Journal of Air Transport Management xxx (2016) 1–11

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight

Jafar Rezaei*, Alexander Hemmes, Lori Tavasszy

Transport and Logistics Group, Faculty of Technology, Policy and Management, Delft University of Technology, 2628 BX Delft, The Netherlands

ARTICLE INFO

Article history:
Received 6 February 2016
Accepted 7 February 2016
Available online xxx

Keywords:
Air cargo
Freight
Logistics chain
Multi-criteria decision-making
Best worst method (BWM)
Bounding configuration

ABSTRACT

Airlines typically carry out freight transportation in a hub and spoke structure, where the movements between the outstations and the hub are served by trucks. To transport freight efficiently, air carriers must consider bundling options for shipments that are delivered at outstations and have to be moved to the hub. There are three options when it comes to bundling freight: on 'through unit load devices' (T-ULD) (all freight for the same flight at the hub), on 'mixed unit load devices' (M-ULD) (freight for different flights at the hub) and loose freight in trucks. The optimal freight bundling configuration for carriers, taking into account their main KPIs (key performance indicators), is unknown. This research formulates the problem as a multi-criteria decision-making (MCDM) problem, allowing carriers to decide which configuration is optimal for a given outstation. The selected KPIs (cost, (un)loading time, and quality) are formulated as mathematical functions. A new MCDM, called best worst method (BWM), is then used to identify the best configuration with respect to the three KPIs. The proposed methodology is applied to KLM Cargo to identify the best configuration for the selected outstations that supply freight to the KLM hub at Schiphol Airport. This case study shows that there are different optimal freight bundling configurations for different outstations and that trucking costs and freight handling tariffs are among the key factors in deciding which configuration is optimal.

1. Introduction

Air cargo, which is defined as any property (e.g.: freight, mail, express parcels) transported by a full-freight aircraft, a combi-aircraft, or under the main deck of a passenger aircraft (Domingues et al., 2014), has at least two advantages over surface transportation (sea, road and rail), the first of which is the speed of the transportation, which is required for specific goods, such as perishable goods or goods that require next morning delivery (e.g. newspapers). The second advantage is the low risk for damage or loss, which means that high-value, time-sensitive goods with a high value-to-weight ratio are suitable for air transportation (Zhang and Zhang, 2002; Ohashi et al., 2005).

The air freight transport chain has different stages, starting at the shipper, leading via forwarders and the carrier (in our case the airline) towards the consignee. The logistics chain of air freight is visualized in Fig. 1 (adopted from Petersen, 2007). Shippers, the clients of the air cargo transporting service, are positioned at the start of the logistics chain (Popescu et al., 2010). They use freight forwarders to transport their shipment to a carrier. Other services being offered by freight forwarders include securing freight, storing freight, consolidating freight, organizing value added services and loading freight trucks. The carrier moves the shipment with airplanes to the respective destination airport, from which forwarders transport and deliver the freight shipment to the consignee, the recipient of the shipment (Petersen, 2007).

Fig. 2 shows an example of a high-level overview of the air freight transport chain. Usually, carriers contract Third Party Logistics Service providers (3PL) in the country or continent of origin to collect freight from freight forwarders and send it to the airport, together with other shipments. The same typically applies to the destination airport, but then in reverse order, as outlined in Fig. 2.

Here we briefly describe the actors involved in this chain:

Shipper: Shipper is the owner or supplier of the freight. It is also called 'consignor', its ultimate goal is to send shipment to the 'consignee'.

Forwarder: Forwarder is the actor that arranges the transport of the freight from shipper to origin outstation or from destination

* Corresponding author.
E-mail addresses: j.rezaei@tudelft.nl (J. Rezaei), alexanderhemmes@gmail.com (A. Hemmes), l.a.tavasszy@tudelft.nl (L. Tavasszy).

http://dx.doi.org/10.1016/j.jairtraman.2016.02.006
0969-6997/

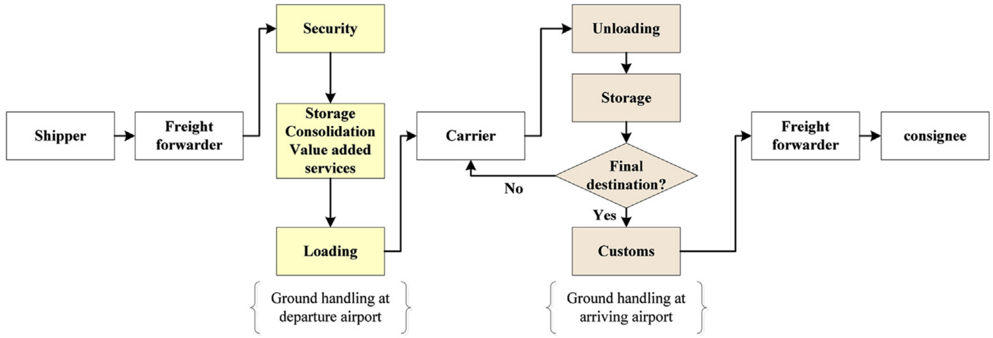

Fig. 1. Air cargo handling process.

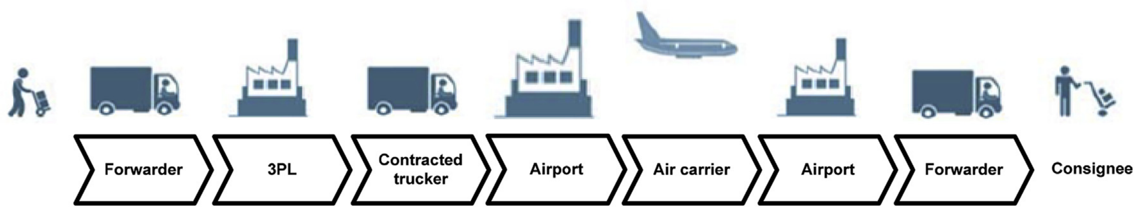

Fig. 2. Air freight transport chain.

airport to consignee. Forwarders often consolidate shipments, so they combine shipments designated for the same flight, in order to get a better price from the carrier. They also provide additional services, such as custom declarations and registrations of dangerous goods.

Outstation: Outstation is a place where an airline receives freight from forwarders or shippers. Outstation is usually operated by Third Party Logistics Service providers (3PL). Airlines usually contract these 3PL companies to process freight for airports.

Road carrier: A road carrier is a trucking company which transports freight from outstation to hub under an airway bill. Air carriers usually outsource their trucking activities to trucking companies. These trucks function as an airline service between outstations and the hub. These trucks comply with all requirements to transport air freight.

Hubs: Hubs receive freight from either trucks originated from outstations or directly from the shipper. Once arrived and accepted in the hub, the palletized freight is stored, ULD's are decomposed to shipment level or (re)built on pallets for the correct. The main goal of the hub is that the shipments are built on the correct ULDs and are ready for carriage before the deadline of the flight.

