Aggregate–disaggregate approach to an airfreight forwarder's planning under uncertainty: a case study

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Resource planning of airfreight forwarders is a complex endeavor, requiring decisions to be made in a dynamic and uncertain environment. Airfreight forwarders acquire airfreight spaces from three sources: allotment from carriers, retail from carriers and subcontracting to partners, all of which differ in terms of cost, flexibility and timing of booking. This real-life problem has many planning decisions (bookings in terms of carriers, route, time, ULDs, etc.). In this case study, we propose an aggregate–disaggregate approach and focus on the most critical decisions. A two-stage stochastic dynamic program first determines, in aggregates, the amount of allotment bookings, retail resources, and subcontracting or surplus co-loading. Then, a heuristic is used to disaggregate resource requirements into specific bookings. An analysis is provided to examine the relevant managerial issues. Based on real-life data, we show several patterns of aggregate resource bookings with respect to different levels of demand uncertainty and cost parameters. We show that resource disaggregation has to balance cost-effectiveness, capacity flexibility and routing flexibility of a resource plan.

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1. Introduction

Airfreight forwarders are third-party brokers/operators who plan, coordinate and manage cargo shipments for enterprises (Chiu, 1995; Williams *et al*, 1997; Feng *et al*, 2015b). Today, with the success of supply chain management, forwarders need to provide comprehensive global logistics services (Wong *et al*, 2009). Forwarders operate in an uncertain environment with tight schedules and frequent impromptu changes from a wide range of regular and ad hoc customers. Because of demand uncertainty, resource planning is a complex endeavor for forwarders. In the air cargo industry, airfreight space takes up about 70–90 % of logistics costs (Zeng, 2003). A forwarder may acquire airfreight spaces in three manners: allotment from carriers, retail from carriers and co-loading with partners, all of which differ in terms of cost, flexibility and timing of booking.

To directly acquire airspace from carriers, the most common booking method is allotment booking—carriers selling their capacity using a long-term contract (Slager and Kapteijns, 2004; Amaruchkul *et al*, 2007; Feng *et al*, 2015a).

Forwarders may book resources from combination carriers and dedicated cargo carriers. Combination carriers serve both passengers and cargos and typically offer extensive service coverage by providing access to a wide network of destinations. Dedicated cargo carriers serve cargo only and offer limited service coverage; however, they can provide a higher capacity in terms of ULD (unit load devices) options and quantities.

To forwarders, allotment booking is the cheapest. The booking is in terms of various types of ULD, by region/zone (e.g., Eastern Europe) or by origin–destination (e.g., Hong Kong–London), per day or per week. A forwarder must book whole numbers of ULD types, with each having a standard weight capacity specification. Within the framework of allotment booking, carriers also offer an assortment of booking schemes, each with a different level of specificity and price. Routing flexibility can be attained by selecting schemes that have flexible routing options. A forwarder may book certain origin–destination arrangements, without specifying the route, and may also book airspace in terms of ULDs covering a period of time for a specific region, without specifying destinations, e.g., an equalization scheme.

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Allotment bookings are commonly done well in advance and about twice a year. For example, in October of a given year, forwarders would sign contracts with carriers for resources spanning from January to June of the following year. Hence, with allotment bookings, there is a great deal of uncertainty on the future demand for which the bookings are made. A major concern with allotment bookings is that such contractual agreements usually do not allow any changes under most circumstances. Since it is difficult to ascertain future demand well in advance, forwarders are often wary of booking either too much or too little allotment resources.

When close to shipping time (less than a month to go), a forwarder may acquire a range of retail resources from carriers. The cost of obtaining retail sources is usually higher than allotment booking from carriers. More importantly, booking at this time allows more reliable demand forecast to be in place and thus a lower risk of booking incorrectly. However, the amount of airfreight space is typically limited.

When the scheduled date arrives, forwarders may need to seek additional capacity. At this point, the only option is to subcontract. Such subcontracting is the most flexible, but is relatively costly and the amount of airfreight space available is typically limited as well. Nowadays, there are quite a number of logistics e-platforms where forwarders may subcontract their shipping needs. Conversely, forwarders may also find themselves having surplus resources. While airlines typically do not allow freight forwarders to resell the unused space purchased under the long-term contract, a forwarder may *co-load* other forwarders' cargo into its own ULD (Lai and Cheng, 2004, American shipper, 2005, Yuan *et al.*, 2010). Such practice allows a forwarder to utilize surplus resources.

A forwarder's resource planning involves combination carriers and dedicated cargo carriers, and a variety of subcontracting or co-loading options with a number of partners. The resource decisions have to seek a proper balance between costs and flexibility (routing flexibility and quantity flexibility). Also, since the decisions are made at different times, there are differing levels of demand uncertainty. Moreover, the decisions could be at a very detailed level involving carriers, routes, ULDs, and for many geographic regions in the world. From a practical standpoint, it is unrealistic for these decisions to be made simultaneously.

This paper is motivated by a project with a major airfreight forwarder in Hong Kong. It is quite clear that this real-life planning problem is a complex one. In this era of global supply chain management, third-party global logistics management has taken on new dimensions in order to satisfy a large variety of needs of companies. For airfreight forwarders, the provision of one-stop, reliable and economical global logistics services are now expected.

This paper contributes to the understanding of the complex environment within which a forwarder has to make a multitude of difficult decisions. We provide a characterization of the decision environment, which is hierarchical with time-definite, uncertain and dynamic factors along the way. Against such a background,

we propose an aggregate model and a solution approach (aggregate–disaggregate) that is simple and practical to implement. We show that resource disaggregation has to balance cost-effectiveness, capacity flexibility and routing flexibility of a resource plan. The present work also highlights the use of aggregate–disaggregate approach to real-life problems.

In the ensuing sections, we first describe the case background and the decision problem. We then develop a two-stage stochastic dynamic programming model for the aggregate decisions in Stages I and II. We also propose a heuristic to disaggregate aggregate resources into specific resource bookings. Based on real-life data, we illustrate how the problem is approached. We expand our examination by showing several patterns of aggregate resource bookings with respect to demand variation and cost parameters.

