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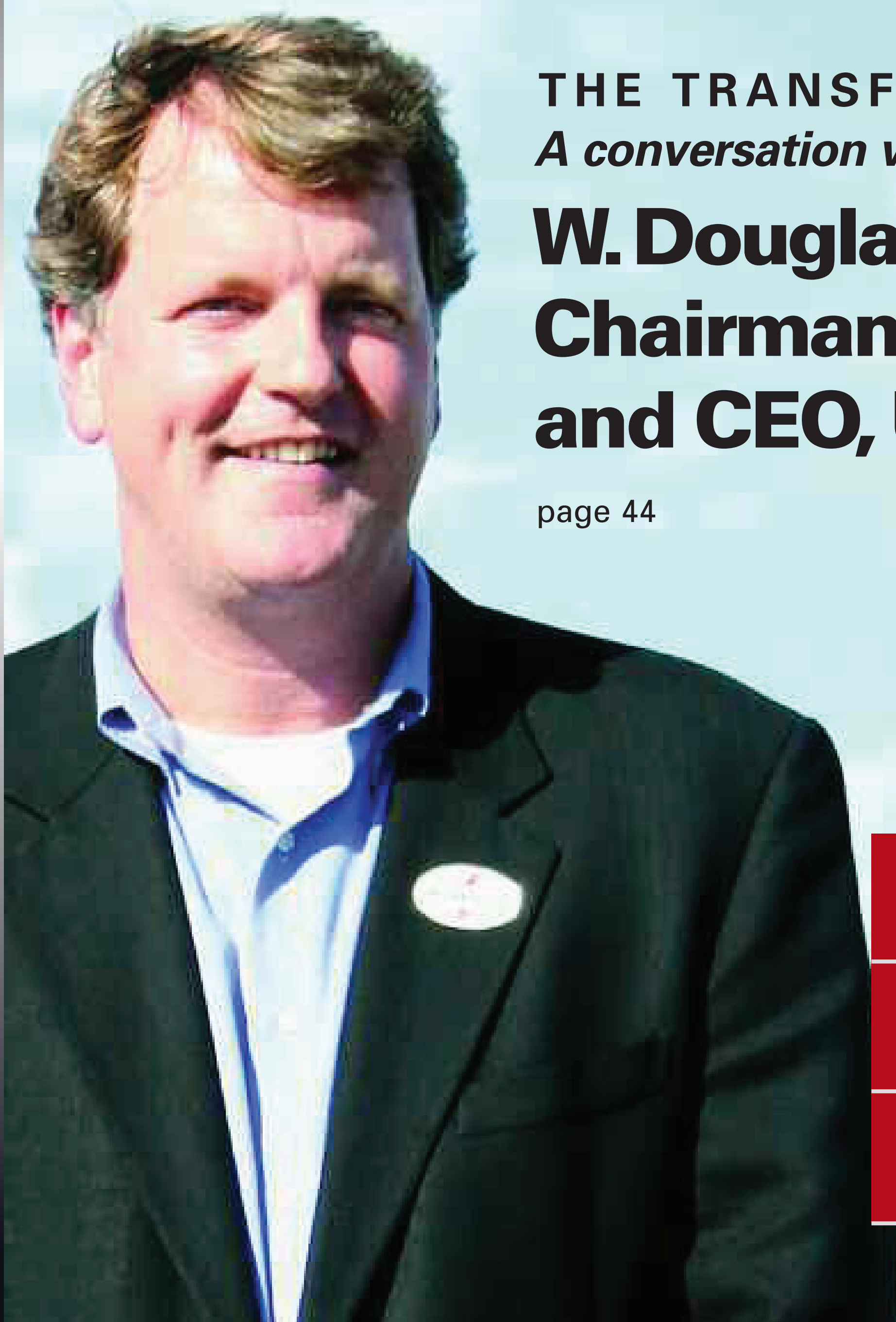
Taking your airline to new heights



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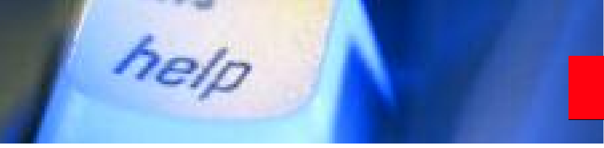