Air carrier: Air carrier is the airline on which the ULDs are loaded and transported to the destination.

Consignee: Consignee is the final receiver of the shipment.

Air freight transport chain might be of some other forms. What we presented above, is the framework we use in our study.

To transport air freight to an airport hub it needs to be palletized on unit load devices (ULDs). The most common ULDs are containers and big metal plates, on which freight can be bundled and tied down. For transportation by truck, the 3PL typically has three options in terms of the transport of shipments to an airport:

- *Through-ULD* (*T-ULD*); this type of ULD contains shipments for the same flight from an air cargo hub. This type is desirable for carriers, but only possible when there is enough freight volume at the outstation for a specific destination to build T-ULDs.
- *Mixed-ULD* (*M-ULD*); ULD that contains shipments for multiple flights.
- *Loose freight*; instead of palletizing freight, shipments are placed on a skid inside a truck.

T-ULDs are restricted by the specifications of the aircraft: if, for example, only belly freight can be accommodated on an aircraft, which is the primary form of carrying air cargo at many large airports (Merkert and Ploix, 2014), the T-ULD pallet cannot exceed 10 m^3 in volume. M-ULDs, on the other hand, are not restricted by aircraft specifications, because these pallets are disassembled upon arrival at the airport hub, as they do not contain shipments for one and the same flight. These ULDs can contain approximately 15 m^3 of freight during transport by truck towards the hub. Transporting palletized shipments has two advantages: (*i*) it reduces the time needed to load and unload the trucks, and (*ii*) it lowers transport and storage cost, because palletized freight uses space more effectively. Disadvantages of transporting palletized shipments are: (*i*) the costs of palletizing freight, (*ii*) the need for moving equipment between hub and outstation, and (*iii*) the requirements of this equipment (Morabito et al., 2000). M-ULDs have an additional disadvantage, in that they also need to be disassembled upon arrival at the airport, because they contain shipments for multiple flights.

Carriers have three different optimization alternatives at their disposal when it comes to transporting palletized freight from a 3PL to an airport. These optimization alternatives apply to a situation in which all freight is palletized. These alternatives are:

1) *Increase the number of T-ULDs for non-constraint destinations*: lower the minimum required volume for building T-ULDs at the outstation for shipments to non-constraint destinations. Because the freight capacity of flights to non-constraint destinations is not completely utilized, it is not necessary to build T-ULDs that utilize all the available cargo space of the ULD. This configuration will increase the number of T-ULDs and reduce the number of M-ULDs.
2) *Transport shipments loose*: shipments with short connection time that are placed on a M-ULD can also be transported loose in trucks instead of palletized. Upon arrival at the airport hub,

loose shipments can immediately be placed on a build-up buffer. This configuration increases the number of loose shipments and reduces the number of M-ULDs.

3) *Optimize trucks*: This configuration is aimed at utilizing all ULD capacity to minimize trucking cost. Therefore, for instance, instead of building lower deck T-ULDs of 10 m^3, M-ULDs of 15 m^3 are built at outstations.

The aim of this study is to identify the optimal strategy for planning freight for transport from outstation to a hub. A multi-criteria decision-making problem is formulated and solved to determine the optimal freight bundling configuration for transport. It is, therefore, important to identify the key factors for selecting the right freight bundling configuration. This study only focuses on the factors that either relate to freight bundling configurations or could impact the optimal configuration indirectly. The scope of this research comprises all the processes from the moment freight is delivered by the freight forwarder to the 3PL to the point that shipments are placed on T-ULDs before flights at an airport freight hub.

This study offers the following contributions. The first contribution is the structured approach designed to model a complex freight system. This model shows the impact of changing the freight bundling configuration on the basis of the KPIs of a logistics service provider in the air cargo sector. The model was designed, verified, validated and tested at KLM Cargo. One of the strengths of this study is that the scope not only includes multiple actors from inside a freight carrier, but also external actors, like truck operators and outstations. This provides a more complete overview of the impact of certain freight bundling configurations. A second contribution of this research is the identification of the key factors in determining the best strategy for outstations that transport shipments to air freight hubs. For this purpose, we use a new multi-criteria decision-making method called best worst method (BWM). While most existing studies focus on one aspect of the problems of this kind, this study takes multiple KPIs into account, which avoids sub-optimality.

The next section contains a literature review involving existing studies on this topic and on the relevant KPIs used in the transport and logistics industry. The methodology is discussed in section 3, followed by an application of this methodology on case study on KLM Cargo in section 4. Section 5 discusses the conclusion and suggestions for future research.

2. Literature review

There is a limited number of studies available regarding the optimization of air freight, a subject that is discussed in section 2.1. A literature review on the important KPIs in the transportation industry is presented in section 2.2.

2.1. Palletization of air freight

Several studies have examined the multi-pallet loading problem, where the goal is to load a set of distinct products with specific quantities on pallets (or in containers). Some researchers have formulated and solved the problem in such a way that the number of pallets (or containers) needed to be minimized, while others have taken profit maximization as their main objective. Terno et al. (2000) formulated the problem as a minimization problem, using the technological constraints, weight distribution over the pallet, and stability aspects as the main constraints of the problem, and proposed a general branch and bound framework to solve the problem. Koide et al. (1995) developed a hybrid methodology (genetic algorithm and beam search algorithm) to design a system for palletizing different kinds of loads. Lau et al. (2009) formulated the profit-based multi-pallet loading problem as a nonlinear integer programming problem, and proposed a hybrid methodology, using heuristic and genetic algorithms, to solve the problem, while Morabito et al. (2000) analyzed the application of an optimization model, which is designed for solving problems regarding arranging products (packages) on pallets and arranging loaded pallets on trucks. These studies illustrate that the research focus on this topic is on the optimization of the pallet build-up process. Unfortunately, however, only a few studies investigated the operational problem of bundling configurations. Perhaps one of the most relevant studies in this area was conducted by Verwijmeren and Tilanus (1993), who considered the operational problem of breaking down incoming loading units and building up outgoing loading units. They considered some constraints, like the limitation of the number of platforms and manpower teams, as well as time restrictions between arrival times of flights and departure times of flights. They applied standard software for network planning to schedule the transshipment operations of loading units at KLM and had good results. A review of existing literature reveals that, so far no one has examined the practical impact of changing freight bundling configuration on the performance of a logistics service provider in the air cargo sector, which is the aim of this study.

2.2. KPIs in logistics chains

Paulen and Finken (2009) define key performance indicators (KPIs) as key organizational metrics that drive the performance of businesses. Based on Paulen and Finken (2009) and Ploos van Amstel and D'hert (1996), we can summarize the following core principles for a KPI: (*i*) it must be measurable in physical and financial units, (*ii*) it must be specific, realistic and representative, (*iii*) it must be performed, defined, and quantified consistently, (*iv*) it must reflect the responsibilities of the involved departments/managers, (*v*) it must make the costs elements transparent, (*vi*) it must be aligned with overall organizational goals, when used by a particular department. In this study, we carefully consider all these requirements when selecting the KPIs.