2. A forwarder's resource planning problem: case background

The forwarder's resource planning problem can be viewed as an aggregate resource planning with resource disaggregation under uncertainty. Table 1 shows the overall framework and the decision environment. There are two decision stages. Stage I is for allotment bookings, which are done well in advance. The global transport network can be partitioned into several big geographic regions (e.g., North America, Europe and Asia). Aggregate decisions for resource planning are made for each region and by week. Based on aggregate regional demand, the forwarder determines the aggregate allotment bookings, along with the preliminary decisions for retail resources and for subcontracting or surplus co-loading. The aggregates would then need to be disaggregated into specific requirements, forming the basis for carrier bookings.

Stage II is for retail bookings, about 1 month before shipping. Here, with updated demand forecast and allotment bookings already in place, the forwarder determines the aggregate needs for retail resources and preliminary needs for subcontracting or co-loading. Similarly, aggregates are disaggregated into specific needs for finalizing bookings. When close to shipping time, the forwarder would perform their shipment planning (Wong *et al.*, 2009; Leung *et al.*, 2009). Depending on actual demand, the forwarder identifies areas having under-booking (subcontracting needs) as well as over-booking (surplus resources to co-load).

When disaggregating into specific bookings, which are in terms of carriers, routes and ULDs, flexibility of the plan needs to be considered as follows.

Proportion of direct flights versus transshipments Shipping requests are specified by origin–destination. Some clients require shipping via direct flights, while others could be as transshipments and may consolidate with other shipments within segments of the route. Here, the forwarder needs to estimate the aggregate amount of shipping requests by origin–destination, as well as the proportion of allocation to direct flights and to transshipments.

Table 1 A forwarder's aggregate resource planning and disaggregation

	<i>Stage I (approx. 6 months before shipping)</i>	<i>Stage II (approx. 1 month before shipping)</i>	<i>Shipment plan (days before shipping)</i>
Aggregation	Based on forecast: Aggregate decisions for allotment booking (by region, by week) Preliminary aggregate decisions for retail booking Preliminary aggregate decisions for subcontracting or surplus co-loading	Based on updated forecast and previous allotment bookings: Aggregate decisions for retail booking (by region, by week) Preliminary aggregate decisions for subcontracting or surplus co-loading	Based on final aggregate demand: Aggregate demand shortage or aggregate resource surplus
Disaggregation	Disaggregation by carrier, by destination, by day, by ULD Preliminary route planning	Disaggregation by carrier, by destination, by day, and by ULD (whole or fraction) or by bulk Preliminary route planning	Shipment to subcontract or surplus resources to co-load, by destination, by day, and by ULD (whole or fraction) or by bulk
Action	Make allotment bookings	Make retail bookings	Shipment and logistics planning Subcontracting or surplus co-loading

Flexibility of transshipments Shipments having origins and destinations within the same region are regarded as short hauls; those from one region to another as either medium or long haul, with long hauls as those requiring more activities. For medium- and long-haul transshipments, forwarders have a greater flexibility in selecting routes and consolidation possibilities. During disaggregation, the forwarder needs to consider routing flexibility and capacity flexibility, as combination carriers have more routing flexibility and dedicated carriers more capacity flexibility.

Multiple destinations within a region and carrier selection A region consists of multiple destinations. The forwarder could disaggregate demand by destinations based on historical record. In fact, carriers offer equalization booking schemes, allowing regional bookings without specifying destinations, thus providing flexibility of resource allocation. Selection of destinations also depends on carriers, as certain carriers only provide selected destination coverage. Moreover, unlike combination carriers, dedicated cargo carriers usually do not have a comprehensive distribution network.

ULD requirement The forwarder has to breakdown resource needs in terms of ULDs. For allotment bookings at Stage I, ULDs must be in whole units. For retail bookings (Stage II) and subcontracting, fractions of an ULD are allowed. Estimate of shipping requests by weight, with respect to each route, needs to be performed. Then, the number of various types of ULDs by carrier/partner would need to be determined.

3. Aggregate planning and resource disaggregation

We first formulate the aggregate resource planning as a two-stage stochastic dynamic programming model, followed by a simple heuristic that disaggregates aggregates into specific bookings. Here, a resource plan is designed for each origin

region (with destinations either within the region or in other regions). Resource planning for an origin region is assumed to be independent of resource planning of other origin regions. It is assumed that all demands have to be satisfied and that there are sufficient resources available via allotment, retail from partners, and subcontracting. While demand for capacity is in terms of both weight and volume (Li *et al.*, 2012), for simplicity, only weight is considered. At the disaggregation level, we assume that demand for each route is less than the sum capacity of the carriers for the duration considered. However, the disaggregation would not address issues at the shipment level as well as the flight level (e.g., loading of shipments to ULDs, assignment of ULDs to flights, flight capacity and frequency).

3.1. The aggregate model: two-stage stochastic dynamic programming model

At Stage I, a forwarder finalizes allotment bookings while making preliminary decisions of retail bookings and subcontracting (or co-loading). At Stage II, with prior allotment bookings, the forwarder determines retail bookings along with decisions for subcontracting (or co-loading). This problem can be formulated as a two-stage stochastic dynamic programming model as follows:

$$\text{SP1: } \max\{E[p_1 m + p_2 n] - cx - E[Q(x, m)]\} \quad (1)$$

$$\text{subject to } x \leq x^U \quad (2)$$

where m is the random amount (aggregate) of shipping requests for a region (for the specific future time) that a forwarder receives prior to Stage II, n be the random amount (aggregate) of shipping requests for a region (for the specific future time) after Stage II, and p_1 and p_2 are revenue rates of shipments at Stages I and II, respectively. Note that the

expected revenue $E[p_1m + p_2n]$ is a constant due to the assumption that all shipping requests have to be satisfied. cx is the expected allotment cost, where x is the aggregate amount of allotment resource and c is the unit cost of allotment resource. x^U is the upper bound of allotment resource. $Q(x, m)$ is the optimal value of the second-stage problem, i.e., minimizing expected cost of retail resource plus expected subcontracting cost minus expected co-loading value. For any given realization of m , $Q(x, m)$ is determined by:

$$\text{SP2: } \min_{y,z} \{ay + E[s \cdot z^+] - E[w \cdot z^-]\} \quad (3)$$

$$\text{subject to } y \leq y^U \quad (4)$$

$$\text{where } z = \begin{cases} m + n - x - y & \text{if } m + n - x - y \leq z^U \\ z^U & \text{if } m + n - x - y > z^U \end{cases} \quad (5)$$

