Systematizing Routing Options in a Global Air Cargo Network Model

This article reports on advances in building air cargo network routing software. This software module is an integral component of a multi-level air cargo supply-demand interaction model. The model is aimed at analyzing and forecasting airborne commodity flows on a global scale. Having a comprehensive overview of the routing options is essential for assigning air freight in networks in real-time as much as possible. Our modeling deals with cargo "alliances" and sub-networks defined by interlining agreements. In the absence of publicly available data, we develop a route typology, as well as a methodology for subsequent choice set formation. Itinerary level observations and preference data act as yardsticks for this exercise. We demonstrate how to address the relevant spatial-temporal routing options for cargo within a maximum range of adjustment strategies, while keeping computational complexity manageable.

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Photo 1: *KLM Boeing 747-406F/ER/SCD being loaded, photo courtesy of Capital Photo (for KLM)*

Introduction

The conduction of quantitative research on air-freight-related topics presupposes an operational model that describes cargo airline operations by a calculation of the relevant supply-and-demand pattern. Several large-scale freight models – e.g. WorldNet (CEC-DG VII 2009) – describe air cargo as part of overviewed aggregated commodity flows [1]. For air-cargo specific investigation purposes, it is essential for analysts to have a more detailed, all-embracing and machine-readable capturing of the supplier network structures, and their actual utilization by airborne commodity flows when centering e.g. around the

- optimization of cargo airport infrastructure and curfew regulations;
- market concentration analysis and forecasts, both globally and regionally;
- selection and dimensioning of pre-flight security measures; and
- internalization schemes of external effects.

The question of route choice in particular, i.e., the path actually taken by shipments, raises a central modeling issue in the field of air cargo. Common methods of ground transport planning, including optimal path search and network assignment algorithms, are increasingly used. In order to keep the overall model size manageable, one needs to find a reasonable compromise between explanatory power, the granularly of observation data, and the desired level of detail.

Reflecting the routing options is not a straightforward task for various reasons. First, the connections between the O&D's are manifold and differentiated: Main-deck freighter operations are complemented by a multitude of belly freight transports on board of scheduled flights – mainly within the FSNC alliances, but also with non-aligned carriers. Second, cargo charters are offered in addition, especially during peak capacity periods and for exceptional goods or flight routes. Last but not least, general air freight transport within the integrators' networks, as a by-product of mail and express services, has been gaining importance. To connect smaller stations or provide door-to-door services, the main leg (or city pair connection) covered by air transport is typically framed by earthbound pre-carriage and on-carriage. This leads to a variety of conceivable transport chains and thus a complex choice situation faced by forwarders, which account for some 80% of the total transported airfreight. Unfortunately, the underlying expert knowledge of decisionmakers is seldom revealed and is only to a minor extent included in textbooks or journal contributions.

Based on this insight, a self-synthesized proxy might reproduce the choice sets at a sufficient quality, giving direction to the actual capacity utilization and macroscopic visible airline network load pattern. This systematization approach in the context of implementing a network routing software aims to get closer to the alternatives that are available to airline decisionmakers, and illustrate policy sensitivity.

Concept of Systemizing Air Cargo Routing Options

This approach is based on overviews such as GRANDJOT (2007) and PETERSEN (2007), which give considerable insight into the activities within air cargo supply chains, market structures and the nature of air freight itineraries [2] [3]. Besides the technological aspects, BUTTON and STOUGH (2000) explain the (local) market concentration level and the formation of air cargo networks also as an outcome of the interplay of regulation and deregulation processes[4]. Further useful sources of information are case studies such as GENSEL (2005), discussing a forwarder's perspective for the air transport chain [5]. The literature also provides well-established methods of covering the heterogeneity of decision-making, leading to quite different specifications of transport models. The main approaches are:

- An a-priori demand segmentation (e.g. ARIMOND and ELFESSI, 2001 [6]);
- A procedure for determining the optimal perceived choice set sizes of business buyers (e.g. KAUFMANN and POPKOWSKY LESZCZYC, 2004 [7]);
- The "narrowing down" to a shortlist of a few remaining options through a constraint-based choice set formation process (e.g. BEN-AKIVA and BOCCARA, 1995 [8]); and finally
- The search for the adequate functional form, in terms of explanatory variables entering the utility function and the use of statistical transformations (e. g. GAUDRY and WILLS, 1979 [9]).

