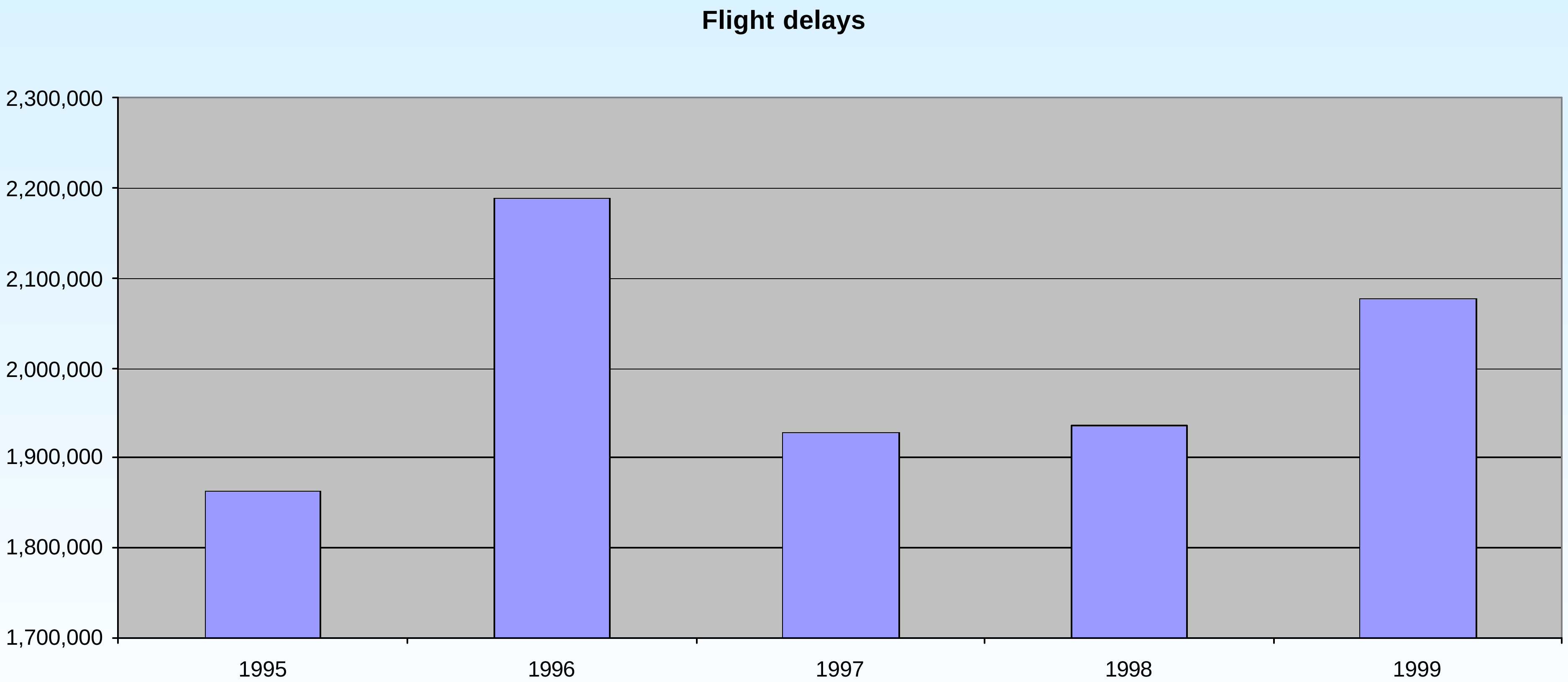
Who am I?

- Start up airline?
  - Just a faculty doing research in airline OR
- Graduated in 99 from Georgia Tech
  - Thesis on airline crew scheduling
    - Integrated approach to routing and crew scheduling
    - Weekly crew scheduling, regularity
  - Funded by the United Airlines
- Faculty at the University of Illinois
  - United Airlines
  - Sabre Inc.
  - ???

Sponsors

- Funded by the OR division of NSF
- Collaboration with Sabre, Inc.
  - Ladislav Letovsky
  - Ellis Johnson
  - Hai Chu

Flight Delays



- Data by the transportation department
- Source: Aviation Week & Space Technology, September 2000

Summer 2000 Collapse

- 11% increase
- Flight delays
  - 1.7% delayed flights in 1995
  - 2.3% delayed flights in 1999
- Summer 2000 the worst ever
- In Summer 2000 Northwest the best on time performance
  - 75% on time arrival rate
- Disruptions
  - Weather related
  - Congestions

Improve Performance

- FAA
  - ATM
  - CDM
- Airlines
  - Recovery procedures
    - Integrated recovery
    - Aircraft recovery
    - Crew recovery
  - Robust solutions
    - Robust aircraft routing
    - Robust crew scheduling

Why Robustness?