Here, z^+ denotes $\max(z, 0)$ and z^- denotes $\max(-z, 0)$. ay is the retail cost, where y is the aggregate amount of retail bookings and a is the unit cost of retail resource. y^U is the upper bound of limits of retail resource, respectively. The last two terms in formulation (3) are the expected subcontracting cost and the expected surplus co-loading value. Here, s is the unit cost of subcontracting, and w is the unit value of surplus resource charged for co-loading. When z is positive, it represents the amount of subcontracting; when z is negative, it represents the amount resource used for co-loading. z^U is the upper bound of subcontracting. Equation (5) makes sure that demand is satisfied by the total amount of allotment resource, retail resource, and subcontracting. It should be noted that SP1 and SP2 can be combined to form a single-stage minimization model. To align with the case background and to make the formulation easy to read, this problem is formulated as a two-stage stochastic dynamic programming model.

The first- and second-order conditions for (7), without considering constraint (4), are

$$(a - s) + (s - w)G(x + y - m) = 0 \quad (8)$$

$$(s - w)g(x + y - m) \geq 0 \quad (9)$$

where $G(n)$ is the cumulative distribution function of $g(n)$. Since the unit cost of subcontracting s is typically larger than the unit value of co-loading resource w in most real-life situations and $g(n)$ is a nonnegative function, the second-order condition is always positive. This means that the objective function is a concave function of y , and the solution to Equation (8) is the global optimum, as long as y is within the upper bound. Otherwise, the optimal solution for y will be at the upper bound y^U . We summarize the results in Proposition 1.

Proposition 1 When the aggregate amount of allotment bookings x is given, the optimal aggregate amount of retail bookings of Stage II is

$$y^*(m, x) = \begin{cases} m - x + G^{-1}\left(\frac{s-a}{s-w}\right) & \text{if } m \leq x + y^U - G^{-1}\left(\frac{s-a}{s-w}\right) \\ y^U & \text{if } m > x + y^U - G^{-1}\left(\frac{s-a}{s-w}\right) \end{cases}$$

where $G(n)$ is the cumulative distribution function of $g(n)$, and $G^{-1}(k)$, $0 \leq k \leq 1$ is the inverse function of $G(n) = k$.

We now examine the optimal decisions of SP1 model. Let $f(m)$ be the probability density function for m , demand prior to Stage II. Denote $G^{-1}\left(\frac{s-a}{s-w}\right)$ as π . Substituting y with the optimal amount based on Proposition 1, SP2 model is then written as:

$$Q(x, m) = \begin{cases} a(m - x + \pi) + s \int_{\pi}^{\pi+z^U} (n - \pi)g(n)dn - w \int_0^{\pi} (\pi - n)g(n)dn & \text{if } m \leq x + y^U - \pi \\ ay^U + s \int_{x+y^U-m}^{x+y^U-m+z^U} (m + n - x - y^U)g(n)dn - w \int_0^{x+y^U-m} (x + y^U - m - n)g(n)dn & \text{if } m > x + y^U - \pi \end{cases} \quad (10)$$

3.1.1. Optimal decisions We first examine the optimal decisions of SP2 model. Let $g(n)$ be the probability density function for n , demand after Stage II. Equation (3) is then written as:

$$\min_{y,z} \left\{ ay + s \int_0^{\infty} (z)^+ g(n)dn - w \int_0^{\infty} (z)^- g(n)dn \right\} \quad (6)$$

Substituting the limits based on Equation (5), we have

$$\min_{y,z} \left\{ ay + s \int_{x+y-m}^{x+y-m+z^U} (m + n - x - y)g(n)dn - w \int_0^{x+y-m} (x + y - m - n)g(n)dn \right\} \quad (7)$$

Therefore, $cx + E[Q(x, m)]$ in Equation (1) is then written as (also subject to $x \leq x^U$):

$$\begin{aligned} cx + & \int_0^{x+y^U-\pi} \left[a(m - x + \pi) + s \int_{\pi}^{\pi+z^U} (n - \pi)g(n)dn \right. \\ & \left. - w \int_0^{\pi} (\pi - n)g(n)dn \right] f(m)dm \\ & + \int_{x+y^U-\pi}^{\infty} \left[ay^U + s \int_{x+y^U-m}^{x+y^U-m+z^U} (m + n - x - y^U)g(n)dn \right. \\ & \left. - w \int_0^{x+y^U-m} (x + y^U - m - n)g(n)dn \right] f(m)dm \end{aligned} \quad (11)$$

It can be shown that the first-order derivative of Equation (11) on x is:

$$\begin{aligned}
& c - a \cdot F(x + y^U - \pi) + s \int_{\pi}^{\pi+z^U} (n - \pi)g(n)dn \cdot f(x + y^U - \pi) \\
& - w \int_0^{\pi} (\pi - n)g(n)dn \cdot f(x + y^U - \pi) \\
& - s \int_0^{\pi+z^U} (n - \pi)g(n)dn \cdot f(x + y^U - \pi) \\
& - s \int_0^{x+y^U-\pi} G(x + y^U - m + z^U)f(m)dm - s \\
& \cdot z^U \int_0^{x+y^U-\pi} g(x + y^U - m + z^U)f(m)dm \\
& + (s - w) \left[f(x + y^U - \pi) \int_0^{\pi} (n - \pi)g(n)dn \right. \\
& \left. - \int_0^{x+y^U-\pi} G(x + y^U - \pi)f(m)dm \right]
\end{aligned} \tag{12}$$

where $F(m)$ is the cumulative distribution function of $f(m)$.

3.1.2. A solution procedure Here, we develop a search algorithm to determine the optimal solutions for this two-stage aggregate model: final aggregate booking for allotments (Stage I) and preliminary decisions for retail resource and subcontracting or surplus co-loading (Stage II).