In what ways can these methods, to some degree, be adopted in practice?
Starting with a broad, assumption-based set of options available to the decisionmaker, the task is to devise numerous routing options and narrow down the result list to the ultimately relevant choice set while keeping the information retrieval costs within realistic bounds.

Taking a look at the real world supply-side information sources for routing and schedule enquiries, one obtains a first set of criteria for identifying the offer most suitable to the customer needs. Table 1 summarizes the requisite data queried by the web user interfaces for some of the leading cargo airlines. These specifications always include the city pair codes and preset time frames, that is, latest acceptance time (LAT) and/or time of availability (TOA). In some cases, a selection of the actual operating carrier, the necessary equipment, and the choice of a branded solution are queried, as they restrict the set of eligible itineraries. Except for a minority of carriers, integration with the route search engines seems to be missing. In other words – the abovementioned specification does not affect the resulting list of itineraries later put on display. As demonstrated by the web user interfaces, timetables and levels of service may be evaluated for the single airline, for "not-aligned" carrier, or at a "cargo alliance" level, e.g. for *SkyTeamCargo*, pillared by the AF/KL joint venture.

Table 1 : *Air Cargo Routing Options Queried by A/L Web Portals*

Alliance	Sky Team Cargo		"Not Aligned"		(Ex) WOW Alliance		
Carrier / Criteria	Korean Air Cargo	AF-KLM Cargo	Emirates Sky Cargo	Air Bridge Cargo	JAL Cargo	LH Cargo	SIA Cargo
Queries Origin / Destination	- Country 3LC City	- - 3LC City	- - 3LC City	- - 3LC City*	- - 3LC City	Region Country 3LC City	Region - 3LC City
Op. Carrier Selection	KE/OAL	AF/KL	<EK>	<RU>	no	no	no
Time Frame Restriction	LAT (Day)	LAT(Day) -	LAT(Hr) TOA(Hr)	LAT (Day)	LAT (Day)	LAT(Hr) TOA(Hr)	-
Levels of Time Criticality	2	16**	-	-	7**	2	-
Branded Solutions	8**		-	-		5	6 **
Equipment/ Load Device	CAO	CAO -	CAO RFS	<CAO>	- -	CAO BUP	-

* alternative airports suggested ** not integrated in route search <> restricted to designated offer subset

Sources: www.siacargo.com, www.airbridgecargo.com, www.lhcargo.com, www.af-klm.com, www.skycargo.com, www.jalcargo, www.cargo.koreanair.com (Access Time: 04-30-2009)

Stage	Category	Possible Specification
(i) Demand Segmentation	**Commodity Type**	Definition of commodity set
	Time Criticality	Distinction between - Overnight cargo - 2-day cargo - General freight / standby
(ii) Choice-Set Size Determination	**Supplier Network Options**	Definition of network alliances and sets of contributing A/L
	City Pair Options	Definition of airport catchment areas (for origin and destination)
(iii) Choice-Set Formation and Qualification	**Access / Egress Links**	Assumptions on ground transportation times
	Network Topology	Exemplary trunk network or complete flight schedule
	Weekly Variation of Demand	Distribution to and assumptions on days' latest acceptance times
	Optimal Path Search Strategy	Minimum transport duration or minimum generalized costs
	Imposition of "Hard" Route Search Constraints	Required equipment, unitized shipment (BUP) yes/no
(iv) Choice	**A/L Level Choice Model**	Compensatory model / Random utility maximization (→ Set of explanatory variables)
	Consignor Level Choice Model	Revenue-maximizing assignment to residual capacities

Table 2 : *Systematization of Air Cargo Route Choice*

The four previously mentioned methods are now arranged as four successive stages of a choice process: Demand segmentation, choice sets' size determination, choice set formation/qualification, and choice. Note that the full set of these stages is needed to fully cover the complex supply side, the needs of various air cargo consignment types, and the resulting multi-dimensional space of conceivable itineraries.