Ploos van Amstel and D'hert (1996) developed performance indicators in the distribution sector comprising of four hierarchical decision-making levels. At an operational level, they defined KPIs for warehousing and transport. Warehouse functions that can be relevant to this study are labor costs per unit of output volume (m^3, ton), total number of trucks unloaded per worked time unit and cost warehouse operations per unit of output volume. These KPIs are mentioned because various freight bundling configurations in particular have different outputs with regard to these KPIs. For example, given a constant volume of freight, processing more T-ULD through the hub will reduce the number of M-ULDs that need to be broken down, which in turn means that less labor is required.

Also, various transport KPIs are mentioned by Ploos van Amstel and D'hert (1996). One of the KPIs they include that could vary given the possible freight bundling configurations at the total transport level is that of costs per shipment, which are composed of two parts: (*i*) variable cost, which is a function of shipment size, (*ii*) fixed part, which is the main part of shipment costs and is independent of the shipment size (Daganzo, 2010). Transporting more T-ULDs indicates that the freight being transported is divided over a higher number of pallets. Consequently, more trucks are needed to transport these pallets, compared to transporting a higher percentage of M-ULD.

Looking at a more decomposed level of transportation, the throughput time loading and costs (labor) per loaded unit are higher in case of transporting freight in a more 'loose configuration', which means that the number of truck (un)loaded per worked time unit is higher with palletized freight. (Un)loading time has a significant impact on fleet size, unit cost, daily production and average truck utilization, which demonstrates the critical role of this KPI (Acuna et al., 2012). (Un)loading time is important for outstations and truck operators: a faster (un)loading process means that these stakeholders need less time to carry out their activities. This KPI is very important and has been used in several other studies (e.g. Ankersmit et al., 2014; Van Duin et al., 2007).

Another important KPI for the air cargo industry is quality, which has received less attention in literature. Wang (2007) used quality function deployment (QFD) to evaluate the air cargo service quality with regard to the three main dimensions of professionalism, physical service, and correctness and positivity. Chen et al. (2008) proposed a hybrid methodology, including fuzzy set theory, balanced scorecard and theory of constraints, to evaluate and improve the air cargo service in Taiwan, with a focus on improving the efficiency and safety of air cargo. One of the most objective ways to measure the quality of air freight is to use the flown-as-planned (FAP) measure, which is in fact an integrative measure. FAP is the percentage of shipments that is flown on the initially booked flight. A shipment is not flown-as-planned when it needs to be rebooked to a later flight. Due to the increased competition, this KPI has a high priority for many air carriers.

Reviewing the literature we can find cost, time, and quality as the three most important KPIs which are considered to evaluate the performance of a logistics system (see, for instance, Bagchi, 1996; Van Landeghem and Persoons, 2001; Gunasekaran and Kobu, 2007). The first KPI we consider for our proposed model is a cost-related KPI. Cost will be incurred by the 3PL (warehousing operations), truck operator (trucking cost) and in the hub (labor cost). Throughput time loading is another KPI that is important, not only for the air carrier, but for the 3PL and trucking companies as well, and it is included in this study through the total (un)loading time. The third KPI that is included in this research is the quality of the air freight flow. To summarize, the following KPIs are included in this research:

- Total cost
    - Outstation operations cost
    - Trucking cost
    - Hub operations cost
- Total (un)loading time
- Quality

3. Mathematical modeling

In this section, we first present the notations and assumptions used in the remainder of this section, and then discuss the mathematical modeling of the problem.

3.1. Notations and assumptions

The following assumptions are made to model the problem:

a. All shipments are available for the 3PL when needed for transport.
b. There are no limitations to the number of required trucks or workers in the hub.
c. 3PL has sufficient capacity, time and space to process all freight bundling options, as well as the hub.
d. The quality of the shipments is based on the distribution of shipments over the three options (Loose positions, M-ULD, and T-ULD).

3.2. Identifying the approximated ratios between the three options

The three alternatives discussed in the introduction describe the interchangeability between the three input options (Loose positions, M-ULD, and T-ULD) as shown in Fig. 3. For instance, the arrow from the M-ULD to Loose visualizes the flow of shipments that will be transported loose instead of on M-ULDs. As such, the three arrows between the input variables represent the three alternatives.

The unit that is used for the modeling here is 'position'. A position indicates a ULD or the equivalent size of a ULD with loose freight. This unit is chosen because it is used frequently in the air cargo industry. Here, we show how to quantify the ratios between the input options (Loose positions, M-ULD, and T-ULD), which are shown on the input side of Fig. 3. The relationship between two input options is not 1:1. All three freight bundling configurations have different freight capacities, and shipments vary in volume, weight, dimension and shape.

The total number of T-ULDs is influenced by three factors: (*i*) initial number of T-ULDs, (*ii*) number of additional M-ULDs due to truck optimization (alternative 3) and (*iii*) number of additional T-ULDs for non-constraint destinations (alternative 1). The total number of M-ULDs is also influenced by the latter two factors, but in the opposite direction. The number of loose positions is determined by the number of additional loose positions that are used for transport. The ratios are used to express the change from the initial to the new situation.

The following functions are used to determine the number of positions per input option (Loose positions, M-ULD, and T-ULD):

$$P_{tn} = P_{ti} + E_t - \left(\frac{E_m}{R_{tm}}\right) \tag{1}$$

$$P_{mn} = P_{mi} + E_m - \left(\frac{E_t}{R_{mt}}\right) - \left(\frac{E_l}{R_{ml}}\right) \tag{2}$$

$$P_{\text{ln}} = P_{li} + E_l \tag{3}$$

As finding these ratios is a critical part of the proposed methodology, we first describe the way we find these ratios in general (the elements of the description can be found in Table 1). We then provide a numerical example for more clarification (Table 1).

The new number of T-ULDs (P_{tn}) can be determined by taking the initial number of T-ULDs (P_{ti}), add the extra number of T-ULDs (E_t) and subtract the number of T-ULDs of which the shipments are transported on M-ULDs in the new situation.

Because M-ULDs have the highest freight capacity, the alternatives that are aimed at processing less M-ULDs will have a ratio of 1 or higher. The truck optimization (alternative 3) will therefore have a ratio smaller than 1.

On the basis of these mathematical formulations, the impact of the three optimization alternatives on the three input options and the total number of required positions can be determined. Because ratios will have a big impact on the output, so these ratios (R_{tm}, R_{mt} and R_{ml}) should be selected carefully.