- Step 1: The initial value of allotment booking, x , is set to equal $E[m + n]$
- Step 2: Calculate the total expected costs of $cx + E[Q(x, m)]$ as follows
- Step 2.1: Discretize the nonnegative range of $f(m)$ into equal intervals depending on the precision desired
- Step 2.2: For each interval, which represents a value of m , determine y^* based on Proposition 1
- Step 2.3: Determine the value of $Q(x, m)$, based on model SP2
- Step 2.4: Calculate the value of $E[Q(x, m)]$, for all intervals
- Step 3: Determine the gradient descent of $cx + E[Q(x, m)]$ at the current solution, based on Equation (12). Determine the next value of allotment booking x' . Calculate the total expected costs of $cx' + E[Q(x', m)]$, following steps 2.1–2.4
- Step 4: Update the current best solution with x' . Stop, if $cx + E[Q(x, m)] - cx' - E[Q(x', m)]$ is a significant small number, or if x' equals to x^U ; otherwise, return to step 3

- Step 5: Randomly generate initial value of allotment bookings (from feasible x), repeat steps 1–4 to search for another best solution. Stop if precision required is reached; otherwise, repeat step 5

3.2. A disaggregate heuristic

Figure 1 depicts the disaggregation heuristic, which disaggregates with the objective of saving costs while satisfying shipping requests. Detailed steps and a basic style pseudocode to present the heuristics are included in “Appendix.”

Note that in practice, if the forwarder is not satisfied with the disaggregation solution, he/she could iteratively re-run the heuristic to approach a desired solution, by adjusting the capacity of carriers and ULDs, shipping requests (by destination region or by route), estimates of ULD rates, etc.

3.3. Retail resource and subcontracting or co-loading decisions based on updated demand: Stage II

After the allotment decisions (aggregate and disaggregate) are made at Stage I, the forwarder would continue to update the demand forecast. Until Stage II when the retail resource decisions have to made (around 1 month before action time), the forwarder would need to solve the SP2 model given the prior allotment decisions (i.e., replacing x with known value) and with the updated forecast (i.e., updating n). The decisions are the aggregates: retail resource, subcontracting, and co-loading, which are determined using only Steps 2.2 and 2.3 of the solution algorithm (Section 3.1). Similarly, based on the aggregates, the disaggregate heuristics (Section 3.2) would be used to disaggregate retail resource decisions. At this point, both allotment and retail resources are final. When action time finally comes, the forwarder would need to seek subcontracting from partners if final demand exceeds acquired resources, or seek co-loading if final demand is less than acquired resources.

4. A real-life illustrative example

Consider the forwarder making resource decisions (at Stage I) to satisfy shipping requests of an origin region (for a specific destination region) for a particular week. Here the example is based on the forwarder's cargo shipment from East Asia region to US West Coast region. Demand is assumed to be normally distributed where 1 unit of airfreight space refers to the capacity of 100 kg maximum gross weight (kg). The relevant cost parameters (Table 2) are given based on the TACT (The Air Cargo Tariff) rates offered by International Air Transport Association. Note also that IATA is an important source of information for airfreight planning. Other related parameters are obtained during field visits to a

Figure 1 Flowchart of resource disaggregation.

number of forwarders in Hong Kong. A more detailed discussion of obtaining real-life data can be found in Yin (2003).

This example is a long-haul case. Cargos are shipped from Hong Kong (East Asia region) to Los Angeles and Seattle (US West Coast region). These weekly shipping requests can be served by either transpacific direct flights (with single flight) or transshipment resources (with multiple flights and via Tokyo or via Seoul). We assumed that transshipment via Seoul is relatively more economically desirable. The specific transport routes are shown in Figure 2. There are four carriers

providing airfreight space, including Cathay Pacific (CPA), All Nippon Airways (ANA), Korean Air (KAL), and United Parcel Service (UPS) (Table 3). Capacity limits of carriers for each route are listed in Table 4, the sum of which exceeds the demand for the route. We assume that there are three types of ULD: LD-3, LD-9, and AQ-6, offering 16, 32, and 68 units of space, respectively (Airlog Group, 2011). Each carrier's capacity is a combination of these three types of ULDs, where LD-3 is the most expensive and AQ-6 has the lowest charging rate per unit (S.1 of online supplementary material).

Table 2 Parameters of an illustrative example in aggregate resource planning

Demand (unit: 100 kg)		Revenue rate of shipments (p_1, p_2)	Unit cost/value of resources (\$)				Upper limits of resources (unit: 100 kg)		
Stage I (m)	Stage II (n)		Allotment (c)	Retail (a)	Subcontracting (s)	Surplus (w)	x^U	y^U	z^U
N(2000, 400)	N(400, 80)	45	25	28	39	18	3000	1000	250

Figure 2 Transport routes from Hong Kong to Los Angeles and Seattle.**Table 3** Transport routes and carriers

Distance	Origin	Destination	Routes	Carriers
Long haul	Hong Kong	Seattle	Direct flight from HKG to SEA	Cathay Pacific (CPA)
			Transshipment from HKG to SEA via TYO (including a short haul from HKG to TYO)	United Parcel Service (UPS)
		Los Angeles	Transshipment from HKG to SEA via SEL (including a short haul from HKG to SEL)	Cathay Pacific (CPA)
			Direct flight from HKG to LAX	All Nippon Airways (ANA)
			Transshipment from HKG to LAX via TYO (including a short haul from HKG to TYO)	Cathay Pacific (CPA)
			Transshipment from HKG to LAX via SEL (including a short haul from HKG to SEL)	Korean Air (KAL)

Hong Kong (HKG), Seattle (SEA), Los Angeles (LAX), Tokyo (TYO), Seoul (SEL).

4.1. Aggregate resource decisions and specific bookings

This example is solved using the heuristic procedure in Section 3.1.2 (coded in MATLAB R2011, see also S.2 in online supplementary material). The solution of (x, y, z^+, z^-) is (2273, 232, 21, 126). That is, in aggregates, the allotment booking for the region is 2273 units and the preliminary plan is to book 232 units of retail resource, while having expected subcontracting of 21 units and expected surplus of 126 units. Expected optimal profit is \$46,112, and expected total cost is

\$61,888. The aggregate decisions are then disaggregated (following pseudocode in “Appendix”) as follows.

Step 1: The demands (by destinations) within the US West Coast region are estimated: 30 % of shipping requests are to SEA (i.e., $2273 \times 30\% = 682$ units) and 70 % to LAX (i.e., 1591 units). Further, 40 % are restricted for direct flights (i.e., 273 units for SEA and 636 units for LAX), and others can be served as transshipment

Table 4 A transshipment tableau for resource disaggregation

From	To				Supply
	TYO	SEL	SEA	LAX	
HKG	\$5 314	\$4.5 1050	\$25 273	\$25 636	(650, 1050, 400, 900)
TYO			\$19.5 59	\$19 255	(200, 450)
SEL			\$18.5 350	\$18 700	(350, 700)
Demand	0	0	682	1591	

()—Capacity limits by destination.