The ways to handle this problem at the air network topology side include the intentional creation of a hierarchy of trunk lines, feeder lines, and ground access lines, making sure that the system relevant paths are taken within that synthetic timetable networks.

This paper focuses on the scope of model designs beyond the aspects of the network topology. We presuppose real-world timetables such as the OAG database [10]. Table 2 overviews the modeler's degrees of freedom when executing the four stages. In the following, the possible model specifications will be explored and their explanatory content will be analyzed – process stage by process stage– in more detail.

Demand Segmentation

In contrast to the relative uniformity of passengers conveyed by air, the nature of goods varies widely in air freight. It makes sense to differentiate between the types of commodities that need to be transported insofar as it is of any relevance to the route selection. This can be achieved by a breakdown of the origin-destination transport volume by commodity groups and in terms of time criticality. The segmentation should be carried out at the beginning of the modeled routing process in order to submit the specific requirements to the succeeding process stages. Once this classification is applied, constraints will be imposed on the search for potential itineraries, ensuring the respective deadlines or the exclusion of hazardous goods.

Choice Set Size Determination

According to ORTÚZAR and WILLUMSEN (2001), the delimitation of options in large choice sets is a crucial point in the model specification, leading to a search for a trade-off between relevance and complexity [11]. There are two main dimensions constituting the choice set: City pair options (a) on the one hand and the variety of suppliers (b) serving that origin-destination pair on the other.

a) City Pair Options

In contrast to passenger airlines, in air cargo one may suppose a high geographical variability of the actual departure, transfer, and arrival airport. Also, unusual itineraries should be considered as long as the service level agreement to the customer can be met and the airline's income statement is still positive. The extension of catchment areas for both origin and destination is an arbitrary decision taken by the modeler. For smaller states by land area, harboring major hub airports such as Luxemburg (LUX), the cross-national assignments to traffic zones may far outnumber domestic traffic. The geographical mapping of transports originating or terminating at a traffic cell to "neighboring" airports thus opens a choice dimension. Particularly for connections between areas of a high airport population, this may yield a multitude of possible itineraries. To illustrate the city pair options generated by the two independent sub-dimensions for origin and destination, one can imagine plane grids, as depicted in Figure 1.

b) Supplier Options

A second choice dimension arises from the existence of oligopolistic origin-destination markets. The expected choice set size is roughly given by the inverse of supply side market concentration from origin *and* destination cells' point of view. Network alliances, grouping several cargo airlines, as well as notable "not-aligned" carriers of local presence are regarded as the primary market players, accounting for most of the route capacity. According to a brief analysis of popular origin-destination airfreight markets, this should keep the number of options in the single digit range, if the residual capacity, represented by a assumption of marginal market actors, is neglected.

Note that the reproduction of global network alliances is not just a methodological means of choice set delimitation. Although we see cargo alliances expand and decrease over time, the associated advantages such as market coverage, extended network