- FTC (excess cost/flying time) for large fleets below 1%
- Solutions use many tight, short connections.
  - Such connections are very vulnerable to disruptions.
- 1% FTC in planning for large fleets translates into 8% to 10% FTC in operations.
- 3% FTC for smaller fleets results in 6% FTC in operations.
- Solutions
  - Better recovery procedures
  - Robust solutions

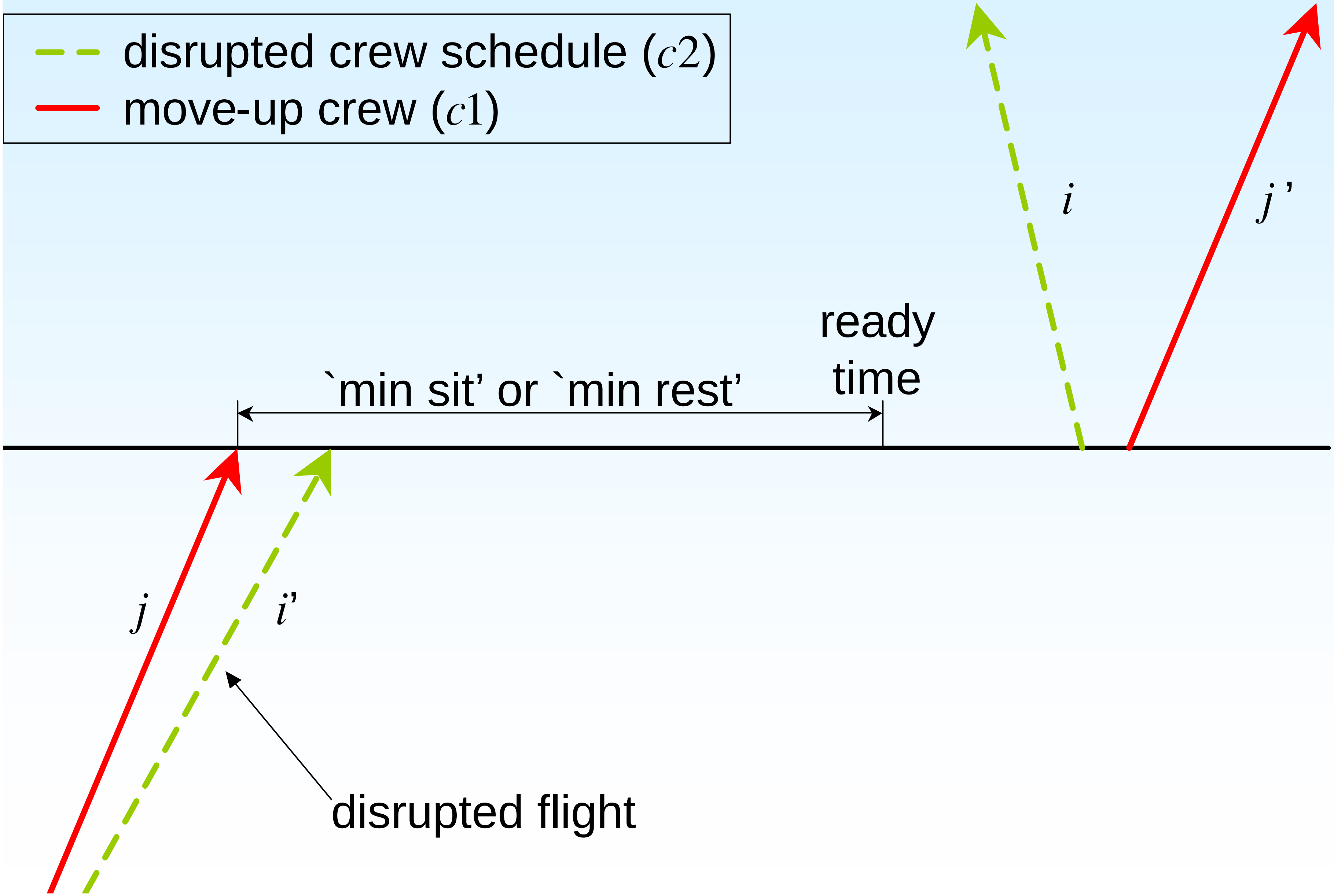
Crew Recovery

- A crew is late and cannot fly the next flight in the pairing.
- Recovery: Find a crew that will fly the next flight.
- Crew swaps
- Reserve crews

Move-up Crews

- Crews that are ready to cover a different flight.
  - At least
    - Ready to fly
    - Same crew base
    - Same number of days till the end of the pairing
- Potentially in operations yields crew swapping.
- Choice of flight cancellation

Move-up Crews



Robust Crew Scheduling: Move-up Crews

- Two objectives
  - Low cost
  - Maximize the number of move-up crews.
- Maximizing the number of move-up crews.
  - Add a constraint: cost $\leqslant K$.
  - ‘Goal programming’
    - Solve first the traditional crew scheduling problem.
    - Select a subset of low cost pairings.
    - Maximize the number of move-up crews over the selected pairings.