Table 5 Resource disaggregation by carrier and by ULD

Amount of ULDs (LD-3, LD-9, AQ-6)	CPA	ANA	KAL	UPS
Direct flight from HKG to SEA	(0, 0, 0)	NA	NA	(0, 0, 4)
Direct flight from HKG to LAX	(0, 0, 0)	NA	NA	(0, 1, 9)
Transshipment from HKG to SEA via TYO	(0, 0, 0)	(0, 2, 0)	NA	NA
Transshipment from HKG to LAX via TYO	(0, 0, 3)	(0, 2, 0)	NA	NA
Transshipment from HKG to SEA via SEL	(1, 0, 0)	NA	(0, 0, 5)	NA
Transshipment from HKG to LAX via SEL	(2, 0, 0)	NA	(0, 0, 10)	NA

NA not applicable.

- Step 2: While there are two transpacific direct flights, the transshipment flights have two routing options (via TYO or via SEL). Transshipments via SEL are more cost-effective. Based on the capacity limits of carriers for each route, we disaggregate the transshipment requirements into specific bookings by route, using a transshipment tableau (Table 4)
- Step 3: We further disaggregate the above bookings by ULD based on cost-effectiveness. With three types of ULD and given the charging rate of ULDs offered by carriers with respective capacity limits, we disaggregate the resource booking by carrier and by ULD (Table 5)

4.2. Effectiveness and efficiency of solution procedure

On aggregate planning solutions Based on this example, a computational experiment is performed for the aggregate heuristics algorithm, which is found to be effective in obtaining a satisfactory solution. Here, we randomly generate 50 cases based on the parameters in Table 6. Demand is assumed to be normally distributed. The computation results show that the objective values of heuristics solutions deviate from the optimal objective values by 0.0029 %. The results suggest that the algorithm is effective in obtaining a very good solution.

On resource disaggregation heuristics We examine the efficacy of the resource disaggregation heuristics (Section 3.2)

by comparing the heuristics solution with a “best” solution found using OptQuest, Arena’s add-on optimizer. Here, based on estimates that 20 % of weekly shipping requests destined to SEA and 60 % to LAX, and 20 % are uncertain, we develop an OptQuest program to search for an improved disaggregation solution. We randomly generate 10 instances based on the parameters in Table 6. We use the allocation—20 % of resource to SEA, 60 % to LAX and 20 % with an equalization scheme—as an initial solution, along with a practical range of equalization scheme booking decisions. We use OptQuest to examine 50 alternative solutions. Each solution is assessed by 300 random-generated replications. On average, the heuristics solution is 0.85 % below the objective value of the “best” solution.

Similarly, based on the case for combination carriers and dedicated carriers (later in Section 6.2), we also develop an OptQuest program to search for an improved disaggregation solution. Ten instances are randomly generated and examined. On average, the heuristics solution is 0.98 % below the “best” solution.

5. Analysis of aggregate resource bookings

We examine the behavior of aggregate resource booking at Stage I (aggregate decisions from the two-stage stochastic dynamic program). Our analysis is based on the real-life example in Section 4. We show several patterns of aggregate resource bookings with respect to different demand variations

Table 6 Parameters for generating examples of aggregate resource planning

Demand (unit: 100 kg)		Revenue rate of shipments (p_1, p_2)	Unit cost/value of resources (\$)				Upper limits of resources (unit: 100 kg)		
Stage I (m)	Stage II (n)		Allotment (c)	Retail (a)	Subcontracting (s)	Surplus (w)	x^U	y^U	z^U
Mean $\sim U(1500, 2000)$ Standard deviation $\sim U(0, 800)$	Mean $\sim U(200, 600)$ Standard deviation $\sim U(0, 100)$	$U(40, 50)$	$U(20, 25)$	$U(25, 30)$	$U(30, 40)$	$U(15, 20)$	3000	1000	250

$U(a, b)$ is a continuous uniform distribution where a and b are its minimum and maximum values.

and cost parameters, depicting that capacity limit of respective resources can have a significant impact on booking patterns. In particular, we explore over-booking scenarios (defined as resulting in surplus co-loading) and under-booking scenarios (defined as resulting in subcontracting) with respect to respective unit costs of resources. Later in Section 6, we will examine disaggregation behavior and effects of flexibility of retail resources.

5.1. Behavior of aggregate resource bookings versus demand variation

We examine the optimal decisions of aggregate resource bookings, with respect to a range of coefficient of variation (CV), i.e., ratio of the standard deviation to the mean of demand. Figure 3 shows three different behaviors of aggregate resource bookings as CV increases.

A U-shaped allotment booking curve For this base-case example, as coefficient of variation increases, the amount of allotment booking initially decreases (Figure 3a). Such decrease is due to the fact that the use of retail resource is more desirable at a low variation level. When the use of retail resource reaches its capacity limit as demand variation increases, the forwarder then returns to the use of allotment resource. The sum of allotment and retail resource increases throughout the range of demand variation tested. Surplus resource increases throughout the range as well, suggesting an over-booking scenario. That is, with this set of costs, even when demand uncertainty increases, the use of allotment and retail resource remains an attractive one. Correspondingly, subcontracting remains insignificant throughout.

A monotonic increasing allotment booking curve We lower the unit cost of allotment resource from \$25 to \$20 while keeping other parameters unchanged. With the lower allotment unit cost, the amount of allotment booking increases throughout the range of demand variation tested (Figure 3b). Within this range, the use of allotment resource is the most desirable when compared with retail resource and subcontracting. However, when the use of allotment resource approaches its upper limit at a certain variation level, the forwarder would switch to increasing the use of retail resource. Similar to the

preceding case, the sum of allotment and retail resource increases throughout the range of variations tested, resulting in increasing surplus resource—i.e., over-booking scenarios.