Determining the ratios is based on historical data: a selection of outstations must be made that are representative of all outstations. It is necessary first to determine the shipments that were shipped to the hub from these outstations for a period of n days (D_1, D_2, …,

Symbol	Unit	Definition
C	€	Total cost
C_{FTE}	€/FTE	Cost per FTE (full-time equivalent)
C_{hub}	€	Hub operations cost
C_{loose}	€/ton	Cost of handling loose freight at outstation
C_{out}	€	Outstation operations cost
C_{pal}	€/ton	Cost of handling palletized freight at outstation
C_{tp}	€/position	Average cost per position for truck
C_{truck}	€	Trucking cost
E_l	Position	Extra loose with an upper bound of B_l
E_m	Position	Extra M-ULDs with an upper bound of B_m
E_t	Position	Extra T-ULDs with an upper bound of B_t
F_p	€/liter	Fuel price
F_{rp}	€/liter	Fuel reference price
F_{shr}	%	Fuel share, a percentage used in calculating fuel surcharge
P_l	Position	Number of loose positions
P_{li}	Position	Number of loose positions initial
P_{ln}	Position	Number of loose positions new
P_m	Position	Number of M-ULD positions
P_{mi}	Position	Number of M-ULD positions initial
P_{mn}	Position	Number of M-ULD positions new
P_t	Position	Number of T-ULD positions
P_{ti}	Position	Number of T-ULD positions initial
P_{tn}	Position	Number of T-ULD positions new
Q	%	Total quality
Q_l	%	FAP for loose
Q_m	%	FAP for M-ULD
Q_t	%	FAP for T-ULD
R_{ml}	M-ULD/loose	Ratio M-ULD to loose
R_{mt}	M-ULD/T-ULD	Ratio M-ULD to T-ULD
R_{tm}	T-ULD/M-ULD	Ratio T-ULD to M-ULD
T	Minute	Total unloading time
T_{pb}	Minute/position	Time for pallet build up
T_{pl}	Minute/position	Processing time for loose position
T_{pm}	Minute/position	Processing time for M-ULD
T_{ut}	Minute/position	Unloading time for T-ULD
T_{ul}	Minute/position	Unloading time for loose
T_{uu}	Minute/position	Unloading time for ULD
T_{worker}	Minute/FTE	Effective worker time per FTE (full-time equivalent)
W_{lp}	Ton/position	Average weight on loose position
W_p	Ton/position	Average weight on ULD

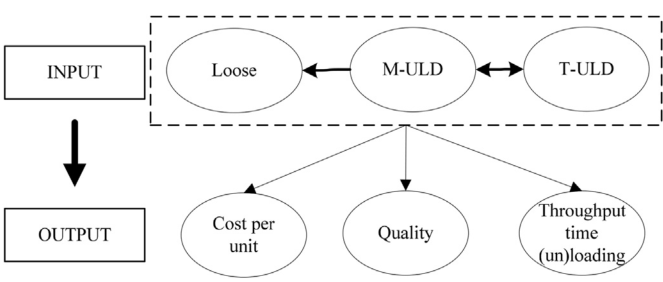

Fig. 3. The relationship between the three input options and the three output KPIs.

D_n). With regard to these shipments (S_1, S_2, …, S_n), data on volume (V), weight (W), special handling code (SHC[1]), handling status (HS[2]), next unload station (flight destination) (NS) and flight departure (FD[3]) must be available. For all the three ratios, the actual (initial) freight planning, following the actual freight planning principles, should be determined first. Generally speaking, plan as many complete T-ULDs as possible and put the remaining shipments on M-ULDs, according to their connection time. An M-ULD can process approximately 15 m^3 of volume of freight, while a T-ULD can process either 10 m^3 or 15 m^3, depending on whether or not main deck pallets (MDP) of 15 m^3 are allowed on the flight in question. Lower deck pallets (LDP) of 10 m^3 are most commonly used by air carriers.

To make the actual freight planning, go through all shipments (S_1, S_2, …, S_n) and assign shipments to T-ULDs that can, either individually or collectively, utilize a ULD for a specific flight. In column T-ULD (initial) these shipments can be assigned to T-ULD by placing a T_1, T_2, …, T_n. The remainder of the shipments must be ranked according to the flight departure (FD) or connection time[4] and assigned to M-ULDs by placing M_1, M_2, …, M_n in the M-ULD column (initial).

Planning the shipments according to the three alternatives varies. The planning procedure will be discussed per alternative:

I. *Extra T-ULDs to non-constraint destinations*: a selection must be made of all non-constraint destinations. The shipment overview must be scanned and shipments or combined shipments with a volume of approximately 4 m^3 or more should be assigned in the column 'new' to T-ULDs instead of M-ULDs. The cut-off point can also be lower or higher than 4 m^3, depending on the total utilization of the non-constraint

[1] Special handling codes are codes that define the type of shipment and indicate if special handlings for transport are required.

[2] "TU" indicates that Cargo Planners assigned this shipment to a T-ULD, "IN" indicates a M-ULD. All shipments with a "TU" handling status can be assigned to a T-ULD in the initial situation.

[3] The date and time of the flight.

[4] Time between the planned arrival of the truck and the departure of the flight.

Table 1
An example of R_{mt} ratio.

D_1						Initial		New		
Shipment	*NS*	*FD*	*HS*	*V*(m^3)	*W* (*kg*)	T-ULD	M-ULD	T-ULD	M-ULD	Loose[a]
S_1	ALA	1 Aug.	TU	10	1400	T1		T1		
S_2	BKK	1 Aug.	TU	9	850	T2		T2		
S_3	DOH	1 Aug.	IN	2	50		M1		M1	
S_4	KWI	2 Aug.	IN	4	400		M1		M1	
S_5	YYZ	2 Aug.	TU	10	1000	T3		T3		
S_6	MEX	1 Aug.	IN	2	600		M1		M1	
S_7	BKK	1 Aug.	IN	6	80		M1		M1	
S_8	ORD	3 Aug.	TU	9	1100	T4		T4		
S_9	XMN	1 Aug.	IN	6	40		M2	T6		
S_{10}	MEX	2 Aug.	IN	3	450		M2	T7		
S_{11}	MEX	2 Aug.	IN	3	250		M2	T7		
S_{12}	PBM	2 Aug.	IN	2	300		M3		M2	
S_{13}	ICN	3 Aug.	IN	1	200		M3		M2	
S_{14}	BKK	1 Aug.	IN	1	100	T2		T2		
S_{15}	XNM	1 Aug.	TU	9	1200	T5		T5		
S_{16}	HKG	3 Aug.	IN	3	150		M3		M2	
S_{17}	EBB	3 Aug.	IN	0.5	150		M3		M2	

NS: next unload station; FD: flight departure; HS: handling status; V: volume; W: weight.
[a] Only applicable for alternative 2.

flights. In the new situation, this will result in more T-ULDs and less M-ULDs.