Model

- Given a flight need to record
  - the crew base of the pairing covering it,
  - the number of days till the end of the pairing.
- Variables
  - pairing binary variables
  - $x_{i,cb,d}$=1 if flight i is covered by a pairing from crew base cb and it has d days till the end of the pairing.
  - $z_{i,cb,d}$ = number of move up crews
  - w_i = 1 if leg i starts a pairing.

Model

- Maximize the number of move-up crews.

$$\max \sum_{i,cb,d} z_{i,cb,d}$$

- Cover every leg i that does not originate at a crew base.

$$\sum_{i \in p} y_p = 1$$

- For every leg i that does originate at a crew base cb

$$\sum y_p = x_{i,cb,d}$$

Model

- For every leg i that starts at a crew base do not count move-up crews at the beginning of pairings.

$$\sum_{i \in p} y_p = w_i$$

- Cover every leg i that starts at a crew base.

$$w_i + \sum_{cb,d} x_{i,cb,d} = 1$$

Model

- Count the number of move-up crews.

$$\sum y_p \geq x_{i,cb,d}$$

- Variable upper bounds

$$z_{i,cb,d} \leq Mx_{i,cb,d}$$

Methodologies

- Quasi set partitioning with side constraints
- Possible methodologies
  - Lagrangian decomposition
    - Relax side constraints, i.e. the constraints that count move-up crews.
    - The resulting problem is a `quasi' set partitioning problem.
  - Resource decomposition
    - Function of x variables
    - Nonlinear optimization
  - Branch-and-price
    - If pairings are generated backwards, pricing can be done efficiently.

Lagrangian Decomposition

- Relax the move-up count constraints.
  - The resulting problem that needs to be solved at every iteration is almost a set partitioning problem.
- Performance depends on the ability to solve these almost set partitioning problems.

$$\min \hat{c}y + \hat{d}x$$
$$A_1 y = 1$$
$$A_2 y = x$$
$$A_3 y = w$$
$$w + A_4 x = 1$$
$$y \text{ binary}$$