A monotonic decreasing allotment booking curve From the base case, we lower the unit value of surplus resource from \$18 to \$8 (and increase the capacity limit of subcontracting from 250 to 1500 units), while keeping other parameters unchanged. Throughout the range of demand variation tested, the amount of allotment booking decreases (Figure 3c). Within this range, the use of retail resource is more desirable when compared with allotment resource. The sum of allotment and retail resource decreases throughout this range. Note that surplus co-loading remains unattractive, while the use of subcontracting increases with a decreasing rate throughout as variation increases, suggesting an under-booking scenario. That is, as uncertainty becomes larger and with this set of costs, it is better not to commit resource early (allotment resource or retail resource) but utilize resource as close to shipping time (subcontracting) as possible.

Note that cost parameters affect allotment booking behavior. For example, when we lower the allotment unit cost from \$25 to \$20, the U-shaped curve (Figure 3a) becomes monotonic increasing (Figure 3b). When we lower the unit value of surplus resource from \$18 to \$8 and increase the capacity limit of subcontracting from 250 to 1500 units while keeping other parameters unchanged, the allotment booking curve becomes monotonic decreasing (Figure 3c). Detail discussion on how cost parameters affect optimal decisions of aggregate resource bookings is included as online supplementary material (S.3 and S.4).

5.2. Effect of asymmetric demand uncertainties of Stages I and II

So far, we have assumed that the demand uncertainties of Stage I and Stage II are identical. Figure 4 shows the behavior of aggregate bookings with respect to combinations of CV at Stage I and CV at Stage II. There are three scenarios:

- Demand uncertainties of Stages I and II are identical (solid curve AB in Figure 4a and curve $A'B'$ in Figure 4b). The

Figure 3 Resource decisions with respect to different coefficients of variation of demand. **a** U-shaped allotment booking curve. **b** Monotonic increasing allotment booking curve. **c** Monotonic decreasing allotment booking curve.

Figure 4 Allotment and retail bookings at different CVs of Stage I and II demands. **a** Allotment bookings. **b** Retail bookings.

U-shaped AB curve is identical to the allotment booking curve in Figure 3a.

- Stage II uncertainty is lower than Stage I uncertainty (region ABD in Figure 4a and region $A'B'D'$ in Figure 4b). The aggregate bookings follow a U-shaped curve (e.g., AB and AD). That is, the change begins at zero variation, where CVs at both Stage I and Stage II increase, with the latter at a lower rate. Correspondingly, retail resource increases initially as allotment resource decreases (e.g.,

$A'B'$ and $A'D'$). When the use of retail resource reaches its capacity limit, the forwarder then returns to the use of allotment resource.

- Stage II uncertainty is larger than Stage I uncertainty (region ABC in Figure 4a and region $A'B'C'$ in Figure 4b). In practice, this scenario is quite typical. Consider the situation where Stage II uncertainty doubles that of Stage I uncertainty. The curve AE shows the allotment booking behavior as demand variations of both stages increase.

Table 7 Resource planning with and without equalization schemes

	<i>Approach 1: without equalization scheme</i>	<i>Approach 2: with equalization scheme</i>
Expected resource decisions (units: 100 kg)		
Allotment booking	2273 (682, 1591, 0)*	2273 (455, 1364, 455)
Retail booking	232 (70, 162, 0)	232 (46, 140, 46)
Subcontracting	165	139
Surplus co-loading	144	169
Expected outcomes (\$)		
Total cost	67,164	66,315
Total revenue	108,000	108,000
Total profit	40,836	41,685

* To SEA, to LAX, with equalization scheme.

Curve *AE* is still U-shaped, but is considerably flatter when compared with curve *AB*. Note also that if the uncertainty at Stage II is increasing faster than that of Stage I, it is no longer desirable to delay resource acquisition to utilize retail resource. Instead, allotment resource is obtained right away as CVs of Stage I and Stage II increase (e.g., curve *AC*), and there is no more U-shaped curve. Accordingly, the increasing curve of retail bookings becomes flat (e.g., curve *A'C'*).

The above analysis explores the effect of asymmetric demand uncertainties on allotment booking and retail booking. Similar analysis can be performed on the corresponding effect on surplus co-loading and subcontracting (S.5 of online supplementary material).

6. Analyzing resource disaggregation: a simulation

To make specific resource bookings, aggregate decisions have to be disaggregated to meet specific needs of shipping requests, which are uncertain and differ in terms of origin–destination, routing requirements, etc. Analytically, it is difficult to analyze disaggregation within this uncertain decision environment. To examine whether a disaggregate resource plan is able to handle different scenarios of specific resource needs, we develop a simulation model for this uncertain decision environment (S.6 of online supplementary material).

Here, within the disaggregation environment, we, respectively, explore the trade-off issues of equalization schemes, between combination carriers and dedicated cargo carriers, and between types of ULDs in a resource plan. We show situations where a disaggregation resource plan can be better off by making specific bookings with equalization scheme and by disaggregating more for transshipments. We show that resource disaggregation has to balance cost-effectiveness, capacity flexibility and routing flexibility of a resource plan. Moreover, we also examine the flexibility of retail resource under different demand uncertainties.

6.1. Flexibility of equalization scheme

Based on the example in Section 4, we examine a situation where a forwarder could include equalization scheme. Here, it is estimated that 20 % of weekly shipping requests are shipped to SEA and 60 % to LAX, and 20 % are uncertain. The forwarder could consider two approaches to disaggregate resource by destination: (1) 30 % of resource to SEA and 70 % to LAX, and (2) 20 % of resource to SEA, 60 % to LAX and 20 % with an equalization scheme. Assume that equalization booking schemes cost 5 % more than destination-specific booking. The uncertain planning environment is simulated 300 times. Table 7 shows the results.

With the flexibility offered by the equalization scheme (Approach 2), the resource plan reduces the use of subcontracting (from 168 to 139 units), with the not-needed resource now placed in surplus (from 144 to 169 units). Although paying 5 % more booking cost, this plan is better off, with 2.1 % increase in expected profit compared with Approach 1 (without equalization scheme). In this example, when equalization schemes cost more than destination-specific bookings by more than 15 %, the scheme is no longer desirable. It can also be shown that the forwarder can now book less (up to 25 units) to achieve a better profit level. That is, the flexibility of equalization scheme allows a lower amount of airfreight flight space to be acquired.