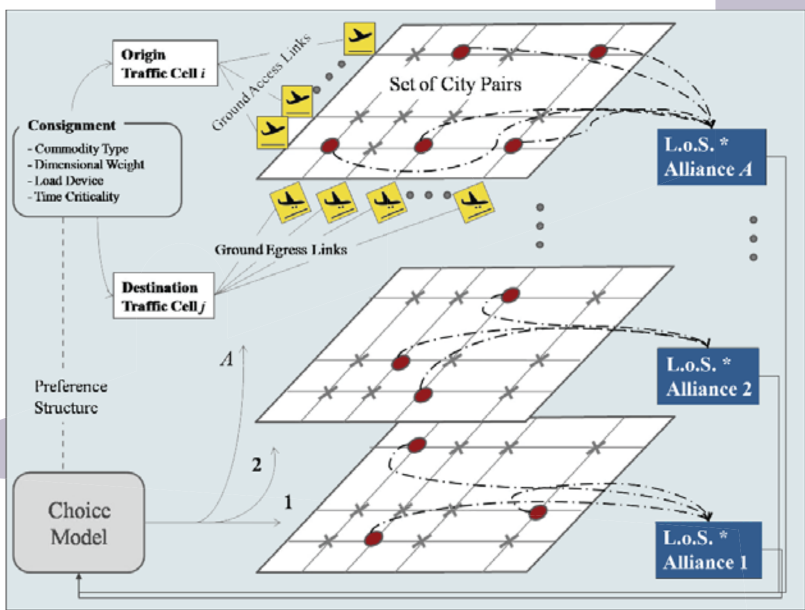

Figure 1: *Route Choice Set Size Determination Assuming Oligopolistic Markets (Source: Own Representation)*

connectivity, and capacity pooling suggest a modeling of supply network structures as a superposition of competing alliance networks. The primary choice set elements are alliances with universal interlining agreements. There are supplemented by few "not-aligned" carriers of significant global and/or local presence, which offer at the same eye level.

In connection with the city pair options, we obtain a selection of these plane grids lying upon each other, as displayed in Figure 1. Their edges have an imaginary transport connection to be accessed from the origin traffic cell *i* or arriving at destination traffic cell *j* respectively.

The supplier alliances' resulting level of service is given by the summarization of eligible city pair connections. Due to the abovementioned geographical variety in air cargo, the overlap between the "eligible" grid intercepts may be minimal among the suppliers, since alliances operate largely disjunctive networks. The scattering of city pairs necessitates this effort in order to get the full picture of origin-destination markets.

Choice Set Formation and Qualification

At this point, the precise itineraries for all routing combinations elaborated so far have to compute every flight plan period, refining the route search by commodity types and time restrictions (according to the segmentation step (i)) – and the predetermined combination sets of city pairs and alliances / suppliers (according to the prior choice set size determination (ii)). The following parameters are mainly shaping the outcome of the optimal-path search:

- The valuation / pricing of the access and egress effort to/ from competing airports;
- The underlying network topology: Either an exemplary trunk network to reduce input data complexity and computing times, or a complete flight schedule per period;
- The weekly variation of demand and whether there is a fixed or supply-dependent distribution to the days of operation;
- Assumptions on every day's latest acceptance times (LAT); and
- The route search strategy: Minimum transport duration or minimum generalized costs.

There are a number of hard restrictions introduced to meet the specific requirements of every demand segment. These can be grouped into:

a) Equipment Constraints
The exemplary consignment properties (such as the nature of good, weight and dimensions, hazmat) must be aligned with the technical possibilities of the scheduled aircraft (A/C „Design density", access door dimensions, fuselage cross-section, leftover weight/ volumetric capacity, hazmat precautions). This clarifies the requirements of a widebody vs. narrowbody aircraft, belly vs. main deck cargo holds of dedicated freighters, or even special charters for outsized-/ super-heavy shipments.

b) Itinerary Constraints
Imposed Restrictions on the itineraries according to customer demand include the general interdiction of equipment changes, transshipments at certain airports, or carrier changes. Special freighters would require exclusive charters.

Given such a broad range of restrictions, the route search will fail in many cases as there is no scheduled service that fulfils all requirements. This may occur notwithstanding the fact the city pair connection of the respective supplier appears possible in theory. The successfully generated itineraries are marked on the alliance-specific grids, as illustrated in Figure 1.

Choice

The concluding element of the route choice model specification is the choice procedure. We concentrate on compensatory type of choice models of the multinominal logit (MNL) type. The available options are not factored out by some elimination process but captioned with their specific utility value obtained through a functional mapping of the itinerary characteristics to this scalar. Depending on the resulting utilities, the MNL then assigns a probability to every option considered.