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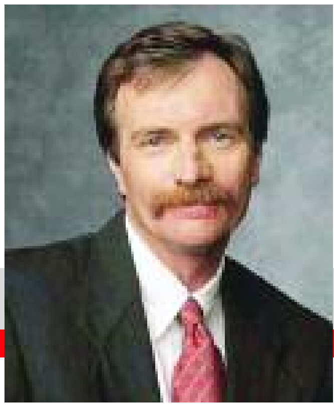
BARRY SMITH, CHIEF SCIENTIST, SABRE HOLDINGS



Robust Airline Fleet Assignment

Through fleet assignment models that incorporate station purity — limiting the number of fleets that serve each station — airlines can better address crew, maintenance and operational issues.

A fleet assignment model, or FAM, is used by many airlines to match aircraft to flights to maximize operating profit. Two prominent carriers — American Airlines and Delta Air Lines — have reported that the use of fleet assignment models can increase annual profits by more than US$100 million. Fleet assignment models are part of a multistep process that creates an airline's operating plan, refines it and ends with its execution. The quality of the plan and the profitability of an airline can be further improved if fleet assignment models anticipate and produce solutions favorable to subsequent planning and operational processes. The processes affected by fleeting decisions include:

- Crew scheduling — Fleet assignment solutions that include fleets serving a smaller number of stations with greater frequency provide more flexibility for crew assignment and can reduce crew costs.
- Aircraft maintenance — Airlines must provide equipment, spare parts and qualified mechanics to operate various aircraft types at each station; limiting the diversity of aircraft serving each station can reduce maintenance costs.
- Operations — Airline schedules are rarely operated exactly as planned, and airline operations are disrupted by weather, mechanical and air traffic control problems. As a result, aircraft and crews are reassigned from the original plan. The cost of recovering from schedule disruptions is affected by the opportunities to swap aircraft and/or crew. Commonality in fleet types serving each station increases the opportunities for swaps and can increase airline dependability and reduce the cost of disruptions.

Initial fleet assignment formulations did not anticipate the impact of fleeting solutions on the subsequent planning and operational processes. Our research group at Sabre Holdings developed an approach to address the crew, maintenance and operational issues through station purity, limiting the number of fleets that can serve each station. This makes the FAM problem harder to solve, but working with our academic partners, we developed a computational approach that is efficient enough to incorporate station purity into large FAM problems. The solutions achieved with this approach are robust relative to crew planning, aircraft maintenance and operations.

HIGHlight

By imposing purity and reducing aircraft dispersion in the network … carriers can save up to US$30 million a year.

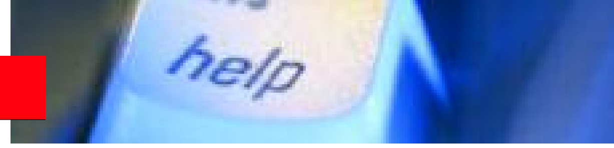
Airline Fleet Assignment Modeling

The airline fleet assignment problem has been a topic of academic and industrial interest since at least 1955. The most basic model maximizes airline operating profit subject to a few constraints, including:

- Cover — Every flight leg must be assigned exactly one fleet type,
- Balance — Aircraft cannot appear or disappear in the network,
- Plane count — For each fleet, the total number of aircraft on the ground or in the air at any point in time cannot exceed the total available.

While fleet assignment models added significant profit to American and Delta, the model scope was initially limited to the capacity planning process. Significant improvements have been made to make fleet assignment solutions more maintenance and crew friendly.

These fleet assignment formulations typically assume that the schedule will be flown as planned, which rarely happens. Airline operations are frequently disrupted by unplanned events such as airport capacity reductions due to weather, ATC delays and mechanical problems. And changing conditions such as varying demand can result in airlines choosing to alter the schedule. Depending on the number and severity of disruptions, a significant percentage of airline flight operations can be affected. For example, in December 2000, 33 percent of all U.S. flight arrivals were delayed by more than 15 minutes.



> "By imposing purity and reducing aircraft dispersion in the network, we estimate that U.S. domestic carriers can save up to US$30 million a year."

