Global air cargo model for trade flow analysis and strategic decision-making support

Alessandro Bombelli,* Lars J. J. A. Meijs,† Bruno F. Santos,‡ Lóránt Tavasszy,§, and Daniel dos Reis Miranda¶

Although only 1% of the total volume of the world trade is transported via air, the orientation towards high value products results in a share of almost 35% of international trade value. This makes the air cargo routing analysis an interesting and still fairly unexplored, unlike its passenger routing counterpart, research topic. In fact, while information on yearly trades on a country-to-country Origin-Destination (OD) pair is available, little research has been performed on mapping how each trade is split between trade origin country O and trade destination country $\mathcal{D}$. This means that the major stakeholders involved in the air cargo industry have little or no clue about how trades are distributed at the airport-to-airport OD pair level. Every stakeholder has its own isolated view and "local" Key Performance Indicators, but a global understanding of the air trade distribution is lacking, and could be used for better decision-making. Being able to accurately determine the trade distribution between airports would provide insights at different levels. As example, (i) the competitiveness between airports could be analyzed and better understood, (ii) freight forwarders could assess/modify their airport choice strategy by analyzing trade flows, (iii) the effect of the addition of new trading routes on the overall trade distribution could be assessed and used for future strategic decisions by stakeholders. This paper presents a global scale model to estimate trade flows at the airport-to-airport OD pair level. The overarching goal is to address the aforementioned research gap and provide a tool that could be used by stakeholders (e.g., airports, airlines, or freight forwarders) for future decision-making.

With the goal of a global scale model in mind, some assumption were made to have a model sufficiently accurate, yet computationally manageable. (i) Origins and destinations of trades are clustered into single centroids that capture the average location of air cargo land movements within each country. (ii) Trade flows are considered as a whole, and not split into commodities. (iii) Network capacity is not explicitly considered, i.e., trade flow capacity is

*Postdoctoral researcher, Transport & Planning, Faculty of Civil Engineering and Geosciences, and Air Transport and Operations, Faculty of Aerospace Engineering, Delft University of Technology

†Seabury Consulting

‡Assistant Professor, Air Transport and Operations, Faculty of Aerospace Engineering, Delft University of Technology

§Full Professor, Engineering Systems and Services, Faculty of Technology, Policy and Management, and Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology

¶Seabury Consulting

assumed to be unlimited. The model has three main inputs. (i) Yearly country-to-country trade data, which define the demand side, (ii) scheduled flight services between airports, which define the supply side and (iii) airport yearly throughput data, which are used for calibration purposes. Input (i) defines the countries considered in the model. For each country a set of airports is selected, and input (ii) is used to define air connections between airports. Trade origin countries are also allowed to use airports of adjacent countries that are considered attractive enough (attractiveness is assessed using distance as metric). The same policy is applied to destination countries. Airside routes are computed using a k-shortest path algorithm, which selects routes that minimize a generalized cost that accounts for distance traveled, time of flight (and preference towards a fast and expensive, or slow and cheaper option via value-of-time parameter), and intangible factors characterizing the attractiveness of an airport, and that are condensed into a single parameter, i.e., the impedance parameter. The overall set of routes defines the choice set between $\mathcal{O}$ and $\mathcal{D}$. Figure 1 shows how a trade from $\mathcal{O}$ to $\mathcal{D}$ is modeled. $\mathcal{O}$ has 3 trade origin airports: A_1 and A_2 within its boundary, and A_3 from adjacent country $\mathcal{A}$. The possible trade destination airports are A_6 and A_7, while airport A_5 from transshipment country $\mathcal{T}$ can be used as intermediate stop for non-direct routes.