Resource Decomposition

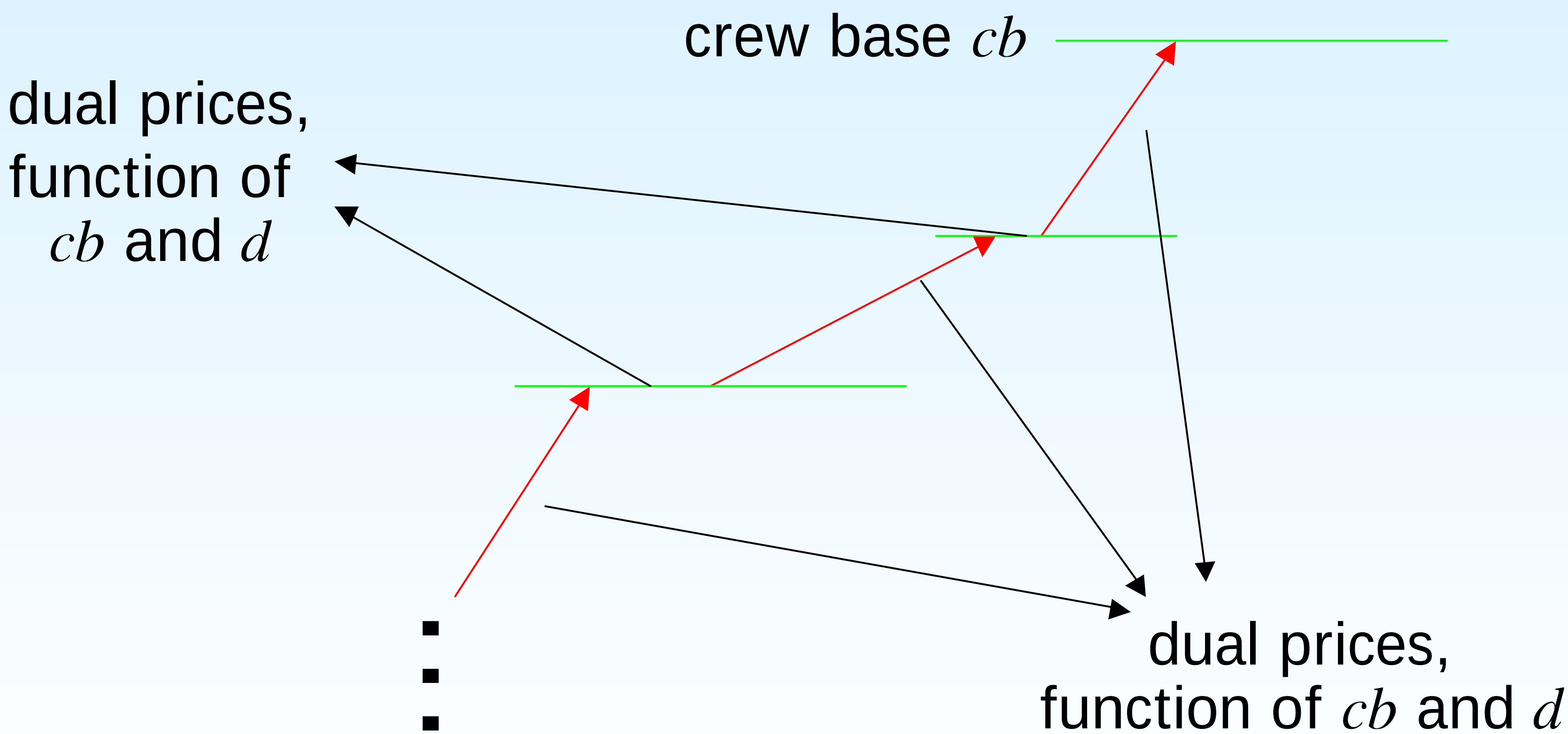
- Given binary x,w satisfying the cover constraint consider $f(x, w)$, where f is the objective value of the model given fixed x and w.
- Evaluating f is easy.
- Use nonlinear programming techniques by choosing different x and w.

Branch-and-Price

- Design a parallel branch-and-price library.
- 'Subclass' it to obtain a parallel branch-and-price crew scheduling solver.
- Pricing for the model:
  - Every connection arc has dual prices corresponding to the move-up count constraints, i.e. days d.
  - If constrained shortest path or enumeration is performed backwards, pricing is as efficient as it is for the traditional crew scheduling problem.

Pricing

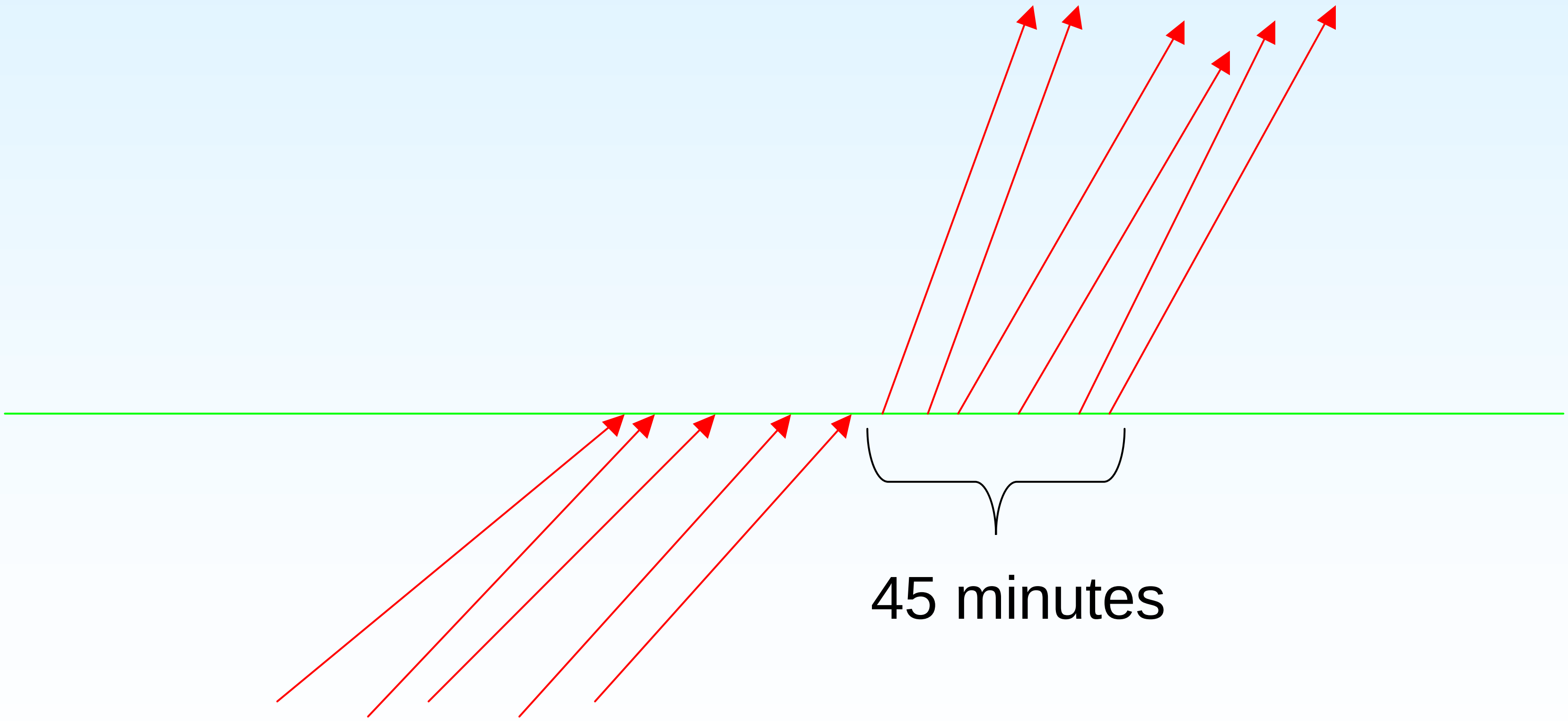
Backward pairing generation or constrained shortest path