In effect, the route choice is a two-level choice performed by different decisionmakers – the consignor (or forwarding company) – for the overall transport chain door-to-door and the cargo airline in charge of the main flight leg. As in reality – regardless of tracking and tracing opportunities once the cargo translocation is underway – the airlines' choice process is hidden and, in contrast to passenger flights, not relevant as far as the promised level of service is achieved at the end. Except for the case of the integrators, that is commodity type mail / express parcels, the markets of global forwarding and the airfreight transport can be clearly separated.

This allows for a decomposition of the two choice levels. As the "internal" scheduling of air cargo constitutes another problem and is subject to the carrier's internal assignment algorithm based on long-term contracts and revenue management considerations, one may aggregate the intra-carrier transport opportunities or assume an exemplary itinerary in the model. Thus, the ultimate decision is left to the consigner. The corresponding MNL will tell which supplier or connection is actually favored.

Application

The DLR air cargo supply-demand interaction model serves as the testing environment for the systematization framework presented [12]. It integrates three points of view onto the global air cargo industry in the form of interlinked sub-models:

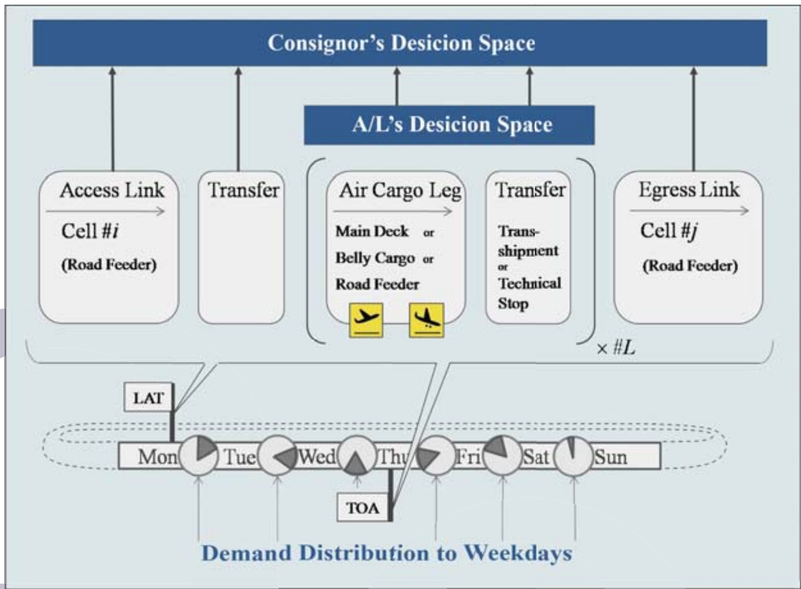

Figure 2: *Creation and Assessment of Air Cargo Itineraries (Source: Own Representation)*

The "Macro Model" addresses the demand generation and market interaction with supplied transport capacities on an aggregated level, comprising the storage and evaluation of a 90x90 matrix of "True O&D"-air-freight markets

The "Connection Builder" sub-model, also referred to as cargo routing module, performs the route search, evaluation, and the demand assignment for a sample week. Based on present or historic flight plans published by the OAG and complementary airline information, the module creates feasible itineraries for air freight, according to prescribed strategies. Besides the routing information, the module returns the maximum capacities as well as the level of service characteristics of the respective spatial-temporal paths in the network (Figure 2).

The network currently comprises 710 airports of relevance. The timetables of every supplier group, typically consisting of several thousand flight legs were encoded and mapped onto the traffic cell structure.

This is followed by plausibility test for the itineraries synthesized, the observation of realistic connecting times, and all service level indicators obtained [14]. The verifications also include the feasibility checks of the itineraries for the varying commodity types. Seeing that an O&D demand matrix is assigned by a spillover-recapture method based on the identified airport pair itineraries, the consistency of the carriers' transport performances (in ton-kilometers taken), load factors and transit volumes per sector as well as the resulting incoming / outgoing cargo volumes at selected airports have to be ensured. The informative value is strongly dependent on data availability. The analyst recognizes the need to include a second opinion of knowledgeable partners, typically granted on a confidential basis.