II. *Transport shipments loose instead of on M-ULDs*: the shipments that are initially placed on M-ULDs need to be ranked according to connection time. Shipments with a connection time under 24 h must be placed on loose positions in trucks. These positions can process approximately 10 m^3 of freight. This option will reduce the number of M-ULDs and increase the number of loose positions, while the number of T-ULDs remains unchanged.

III. *Optimize trucks*: All LDP T-ULDs can be supplemented to 15 m^3 with additional freight to varying destinations. All these LDP T-ULDs become M-ULDs.

It is recommended to repeat this step for as many days as possible, because this will improve reliability. The ratio per day can be determined using the following functions:

$$R_{mt} = \frac{\max_i\{T_i^{new}\} - \max_i\left\{T_i^{initial}\right\}}{\max_i\left\{M_i^{initial}\right\} - \max_i\{M_i^{new}\}}, \tag{4}$$

$$R_{tm} = \frac{\max_i\{M_i^{new}\} - \max_i\left\{M_i^{initial}\right\}}{\max_i\left\{T_i^{initial}\right\} - \max_i\{T_i^{new}\}}, \tag{5}$$

$$R_{ml} = \frac{\max_i\{L_i^{new}\} - \max_i\left\{L_i^{initial}\right\}}{\max_i\left\{M_i^{initial}\right\} - \max_i\{M_i^{new}\}} \tag{6}$$

For example, $R_{mt} = 2.5$ indicates that, if the total number of M-ULDs decreases with one, the total number of T-ULDs increases with 2.5. The average ratio of all days (D_1, …, D_n) determines the ratios that can be used in equations (1)–(3).

Example: This example illustrates the steps to determine the ratio R_{mt}. Table 1 presents an example of a list of shipments that need to be planned on trucks for transport to an airport hub. The option of building additional T-ULDs to non-constraint destinations is applied to this list of shipments. For this option, the connection time (CT) is not relevant. The special handling codes (SHC) and flight times are also excluded from this example for the sake of clarity.

In the initial column, the shipments are assigned either to a T-ULD or to an M-ULD. Shipments with the same ULD number are placed on the same ULD. In the initial situation, 5 T-ULDs and 3 M-ULDs are used. For this example, it is assumed that MEX and XMN are non-constraint destinations, which means that it is not necessary to plan optimally utilized ULDs to these destinations. S_{10} and S_{11} are both planned to be shipped to MEX and are combined 6 m^3. These combined shipments can be placed in the new planning on one T-ULD (T7). Shipment S_9 can also be transported on a T-ULD. In the new situation, only 2 M-ULDs are needed to transport the remaining shipments to the airport hub. This planning can be summarized as follows:

$$Max_i\left\{T_i^{initial}\right\} = 5,\ \ Max_i\{T_i^{new}\} = 7,\ \ Max_i\left\{M_i^{initial}\right\} = 3,\ \ Max_i\{M_i^{new}\} = 2.$$

By using equation (4) the following ratio can be found: $R_{mt} = \frac{7-5}{3-2} = 2$.

$R_{mt} = 2$ shows that, for this specific day, two additional T-ULDs are planned and the number of M-ULD is reduced by 1.

3.3. Formulating the key performance indicators

We consider three different KPIs: total costs, total (un)loading time, and quality, which are formulated below.

3.3.1. Total costs

The total costs of the system are calculated as follows:

$$\textit{Total costs} = \textit{outstation operations costs} + \textit{trucking costs} + \textit{hub operations costs}$$

Outstation operations costs: these costs are calculated based on weight (per ton) instead of position. To determine the outstation operations cost, the average weight utilized on a ULD is used, as is the average weight of loose shipments placed on a position in a truck. These types of freight-bundling configurations are separated, because 3PL at outstations can use different tariffs. At a decomposed level, the function that can be used to determine the outstation operations cost is:

$$C_{out} = (P_t + P_m)W_p C_{pal} + P_l W_{lp} C_{loose} \tag{8}$$

Trucking costs: the trucking costs are based on the number of positions in trucks, the truck price and the actual fuel price. Factors such as the transport of cooled or dangerous goods are excluded from this function, because they are related to shipments rather than freight bundling configurations and, as such, will not affect the output of the model. Truck prices vary between truck operators and types of contracts, for instance a Full-Truck-Load (FTL) or a Per-Pallet (PTL). Under a FTL deal, the contractor pays for the entire truck, independent of the number of ULDs being shipped. Under a PTL deal, the contractor pays for the number of booked positions in a truck. The average price for a position should be used as truck price, taking the frequency of usage of the various contracts into account. Most trucking contracts also include a fuel surcharge, which is related to the fuel price and incorporates a charge in the trucking cost directly related to changes in the fuel price, as a percentage of the total trucking cost. If this surcharge is not included in the contract, this can be excluded from the function. The trucking cost can be modeled based on the following function:

$$C_{truck} = (P_t + P_m + P_l)C_{tp}\left(1 + F_{shr}\frac{F_p - F_{rp}}{F_{rp}}\right) \tag{9}$$

Hub operations costs: because all three types of freight bundling configurations require different processing activities in the hub, the KPI function of the hub will make a distinction between these different types, which is visible in the top half of the fraction. The costs are based on the time needed to process the ULDs and loose freight, until the ULDs are ready for carriage and stored until flight departure. This time is related to costs that are based on the salary of an employee in the hub and his/her effective work time. All time parameters in this function should represent the total duration of the activity, and must include all the time spent by all the workers involved. The hub operations costs can be determined by the following function:

$$C_{hub} = \frac{P_l\left(T_{pl} + T_{pb}\right) + P_m\left(T_{pm} + T_{pb}\right) + P_t T_{ut}}{T_{\text{worker}}} C_{FTE} \tag{10}$$

All three presented functions combined represent the total costs:

$$C = C_{out} + C_{truck} + C_{hub} \tag{11}$$

3.3.2. Total (un)loading time

This KPI can be formulated by multiplying the actual unloading time with the number of positions. Both ULDs have the same unloading time, while the unloading time of loose positions is longer. The time parameters in this function vary from the time parameters used to determine the hub operations cost, because this function uses the actual unloading times, and the time parameters used to model the hub operations cost are based on the total time of all the workers involved.

$$T = (P_t + P_m)T_{uu} + P_l T_{ul} \tag{12}$$

3.3.3. Quality

In the air cargo industry, quality is measured with the flown-as-planned (FAP) figure, which indicates which percentage of the shipments is flown on the booked flight. Quality is a KPI that depends very much on a large number of external factors, which makes it difficult to model. Consequently, these external factors are excluded from this study. The percentage of FAP shipments is modeled as follows:

$$Q = \frac{P_t Q_t + P_m Q_m + P_l Q_l}{P_t + P_m + P_l} \tag{13}$$

3.4. Defining the bounds of the system

The bounds refer to the amount of freight that is eligible for being switched between input options (Loose positions, M-ULD, and T-ULD). Bounds need to be selected for building additional T-ULDs ($E_t \leq B_t$), transporting shipments loose ($E_l \leq B_l$) and truck optimization ($E_m \leq B_m$), and can be selected by looking at the availability of freight eligible for switching. This can be evaluated during the historical data analysis.