A plan that is optimal with respect to expected conditions may not be optimal or even feasible in actual operation. Fleet assignment solutions can affect the time and cost required to return to planned operations. We have supported research efforts at the Massachusetts Institute of Technology to develop an aircraft routing model that encourages overlapping routes in the solutions so aircraft have more swap opportunities in the event of an operational disruption. Partnering with MIT, we supported the development of a strategy to layer the schedule into relatively independent sets of flights so operational disruptions can be dealt with in one layer without spreading to others. These robust solutions significantly reduce passenger delays and disruptions compared to traditional fleet assignment solutions. We also supported research at Georgia Tech to develop a FAM formulation to increase operational robustness by reducing hub connectivity, resulting in operations with fewer cancellations and delays.

Most recently, we have pursued station purity as a method to increase FAM solution quality.

Station Purity

Station purity limits the number of fleets serving a given station. Airlines can impose purity by fleet or family. A family is defined as fleets that are crew compatible. For example, 737-300 and 737-800 are crew compatible and are contained in the same 737 family.

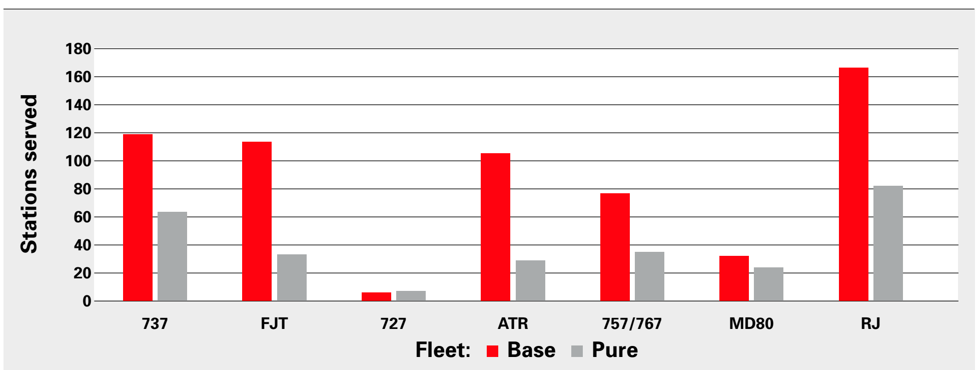
Imposing purity provides benefits in planning, operations, maintenance and capacity swapping. From a planning perspective, purity at a spoke provides more flexibility in crew scheduling; there are more outbound options for each inbound crew. As a result, the additional costs associated with long layovers and double overnights can be reduced. In operations, purity provides more opportunities for crew move-ups and swaps at the spokes. Since families are defined as crew compatible, there is no reduction in flexibility by having purity at the family rather than at the fleet level. To support routine and ad hoc maintenance, airlines must ensure ground equipment compatibility and stock spare parts as well as have appropriately qualified mechanics for each equipment type serving a station. There are many systems, parts and procedures common to fleets within a family. Since purity reduces the number of families serving the typical spoke station, there is a corresponding reduction in parts and maintenance costs. One U.S. major carrier estimated that it cost approximately US$500,000 per year to add a family type to a station. Some airlines swap equipment to match capacity to demand. This is typically done within crew-compatible families. Purity at the family level does not reduce flexibility relative to capacity swaps.

The impact of purity on the dispersion of fleets within the network can directly reduce costs. By having a more pure fleet distribution, airlines can reduce the number of stations a particular type of aircraft serves; thereby reducing the number of stations that have to be equipped to serve that type of aircraft.

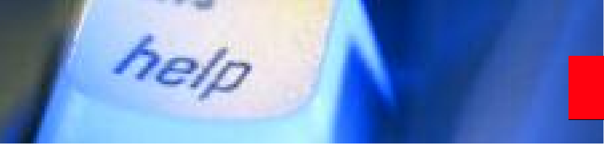
Bringing Purity to the FAM

Station purity makes fleet assignments more difficult to solve. For large cases, adding purity to the typical FAM problem can increase run-times by a factor of five. We developed the station decomposition approach to make fleet assignment models more efficient with respect to purity. Station decomposition takes advantage of the hub-and-spoke structure of typical traditional airline flight networks. In some networks, almost all flights operate either to or from a small number of hubs. If we remove the hubs in a pure hub-and-spoke network, the network decomposes into separated spoke stations, each with its own set of flights. Because