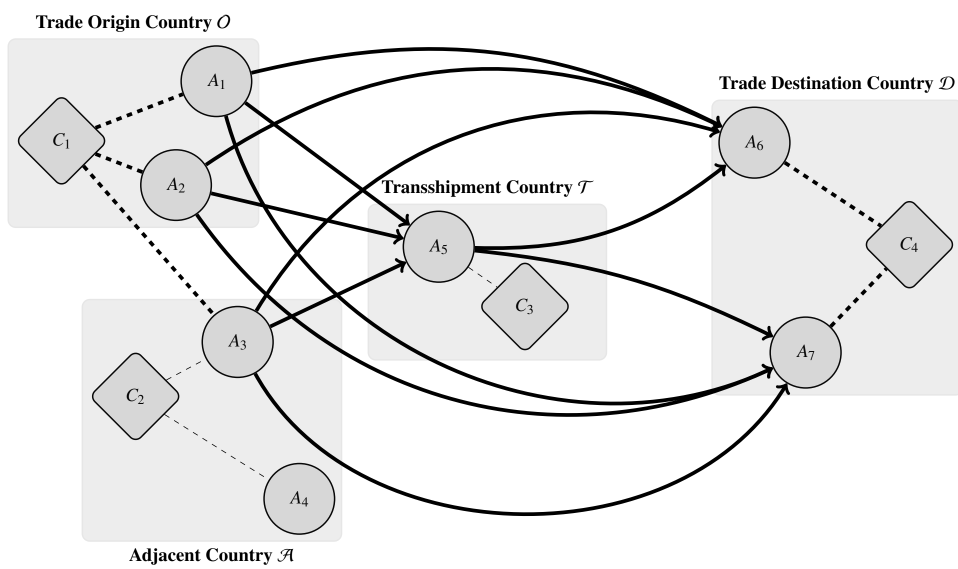
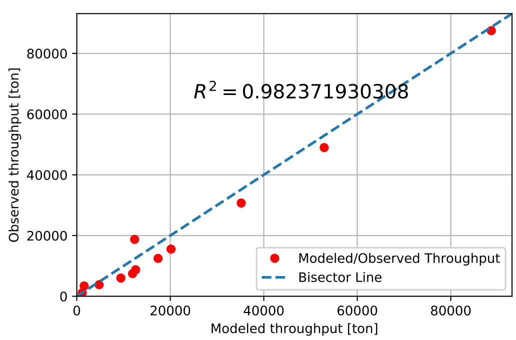


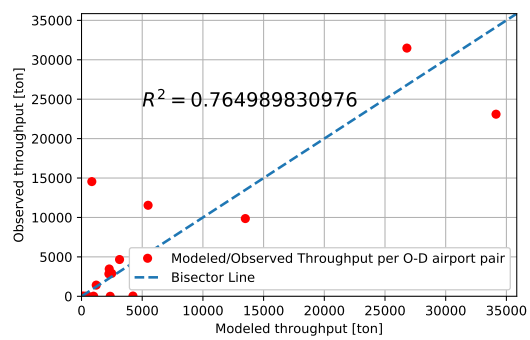
Fig. 1 Example of trade between a trade origin country $\mathcal{O}$ and a trade destination country $\mathcal{D}$. An adjacent country $\mathcal{A}$ and a transshipment country $\mathcal{T}$ are also included.

A route choice model is then applied to the choice set. The output of the model is a set of route probabilities. The overall trade is divided among the different routes according to their specific probability. Note that this process implies knowledge of all parameters of the route choice model, in particular of the logit scale parameter and the set of airport impedances. As a matter of fact, the airside route selection and the route choice model are part of a calibration process, whose objective is the calibration of the values of the logit scale parameter and the set of airport impedances. Calibration is performed via a multi-objective optimization process that minimizes the difference between the observed throughput (input (iii)), and the modeled throughput.

Two application examples are presented to show the capabilities of the model. The first is a small scale example, where trade from United States to Brazil is analyzed. United States are divided into 6 different origin trade countries to reach a better granularity level. Overall, the model has 12 airports and 71 airside connections. Results are analyzed by comparing (i) observed/modeled airport throughput, and (ii) observed/modeled airport-to-airport trade flows (being data available for this particular case) via linear regression. We obtain a R-squared value of 0.98 at the airport throughput level, and value of 0.76 at the airport-to-airport trade flow level (results are shown in Fig. 2). The small scale of this example enables to fully dive into the model and understand the structure of the modeling strategy.



(a) R^2 for airport yearly throughput.



(b) R^2 for airport-to-airport trade flows.

Fig. 2 Airport yearly throughput and airport-to-airport trade flow for the United States-Brazil example.

The second example is a full world model, which accounts for 98% of air trade. Preliminary results show a R-squared value of 0.88 for airport throughput. This example enables to define clusters of airports, whose effect on the full model can be analyzed and assessed. We refer to high-throughput airports, integrator hubs (e.g., Louisville), transshipment-focused airports (e.g., Anchorage), island country airports (with no possibility to rely on adjacent countries for trade), that play a different role in the full air cargo trade network. As example, integrator hubs are generally underestimated by the model because of the quality of the trade data available.

In fact, processed trade data account for wide-body full freighters and passenger aircraft and narrow-body full freighters, but not for charters and integrator aircraft, and will clearly fall short in modeling the throughput of airports that heavily rely on integrators. In addition, the full world model, thanks to the number and variety of air connection alternatives, offers the possibility to generate "what-if" scenarios, such as disruptions or new routing options. It will be analyzed how these scenarios affect the airport yearly throughput, and how trade flows are re-distributed. The analysis of how the system reacts to these changes can be a starting point to evaluate attractiveness of airports for air cargo trade, and to provide recommendations to stakeholders for future decision-making.