6.2. Combination carriers versus dedicated cargo carriers

We examine a situation where a forwarder could book from both combination carriers and dedicated cargo carriers, with the former having more transshipments and therefore more consolidation opportunities and the latter having more direct flights but a higher capacity. Typically, the fees of a dedicated cargo carrier are less than that of a combination carrier. The analysis would address the trade-offs between route flexibility, quantity flexibility, consolidation opportunity, and handling fees.

Based on the example in Section 4, we consider a situation where shipper's requests for direct flight are uniformly distributed from 30 to 50 %. Here, a forwarder could consider making the following bookings: (1) 50 % by dedicated cargo

carrier—assumed to be direct flights, and (2) 60 % by combination carriers—assumed to be all transshipments. Note that shipping requests not restricted to be direct flights can be served by either combination carriers or dedicated carriers. Combination carriers have a better chance to consolidate with other shipments. Here, we assume that combination carriers cost 5 % more than dedicated cargo carriers and that consolidating shipments (using either type of carriers) could save 40 % of booking costs. We simulate the uncertain planning environment 300 times. Table 8 shows the results of these two resource plans.

The increase in combination carrier booking increases the amount of subcontracting because of the lack of direct flight resources. Correspondingly, it decreases the amount of surplus. Here, Approach 2, because of more disaggregation to transshipment resources, increases consolidation cost savings. Such increase is enough to offset the incremental cost of booking fees, with the combination carriers enjoying a slight edge in expected profit.

6.3. Planning ULDs

We explore disaggregation at the ULD level. Based on the example in Section 4, we examine a situation of three ULD types, i.e., LD-3, LD-9, and AQ-6. LD-3 is the smallest one in terms of capacity and AQ-6 is the bulkiest type. LD-3's unit cost is more than LD-9 (assumed to be 5 % more), while that of AQ-6 is less than LD-9 (assumed to be 5 % less). We assume that the daily shipping requests are evenly distributed during the week. The weight distribution (kg per piece of shipments) is assumed to be uniformly distributed from 100g to 500 kg. The weekly aggregate allotment bookings (227,300 kg) are disaggregated by ULD using the heuristic in Section 3.2. To see how well the heuristic solution performs under demand uncertainty, we simulate the uncertain planning environment 300 times, where shipments are loaded to specific ULDs during shipping time. Table 9 shows the results.

Poor ULD planning could lead to more subcontracting due to insufficient ULD capacity, or to a higher level of surplus capacity. Here, allotment booking for each day of the week is: 4 units of LD-3, 2 units of LD-9 and 3 units of AQ-6. The total booked ULD capacity is higher than the aggregate amount by 2.2 %. More than 60 % of allotment resources are booked by AQ-6. The expected amount of subcontracting is 134 units, which is 5.24 % of allotment plus retail resources. The standard deviation of subcontracting is 12.04 units, which indicates that subcontracting is stable. Similarly, for surplus resources, the expected amount is 156 units (6.1 % of allotment plus retail resources) with a standard deviation of 11.30. This ULD solution can be considered as satisfactory, since both subcontracting and surplus are not at a high level and are both stable. Via further simulation, we found that if ULDs can be loaded with fractional shipments (i.e., ULD types not a constraint), then the subcontracting and surplus amounts would be 125 units and 150 units, respectively—indicating that the current solution (134 units, 156 units) is a good one.

We next examine a heavier weight distribution (kg per piece of shipments): uniformly distributed from 500 to 900 kg; for simplicity, we assume the shipments have the same density as the previous lighter distribution (Table 10). Note that since retail bookings can be made with portions of a ULD, it remains

Table 9 ULD planning with disaggregation

Disaggregation of allotment bookings by ULD	
Capacity of ULD unit load (100 kg)	(16, 32, 68)*
Number of ULDs available	(49, 14, 21)
Whole number of ULDs booked	(28, 14, 21)
Resource decisions (100 kg)	
Allotment booking	2324 (448, 448, 1428)
Retail booking	232
Subcontracting	134 (23.76 [#] , 12.04 [^])
Surplus co-loading	156 (22.31 [#] , 11.30 [^])

* (LD-3, LD-9, AQ-6), [#] half width of the 95 % confidence interval of sample mean, [^] standard deviation of the sample.

Table 8 Resource planning with disaggregation for transshipments and direct flights

	Approach 1: 50 % by dedicated carriers	Approach 2: 60 % by combination carriers
Expected resource decisions (100 kg)		
Allotment booking	2273 (1137, 1136)*	2273 (909, 1364)
Retail booking	232 (116, 116)	232 (93, 139)
Subcontracting	133 (31, 102)	151 (78, 73)
Surplus co-loading	141 (121, 20)	132 (56, 76)
Expected costs and savings (\$)		
Allotment booking cost	58,246	58,530
Retail booking cost	6658	6691
Consolidation savings of direct flights	1292	947
Consolidation savings of transshipments	5655	7135
Expected outcome (\$)		
Total expected cost	60,706	60,670
Total expected revenue	108,000	108,000
Expected profit	47,294	47,330

* Direct flights, transshipments.

unchanged as the aggregate amount. For allotment booking, since they must be in terms of whole ULD, the situation differs. For Scenario 2, because of its heavier (and bulkier) distribution and hence a poorer ULD utilization, both subcontracting amount and surplus amount increase, resulting in a decrease in profit (1.4 %, compared with Scenario 1).

6.4. Effect of flexibility of retail bookings at Stage II

So far, our analysis of disaggregation has been assumed that there are no differences between the original estimate of retail booking and the actual realization. In practice, this is not the case as the forwarder would have a chance to revise retail booking after the actual demand is realized several weeks before shipping time. In this section, we examine the impact of having the flexibility to revise retail booking at Stage II. We first consider the individual situations of equalization scheme (Table 7), transshipment versus direct flights (Table 8) and ULD (Table 10), respectively. We show that for all these situations where a forwarder could revise retail bookings, the resource plans result in a reduced amount of subcontracting and a reduced number of surplus resources (S.7 of online supplementary material). Essentially, the flexibility

Table 10 ULD planning: two scenarios of weight distribution

	<i>Scenario 1: lighter shipments</i>	<i>Scenario 2: heavier shipment</i>
Resource decisions (100 kg)		
Allotment booking	2324	2324
Retail booking	232	232
Subcontracting	134	155
Surplus co-loading	156	168
Outcomes (\$)		
Allotment booking cost	56875	56875
Total cost	65789	66392
Total revenue	108000	108000
Profit	42211	41608

Table 11 Resource planning with original estimate and with flexibility of retail bookings

	<i>With original estimate of retail bookings</i>	<i>With flexibility of retail bookings</i>
Resource decisions (100 kg)		
Allotment booking	2273	2273
Retail booking	232	231
Subcontracting	133	47
Surplus co-loading	171	129
Outcomes (\$)		
Total cost	60002	57267
Total revenue	108091	108091
Profit	47998	50733

Figure 5 Retail booking adjustment increases profit (%) with different CVs.

of retail bookings lowers demand uncertainty, thus reducing both subcontracting and surplus resources.