Impact of Purity on U.S. Domestic Schedule



The Boeing 737 fleet serves 120 stations in the base FAM solution. By imposing station purity, it can be reduced to 63, meaning that 57 fewer stations need to be equipped to handle 737 aircraft. There are 57 fewer stations where 737 crews can get stranded due to operational problems. The reduction is even greater for ATR fleet.



the number of flights operating to and from any spoke is a small part of the full schedule, determining fleeting solutions for each spoke is relatively easy. We refer to each feasible solution for a spoke as a fleeting plan. A solution to the full network fleet assignment problem is a collection of plans (one for each spoke) that satisfies aircraft count and flow balance at the hub. In large problems, station decomposition can reduce FAM runtimes by 98 percent. This approach received the Best Technical Paper award at the 2004 AGIFORS symposium in Singapore.

Value of Purity

Station purity provides benefits in both planning and operation. We estimated the benefits of purity in maintenance and crew planning. By imposing purity and reducing aircraft dispersion in the network, we estimate that U.S. domestic carriers can save up to US$30 million a year. We solved the crew pairing problem for base and pure fleet assignment solutions. We found that excess pay-and-credit was reduced from 26 percent to 4 percent by station purity, resulting in savings of approximately US$100 million per year. Added to the US$30 million profit increase from savings in maintenance costs, an overall profit increase of US$130 million per year will be achieved. Purity is profitable in planning alone. Improved operations due to purity will provide additional benefits in terms of costs and customer service.

Fleet assignment modeling has been an important part of the airline planning process for more than 20 years. Models and systems have improved by considering the down-line planning and operational impact of their solutions. The research and development has not slowed down. We are currently working with researchers at the University of Illinois at Urbana-Champaign to develop a process to integrate aircraft routing and crew scheduling into fleet assignment models. This work is promising in terms of increasing profit by reducing crew costs. In the near future, we can expect to see several applications of robustness in airline scheduling and planning systems.

Interested in Learning More?

Additional information about fleet assignment issues can be found in several references, including:

- "Applying Integer Linear Programming to the Fleet Assignment Problem" by J. Abara, *Interfaces*, Vol. 19, No. 4, page 20-28, 1989.
- "Approaches to Incorporating Robustness into Airline Scheduling" by Y. Ageeva, master's thesis, operations research center, Massachusetts Institute of Technology, 2000.
- "Flight String Models for Aircraft Fleeting and Routing" by C. Barnhart, N. L. Boland, L. W. Clarke, E. L. Johnson, G. L. Nemhauser and R. G. Shenoi, *Transportation Science,* Vol. 32, No. 3, page 208-220, 1998.
- "Maintenance and Crew Considerations in Fleet Assignment" by L. W. Clarke, C. A. Hane, E. L. Jonhson, G. L. Nemhauser, *Transportation Science*, Vol. 30, No. 3, page 249-260, 1996.
- "The Aircraft Routing Problem" by R. Ferguson and G. B. Dantzig, *Aeronautical Engineering Review*, Vol. 14, No. 4, 1955.
- "Degradable Airline Scheduling" by L. Kang, doctoral dissertation, operations research center, Massachusetts Institute of Technology, 2003.
- "Airline Industry Metrics" by K. M. Mead, U.S. Department of Transportation Memorandum, CC-2003-048, 2003.
- "Topics in Airline Operations" by J. M. Rosenberger, doctoral dissertation, industrial and systems engineering, Georgia Institute of Technology, 2001.
- "Advances in the Optimization of Airline Fleet Assignment" by R. A. Rushmeier and S. A. Kontogiorgis, *Transportation Science*, Vol. 31, No. 2, page 159-169, 1997.
- "Robust Airline Fleet Assignment" by C. Smith, doctoral dissertation, industrial and systems engineering, Georgia Institute of Technology, 2004.
- "Coldstart: Fleet Assignment at Delta Air Lines" by R. Subramanian, R. P. Scheff, J. D. Quillinan, D. S. Wiper, D. S. and R. E. Marsten, *Interfaces*, Vol. 24, No. 1, page 104-120, 1994.

+count it up

1970 — Year the first jumbo jet, the Boeing 747, entered airline service.

160 — Number of new discount carriers around the world being tracked by the *Official Airline Guide* that could start operations within the next 18 months.

12 — Percent of the more than 2.27 million scheduled flights around the world that are operated by discount airlines.