3.5. Aggregated model

As discussed above, there are three different optimization alternatives, which we refer to as alternative 1, alternative 2, and alternative 3. Taking into account the three different KPIs (total cost, total (un)loading time, and quality), for each outstation, there is a 3 × 3 matrix (see Table 2), which is in fact a decision matrix. To select the best option in light of the three KPIs, we need to know the relative importance of the different KPIs, for which we should use a multi-criteria decision-making method. In this study, we applied a recently developed multi-criteria decision-making method called best-worst method (BWM).

3.6. Best-worst method

Best-worst method (BWM) (Rezaei, 2015) is a pairwise comparison-based multi-criteria decision-making method that can be used to determine the weights of the KPIs, using the following steps:

1) Determine the set of decision criteria;

In this study, these are cost (C), quality (Q) and unloading time (T).

2) Determine the best (B) and the worst (W) criteria.
3) Determine the preference of the best criterion over all the other criteria, using a number[5] between 1 and 9;

$A_B = (a_{Bj})$, where a_{Bj} indicates the preference of criterion B over

Table 2
Decision-matrix.

Outstation A	KPI		
	C	Q	T
Alternative 1	x_{1C}	x_{1Q}	x_{1T}
Alternative 2	x_{2C}	x_{2Q}	x_{2T}
Alternative 3	x_{3C}	x_{3Q}	x_{3T}

[5] This is a 9-point scale with two extremes 1 and 9. That is, in a pairwise comparison of i and j, 1 means i is equally important as j, 9 means i is extremely more important than j.

criterion j.

4) Determine the preference of all other criteria over the worst criterion W, using a number between 1 and 9;

$A_W = (a_{jW})$, where a_{jW} indicates the preference of criterion j over the worst criterion W.

5) Determine the optimal weights;

Solving the following problem will result in the optimal weights for the criteria:

$$\min \xi$$

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \le \xi, \text{ for all } j$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \le \xi, \text{ for all } j$$

$$\sum_j w_j = 1$$

$$w_j \ge 0, \text{ for all } j \tag{14}$$

Solving this problem, the optimal weights are obtained. The following formula is used to check the consistency of the comparisons:

$$\textit{Consistency Ratio} = \frac{\xi^*}{\textit{Consistency index}} \tag{15}$$

The consistency index can be retrieved from Table 3: the lower the 'consistency ratio', the higher the reliability of the comparisons.

After determining the optimal weights of the KPIs, we normalize[6] all x_{ij}, $i = 1, 2, 3, j = C, Q, T$ (Table 2) for every alternative and calculate the overall score of alternative i, as follows.

$$V_i = \sum_j w_j x_{ij}. \tag{16}$$

The alternative with the highest value is the optimal.

4. Application

In this section, the methodology discussed above is applied in a case study involving KLM Cargo.

4.1. The company

KLM Cargo is a subdivision of the 'Koninklijke Luchtvaart Maatschappij' (KLM) that operates independently of other KLM subdivisions. Its hub is located at Schiphol Airport and handles freight that is exported from Europe to intercontinental destinations, and also handles the import freight flow that is distributed throughout Europe. The export freight flow, which is processed in freight building 3 (one of the three freight buildings at the Schiphol hub), originates from over 60 outstations throughout Europe, and is delivered by trucks at the Schiphol hub.

Increased competition in the air cargo industry has caused overcapacity and, as demand decreases, KLM Cargo is looking for opportunities to optimize its operations and minimize its costs, in order to keep operating at competitive prices. Trucking costs are a major cost item relative to the overall costs. The aim of palletizing freight is to keep these costs down, as the loading and unloading of pallets requires less time compared to loose freight. However, as discussed earlier, M-ULDs require handling at the hub, which generates costs, as does palletizing freight at the outstation. As a result, the transportation of loose shipments could be considered. It is, however, unclear what the impact of changing freight bundling configurations is on the KPIs of KLM Cargo. Currently, the hub processes approximately the following distribution of ULDs: 57% T-ULDs and 43% M-ULDs.

4.2. Data collection

This section covers the data collection of the ratios and parameters. The following ratios are found using equations (1)–(3): $R_{mt} = 2.9$, $R_{ml} = 1.25$ and $R_{tm} = 0.67$. The first two ratios indicate that building extra T-ULDs for non-constraint destinations (alternative 1) and transporting shipments loose instead of on M-ULDs (alternative 2) increase the total number of positions needed in trucks transporting the shipments to the Schiphol hub.

Bounds need to be set to determine the amount of freight that is eligible for switching between input options (Loose positions, M-ULD, and T-ULD). The bounds are:

$$E_t \le 0.442 \cdot P_{ti}$$

$$E_l \le 0.758 \cdot P_{mi}$$

$$E_m \le 0.790 \cdot P_{ti}$$

Parameters of 3 outstations (outstation A, outstation B and outstation C) are included. Three different outstations are selected based on their variety in the amount of freight they ship to Schiphol every year, and their distance to Schiphol. Table 4 presents the parameters related to the three outstations. The bottom row displays the number of pallets transported from these outstations to Schiphol in 2013. These figures, combined with the initial T-ULD/M-ULD ratio, determine P_{ti} and P_{mi}. Currently, KLM Cargo does not plan loose shipments to Schiphol, so $P_{li} = 0$.

The values of the remaining parameters are shown in Table 5. Please note that T_{ut}, T_{pl} and T_{pm} represent the total time spent by all employees. For example, if an activity takes 15 min and involves

Table 3
Consistency index table (Rezaei, 2015).

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

[6] The best option is indicated with a 1, the worst with a 0, and all other values are rated between these values. This makes it possible to compare the results of various criteria.

Table 4
The parameters of three outstations.

		Outstation A	Outstation B	Outstation C
C_{tp}	Average cost per position for truck [€/position]	163.95	403.93	221.64
C_{loose}	Cost of handling loose freight outstation [€/ton]	95.94	41.00	69.67
C_{pal}	Cost of handling palletized freight at outstation [€/ton]	79.51	41.00	69.67
	Number of pallets in 2013	11,379	4077	1365

Table 5
Parameter values of KLM Cargo.