Based on the example in Section 4, we consider a composite situation, where aggregate decisions are disaggregated by destination with equalization scheme (Approach 2 in Table 7) and by combination carriers and dedicated cargo carriers (Approach 2 in Table 8). We simulate the uncertain planning environment 300 times. The results are given in Table 11.

With flexibility of revising retail booking, expected subcontracting is reduced from 133 to 47 units, and expected surplus resource is reduced from 171 to 129 units. With flexibility of retail booking, the plan's profit increases 5.7 % compared to with original estimate. We further examine the impact of demand uncertainty on the effect of flexibility of retail bookings, with respect to a range of coefficient of variation of demand. For an incremental change in coefficient of variation, we calculate the percentage change of profit, i.e., (plan's profit with flexibility minus plan's profit with original estimate)/(plan's profit with original estimate). Figure 5 shows the overall pattern of percentage change of profit with respect to the range of demand variation tested. Throughout the range, the percentage change increases.

7. Conclusion

In this paper, we introduce an airfreight forwarder's resource planning under uncertainty, where airfreight space may be acquired from multiple sources and across time. We identify that the decision environment is hierarchical and with many dynamic factors. The paper contributes to the understanding of the complex resource planning environment within which a forwarder operates. We show that the planning problem needs to be addressed both at the aggregate level and at the disaggregate level and that resource disaggregation has to balance cost-effectiveness, capacity flexibility and routing flexibility of a resource plan.

There have been limited works in the literature that address aggregation and disaggregation. We first develop a two-stage stochastic dynamic programming model for the aggregate decisions. To disaggregate aggregate resources into specific resource bookings, we propose a heuristic. This paper also contributes to the application of aggregate-disaggregate approach to real-life problems. The solution approach (aggregate-disaggregate) is simple to implement.

Based on real-life data, an extensive analysis is included to identify managerial insights. Here, we show several patterns of aggregate resource bookings, where demand uncertainty is an important factor. It is also shown that capacity limits of resources can have a significant impact on the booking patterns. Booking scenarios such as over-booking and under-booking are also examined with respect to respective unit costs of resources. For disaggregation, we, respectively, explore the trade-off issues of equalization schemes, between combination carriers and dedicated cargo carriers, and between types of ULDs in a resource plan. The key in resource disaggregation is to strike a balance between cost-effectiveness, capacity flexibility and routing flexibility of a resource plan.

The proposed aggregation–disaggregation approach can be augmented by an optimization–simulation approach. Such an approach has been effectively used in many situations: resource planning (Venema *et al.*, 1997), order planning (Verganti, 1997), transportation network design (Leung and Cheung, 2000) and production scheduling (Tang and Grubbström, 2002). An illustration of an optimization–simulation approach is included as online supplementary material (S.8).

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Appendix

Detail steps of the disaggregation heuristics:

Step 1: Disaggregate resource decisions by destination as follows

- Step 1.1: For each region (short, medium or long haul), estimate respective portions of shipping requests per destination within the region. Then, disaggregate resources to each destination according to its proportion
- Step 1.2: For each destination that is medium haul or long haul, estimate the portion that should be allocated to direct flights and to transshipments. Then, disaggregate resources to direct flights or to transshipments for the destination according to the estimated proportion
- Step 1.3: For regions that the forwarder decides not to specify requests by destination, the corresponding resources are made with equalization schemes

Step 2: Disaggregate resource decisions by route. Here we perform disaggregation with the policy of serving the most restrictive (e.g., tight shipping time) first

Step 2.1: For all direct flight shipping requests, make specific bookings with pre-defined routing arrangement

Step 2.2: For shipping requests allowing multiple routings (e.g., medium and long hauls with transshipments), determine the routings using a transshipment model based on cost-effectiveness while considering shipping time requirements

Step 3: Disaggregate resource decisions by day and by ULD, which is carrier specific and capacity specific

Step 3.1: For each route, estimate the weight of shipping requests of each day

Step 3.2: For each route, rank all the available ULDs in terms of charging rate per resource unit with respect to each day

Step 3.3: For each route, book an available ULD with the lowest charging rate of a specific day. If the booked ULDs offer sufficient resource for the specific demand, stop; otherwise, repeat step 3.3

The above heuristics can be presented as a basic style pseudocode as follows:

```

Sub disaggregate( )
  For region_i = 1 to last_region_number
    If region_i is to be specified by destination Then
      Estimate short_haul_portion_of_region_i
      Estimate medium_haul_portion_of_region_i
      Estimate long_haul_portion_of_region_i
    Else
      Book equalization_scheme_of_region_i
    End If
  Next region_i

  For direct_flight_j = 1 to last_direct_flight_number
    For region_i = 1 to last_region_number
      Allocate flight_route(short_haul_portion_of_region_i)
      Allocate flight_route(medium_haul_portion_of_region_i)
      Allocate flight_route(long_haul_portion_of_region_i)
    Next region_i
  Next direct_flight_j

  For region_i = 1 to last_region_number
    Estimate transshipments(medium_haul_portion_of_region_i)
    Estimate transshipments(long_haul_portion_of_region_i)
  Next region_i
  Run transshipmentModel(transshipments)
  Allocate flight_route(transshipmentModel_results)

  Estimate shipping_requests_of_day_k(flight_route)
  For day_k = 1 to last_day
    Sort ULD_type_v by charging_rate_per_resource_unit
    For ULD_type_v = 1 to last_ULD_type
      Book ULD_type_v
      If ULD_type_v offer sufficient resource Then
        Stop
      End If
    Next ULD_type_v
  Next day_k
End Sub

```

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