- Potential complication: duty elapse time

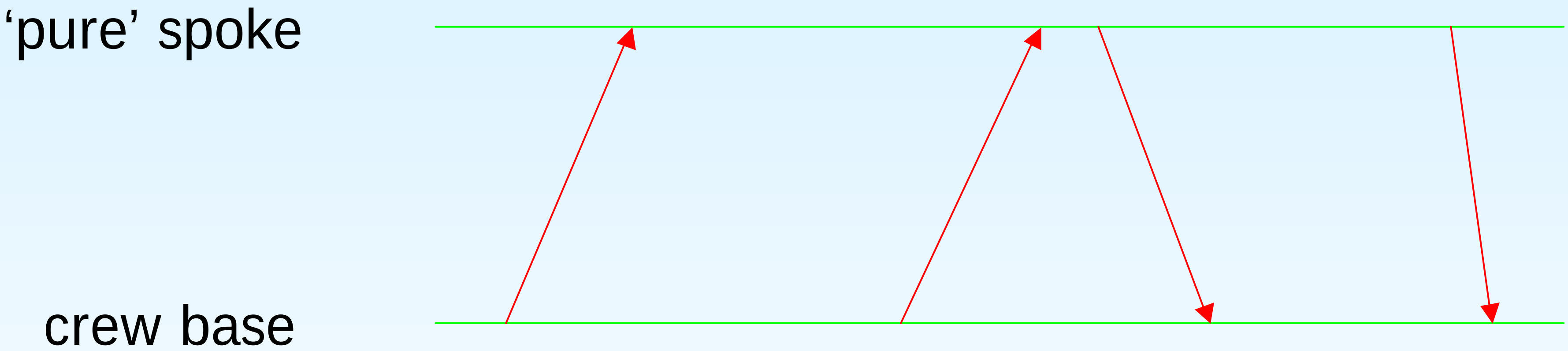
Model Relaxation

- Consider only banks.
  - Desirable to have many crews from the same crew base.



Goal: many crews from the same crew base

Model Relaxation



- The crew can likely return back to the crew base.
- For flights arriving at ‘pure’ spokes relax the crew base requirement.

Preliminary Computation Experiments

- Small fleet of 123 flights
- Choose a small number of columns with low cost.
- Solve with CPLEX
  - Hard IP problems
  - Special branching strategies
  - Optimality not attained.

Preliminary Computational Results

	daily	CSMC	CSMC	CSMC	CSMC	CSMC
pay-and-credit	1223	1922	2194	2119	2055	2010
move-up count	3	8	11	12	13	21

- Trade off between the number of move-up crews and the cost
- Small fleet, not many opportunities for move-up crews
- It is clearly possible to obtain solutions with different number of move-up crews.

Future Research

- Implement methodology for larger fleets.
- Evaluate solutions with a SIMULATION.
- Apply similar ideas to aircraft routing.
- Integrated robust aircraft routing and crew scheduling.