		Values
C_{FTE}	Cost per FTE [euro]	60.000
T_{worker}	Effective worker time per FTE [minutes]	71,175
T_{ut}	Unloading time for T-ULD [minutes]	7.5
T_{pl}	Processing time for loose position [minutes]	56.25
T_{pm}	Processing time for M-ULD [minutes]	115.25
T_{pb}	Time for pallet build up [minutes]	80
Q_t	FAP for T-ULD [%]	86.50
Q_m	FAP for M-ULD [%]	85.20
Q_l	FAP for Loose [%]	85.04
T_{uu}	Unloading time for ULD [minutes/position]	3.75
T_{ul}	Unloading time for loose position [minutes/position]	16.5

two employees, the total time of the activity is 30 min, making it easier to translate this factor into costs, as these costs are based on salary costs. T_{uu}, and T_{ul} affect (un)loading times, which is why the actual time is needed.

4.3. Results

In this section, we discuss the impact of the three freight bundling configurations on the KPIs. The impact is presented in the difference between the initial and the new situation. The results are shown in Table 6.

The impact of the freight bundling configuration on the KPIs discussed below:

- *FAP*: Because T-ULDs have the highest FAP (86.50%), building additional T-ULDs (alternative 1) will lead to the highest FAP. Optimizing trucks (alternative 3) leads to a reduction in the number of T-ULDs and an increase in the number of M-ULDs. As such, this alternative has the lowest FAP of all the three alternatives.
- *Total (un)loading time*: The total (un)loading time is the longest with transporting shipments loose (alternative 2), because unloading loose shipments requires more time (16.5 min per position) compared to pallet (3.75 min). The total (un)loading time is the shortest for alternative 3, because the number of pallets that has to be unloaded is minimized.
- *Total cost*: This KPIs does not favor the same alternative for every outstation:
  - Outstation A, with low trucking prices and a cost difference at the outstation between handling loose and palletized freight, favors loose shipments (alternative 2). The cost savings at the hub and outstation are higher compared to the increased trucking cost.
  - Outstation B favors optimization of trucks due to the high trucking prices (see Table 4).
  - Outstation C, with relatively low trucking cost and with a similar tariff for palletized and loose freight handling at the outstation, favors no option.

The next step is to apply BWM to determine the weights. The following weights are found with help of the BWM (explained in section 3.6), based on the opinion of experts at KLM: $w_C = 0.455$, $w_Q = 0.455$ and $w_T = 0.09$ (the consistency ratio is 0.0994, which implies that the weights are highly reliable). The weights of the total cost and quality are equal, because these two KPIs are the most important KPIs of KLM Cargo that are included in this study.

By normalizing the values of Table 6 and multiplying them with the weights (see equation (16)), the total score of the configuration

Table 6
The results of three KPIs for three outstations.

Outstations	KPIs					
	FAP	*Total (un)loading time*	*Total cost*	*Hub operations cost*	*Trucking cost*	*Outstation operations cost*
Outstation A						
1) T-ULD for non-constraint destination	0.18%	7043.5	€173,792.64	−€144,794.42	€318,587.05	€0.00
2) Transport shipments loose	−0.12%	62,587.2	−€39,262.06	−€78,750.01	€157,272.60	€117,784.65
3) Optimize truck	−0.56%	−6405.0	€240,869.05	€530,574.11	€289,705.06	€0.00
Outstation B						
1) T-ULD for non-constraint destination	0.18%	2523.6	€280,795.50	−€51,878.62	€332,674.12	€0.00
2) Transport shipments loose	−0.12%	22,424.5	€136,011.31	−€28,215.46	€164,226.78	€0.00
3) Optimize truck	−0.56%	−2294.8	−€112,414.81	€190,100.24	−€302,515.05	€0.00
Outstation C						
1) T-ULD for non-constraint destination	0.18%	844.9	€34,294.35	−€17,369.22	€51,663.57	€0.00
2) Transport shipments loose	−0.12%	7507.8	€16,057.38	−€9446.68	€25,504.06	€0.00
3) Optimize truck	−0.56%	−768.3	€16,666.58	€63,646.51	−€46,979.93	€0.00

Please cite this article in press as: Rezaei, J., et al., Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight, Journal of Air Transport Management (2016), http://dx.doi.org/10.1016/j.jairtraman.2016.02.006

alternatives can be determined. The results are presented in Table 7.

In general it can be concluded that the difference between the sum scores of all configuration options is small, except for alternative 3 at outstation A. The following conclusions can be drawn per outstation:

- *Outstation A*: The optimal configuration is transporting shipments loose (alternative 2), mostly due to the high score on the KPI of total costs, despite the increased required number of truck positions ($R_{ml} = 1.25$), and with it the increased trucking costs. The savings of outstation and hub operations costs are higher compared to the increased trucking costs. Alternative 3 is the second most preferred alternative, due to the high score on the KPI quality.
- *Outstation B*: The optimal configuration is to optimize trucking (alternative 3). The price of a position in a truck is relatively high (see Table 4), so it makes sense to try and reduce the number of needed positions in trucks (when focusing on costs). This alternative scores the worst on quality because it stimulates building M-ULDs, which have the lowest assigned FAP.
- *Outstation C*: The optimal configuration is transporting shipments loose, despite the fact that this alternative increases unloading times and reduces the quality of the freight flow (see Table 6). What must be noted is that all alternatives increase costs. It can, therefore, be stated that no change is desired for this outstation.

4.4. Discussion

Here we discuss some of the limitations of the proposed methodology. This mathematical model and the BWM do not incorporate possible barriers or uncertainties attached to these alternatives. For example, with regard to alternative 1, it is very uncertain whether enough freight is available at outstations for non-constraint destinations to build extra T-ULDs, and whether T-ULDs with lower levels of shipment utilization lead to capacity problems on the flights and thereby lower the FAP. There are also questions regarding transporting shipments loose (alternative 2) that need to be examined further, such as: (*i*) are there more damage claims with shipments that are transported loose? (*ii*) how much additional personnel is needed to unload these trucks? and (*iii*) do truck operators have the appropriate trucks available?

The methodology we used in this study is based on the ideal situation in which, when re-planning shipments to determine the ratios, all shipments are available at the outstation and all shipments can be placed on ULDs following a structured procedure. In reality, the outstations need to start building ULDs when shipments are delivered because of time and space limitations. When they wait until all shipments have arrived, they will not have enough time to put all the shipments on pallets. This situation could not be modeled, as historical data was used to research these configurations. It is uncertain what the effect would be when modeled according to these business constraints. Moreover, this methodology does not incorporate any direct relationships between the KPIs, for instance, the potential relationship between total (un)loading time and FAP (quality KPI), or the relationship between cost and FAP. These limitations need to be taken into account before implementing a particular configuration.

It should also be mentioned that, in this study, we consider the bundling configuration as a long-term problem. That is to say, we consider historical data to formulate the three KPIs (criteria) for different outstations, and use BWM to find the optimal configuration for different outstations. This so-called ‘optimal’ solution is considered as a long-term optimal solution, and an (near-) optimal solution for a short-term when the system experiences (low or) no variations. However if the systems experiences significant variations (which is not usual due to relatively stable nature of the outstations characteristics) the solution might be considered as a priori solution. There are two ways that a priori can help for solving the day-to-day operational problem. First, a priori solution could be used as a good initial solution to solve the day-to-day operational problem, if there is a method dedicated for the operational problem. Second, if there is no method developed for the operational problem, then implementing a priori solution to the operational problem could be a good approximation to the expected optimal solution over a certain planning horizon (assuming that the condition within this planning horizon would be the same as the condition used to solve the a priori solution).