For the function proof of the presented concept of systematizing air cargo routing options, the relative flight schedule coverage of all itineraries is regarded as the basic test method. Details can be found in [13].

A preliminary stepwise assignment procedure, exemplary for the schedule of one major alliance, reveals whether the system relevant air freight services (in particular, modeled flights by dedicated freighters, long-haul operations of widebody passenger aircraft and road feeders) were used or not. The provision of seven operations days (or latest acceptance times, LAT) per week in combination with a geographical variability in terms of the airport city pair connection chosen leads to a satisfactory coverage of the network supplied. The overall link coverage rate can be enhanced by employing at least two different route search strategies and a network assignment with equipment-specific capacity restrictions. Immediate readjustments only seem to be necessary with regard to the poorly covered road feeder (RFS) links. This can be achieved by the previously described segmentation through the consignments' time criticalities. Moreover, it remains to be clarified whether some of these RFS links are only operated on demand. An analysis of the residual set of unassigned links quarries a mixture of "decentralized connections" of high frequencies or flights departing right after a weekday's LAT, or short feeder flights including airports of minor relevance for air freight.

Concusions

With this contribution, an all-embracing scheme for air-cargo related route choice is proposed, first abstracting from a certain application context. As many transport demand model results are afflicted with the uncertainty about the considerations and underlying choice sets of the decisionmakers, the problem of arbitrarily modeled routings is tackled by a "brute-force approach" in order to generate numerous conceivable options, and a result, targeted choice set reduction. This modeled decision space is still not an exhaustive coverage of reality. However, the approximation at hand is adequate and is a reasonable trade-off in terms of the delimitations by survey data availability and computation times conceded. The operational implementation of these concepts within the DLR air cargo supply-demand interaction framework capitalizes on the conceptual results achieved so far.

References

[1] CEC-DG VII, WorldNet– Worldwide Cargo Flows. Project Presentation, available at: http://www.worldnetproject.eu, 2009

[2] H.H. Grandjot, Air Cargo Guide: An Introduction to the Air Cargo Industry. Huss Verlag, Munich, 2007, p.125

[3] J. Petersen, Air Freight Industry – White Paper. Georgia Institute of Technology, Atlanta GA, 2007

[4] K. Button, R. Stough, Air Transport Networks – Theory and Policy Implications. Elgar, Cheltenham, 2000

[5] B. Gensel, Optimierungsansatze in Wertschopfungsketten – am Beispiel von Luftfrachtimporten durch einen Logistikdienstleister, Final Thesis, Erfurt University of Applied Sciences, Erfurt, 2005

[6] G. Arimond, A. Elfessi, A clustering method for categorical data in tourism market segmentation research, Journal of Travel Research, 39 (2001), pp. 391-397

[7] Kaufmann, Popkowsky-Leszczycz, An optimization approach to business buyer choice sets: How many suppliers should be included? J. Industrial Marketing Management 34 -1 (2004), pp. 3-12

[8] M. Ben-Akiva, B. Boccara, Discrete choice models with latent choice sets, Intern. J. of Research in Marketing, 12 (1995), pp.9-24

[9] M. J. Gaudry and Wills, Testing the dogit model with aggregate time-series and cross-sectional travel data. Transportation Research B, 13 (1979), pp. 155-166

[10] OAG, User Guide Data Description – Appendices B and C, OAG Worldwide Limited, London, 2008

[11] J. de Dios Ortùzar, L.G. Willumsen, Modeling Transport. John Wiley & Sons; Chichester NY, 2002

[12] P. Meincke, F. Heinitz and D.Steiger, Interaction of Air Cargo Demand and Global Trade in the Light of Current Modeling Approaches, 11th ATRS Conference, Berkeley CA, 2007

[13] F. Heinitz, P. Meincke, Systematizing Air Cargo Routing Options for an Exhaustive Supply Network Modeling. 13th ATRS World Conference, Abu Dhabi

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