



Figure 1: Expected total contributions from different schemes

the upper bound. The cargo capacity κ ranges from 294 to 308. As before, the expected contribution from the Lagrangian relaxation heuristic is at least that from the other two heuristics in all problem instances considered. Also, the expected contribution from the continuous approximation heuristic is at least that from the proportional allocation scheme in every case.

5 Conclusion

The air-cargo business has recently become a significant source of revenue for passenger airlines, some of which sell a large portion of their space to forwarders as allotments. Despite its importance, the number of journal articles on air-cargo revenue management is much less than that on passenger revenue management. Few papers study the allotment decisions, and most of them restrict their attention to a case of single forwarder. The major contribution of the paper to the literature is to extend the study of allotment management to the case of multiple forwarders. The multiple-forwarder case is observed

more frequently in practice compared to the single-forwarder case.

We contribute to the literature by developing a mathematical model to evaluate the expected profit for a given allotment combination and formulating a dynamic programming problem to find optimal allotments for multiple forwarders. Upon recognizing that the computation requirement associated with dynamic programming may be intensive especially when the cargo capacity is large, we develop two heuristic solutions applicable to the industry-sized problem. Through a series of numerical experiments, we evaluate the performance of our proposed heuristics and the proportional allocation scheme, of which variant might be implemented in practice. In one set of the experiments, we find that our heuristic based on the Lagrangian relaxation approach outperforms the other two schemes. In the other set, if it replaces the proportional allocation scheme, the expected contribution gain is about 3.62 percent. This additional revenue becomes crucial for the multi-billion dollar airline industry, which is often operating on slim margins.

The problem that the resource can be sold in advance to intermediaries can be found in other settings, e.g., hotel, cruise, and tour operations. In tour operations, large portions of vacation packages are reserved for travel agencies. Our study may apply to these settings as well.

Lastly, we discuss some possible future research directions. After the forwarders return unwanted space, the carrier sells it to a direct shipper on an ad-hoc/free sale basis. What should be an optimal mix between the allotment and the free-sale? This requires building an omnibus model that captures both the short- and medium-term booking processes. Also, one could study an allocation problem in a network environment, in which each shipment needs to be routed so that it reaches its destination on time. The sequence of flights, upon which each shipment is sent, must be determined. What should be an optimal allotment on each leg and flight? Finally, how should the carrier strike a medium-term contract, when it does not know the forwarders' demands? Since the carrier does not directly deal with the forwarders' customers, their demand distributions