5. Conclusions and future research

This study presents a methodology to test various alternatives for optimizing an export air freight chain, which includes three bundling freight options: on T-ULD (all freight for the same flight), on M-ULD (freight for different flights), and loose freight in trucks. In such a situation, the goal for a carrier is to find the best freight bundling configuration alternative. We first formulate the problem as a multi-criteria decision-making (MCDM) problem considering three KPIs (criteria): costs, (un)loading time, and quality. We formulated mathematical functions to find these three KPIs for different outstations. We then use a newly developed MCDM method called best worst method (BWM) to find the best alternative. By applying the method to a case study at KLM Cargo that

Table 7
The aggregated results using BWM.

	KPIs				
	FAP	*Total (un)loading time*	*Total cost*	Sum	Rank
	0.455	*0.09*	*0.455*		
Outstation A					
1) T-ULD for non-constraint destination	0.46	0.07	0.11	0.64	2
2) Transport shipments loose	0.27	0.00	0.46	0.73	1
3) Optimize truck	0.00	0.09	0.00	0.09	3
Outstation B					
1) T-ULD for non-constraint destination	0.46	0.07	0.00	0.53	2
2) Transport shipments loose	0.27	0.00	0.17	0.44	3
3) Optimize truck	0.00	0.09	0.46	0.55	1
Outstation C					
1) T-ULD for non-constraint destination	0.46	0.07	0.00	0.53	2
2) Transport shipments loose	0.27	0.00	0.46	0.73	1
3) Optimize truck	0.00	0.09	0.44	0.53	2

Please cite this article in press as: Rezaei, J., et al., Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight, Journal of Air Transport Management (2016), http://dx.doi.org/10.1016/j.jairtraman.2016.02.006

includes parameters of various outstations, it became apparent that different freight bundling configuration are optimal for different outstations. Trucking cost and freight handling tariffs at the outstations are key factors in determining which alternative is optimal in terms of the costs involved. Finally, it can be concluded that the distribution of weights in the BWM has a major impact on the results of the problem, as only three KPIs are included and the strength of every alternative is focused on a different KPI. As a result, it is very important to analyze the alternatives in qualitative terms as well.

Based on this study, we are able to suggest some interesting future research avenues. As mentioned before, this methodology does not handle possible relationships between the KPIs, for instance, between the total (un)loading time and quality. However, when the unloading times increase at the hub, it is more likely that shipments will miss their booking flight. This relationship will probably be relevant when unloading times increase significantly, for example when transporting shipments loose. For future research, we suggest examining insights into the relationship between these KPIs, which could improve the methodology, which in turn will make it more reliable. As another interesting avenue for future research, we suggest simulating the arriving patterns, utilization of storage capacity, etc. As no time dimension is included in the research, no constraints, such as storage capacity or unload capacity at the hub can entered into the model, which can be remedied in future research.

References

Acuna, M., Mirowski, L., Ghaffariyan, M.R., Brown, M., 2012. Optimising transport efficiency and costs in Australian wood chipping operations. Biomass Bioenergy 46, 291–300.

Ankersmit, S., Rezaei, J., Tavasszy, L., 2014. The potential of horizontal collaboration in airport ground freight services. J. Air Transp. Manag. 40, 169–181.

Bagchi, P.K., 1996. Role of benchmarking as a competitive strategy: the logistics experience. Int. J. Phys. Distrib. Logist. Manag. 26 (2), 4–22.

Chen, C.H., Chang, Y.H., Chou, S.Y., 2008. Enhancing the design of air cargo transportation services via an integrated fuzzy approach. Total Qual. Manag. 19 (6), 661–680.

Daganzo, C.F., 2010. Logistics Systems Analysis, fourth ed. Springer-Verlag, Berlin Heidelberg.

Domingues, S., Macário, R., Pauwels, T., Van de Voorde, E., Vanelslander, T., Vieira, J., 2014. An assessment of the regulation of air cargo security in Europe: a Belgian case study. J. Air Transp. Manag. 34, 131–139.

Gunasekaran, A., Kobu, B., 2007. Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. Int. J. Prod. Res. 45 (12), 2819–2840.

Koide, S., Suzuki, S., Degawa, S., 1995, August. A palletize-planning system for multiple kinds of loads using GA search and traditional search. In: Intelligent Robots and Systems 95.'Human Robot Interaction and Cooperative Robots', Proceedings, vol. 3. IEEE/RSJ, pp. 510–515.

Lau, H.C., Chan, T.M., Tsui, W.T., Ho, G.T., Choy, K.L., 2009. An AI approach for optimizing multi-pallet loading operations. Expert Syst. Appl. 36 (3), 4296–4312.

Merkert, R., Ploix, B., 2014. The impact of terminal re-organisation on belly-hold freight operation chains at airports. J. Air Transp. Manag. 36, 78–84.

Morabito, R., Morales, S.R., Widmer, J.A., 2000. Loading optimization of palletized products on trucks. Transp. Res. Part E Logist. Transp. Rev. 36 (4), 285–296.

Ohashi, H., Kim, T.S., Oum, T.H., Yu, C., 2005. Choice of air cargo transshipment airport: an application to air cargo traffic to/from Northeast Asia. J. Air Transp. Manag. 11 (3), 149–159.

Paulen, B., Finken, J., 2009. Pro SQL Server 2008 Analytics. Delivering Sales and Marketing Dashboards. Springer-Verlag, New York.

Petersen, J., 2007. Air Freight Industry—White Paper. Supply Chain and Logistics Institute, Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology.

Ploos van Amstel, R., D'hert, G., 1996. Performance indicators in distribution. Int. J. Logist. Manag. 7 (1), 73–82.

Popescu, A., Keskinocak, P., Mutawaly, I., 2010. The Air Cargo Industry. Intermodal Transportation: Moving Freight in a Global Economy, pp. 209–237.

Rezaei, J., 2015. Best-worst multi-criteria decision-making method. Omega 53, 49–57.

Terno, J., Scheithauer, G., Sommerweiß, U., Riehme, J., 2000. An efficient approach for the multi-pallet loading problem. Eur. J. Oper. Res. 123 (2), 372–381.

Van Duin, J.H.R., Tavasszy, L.A., Taniguchi, E., 2007. Real time simulation of auctioning and re-scheduling processes in hybrid freight markets. Transp. Res. Part B Methodol. 41 (9), 1050–1066.

Van Landeghem, R., Persoons, K., 2001. Benchmarking of logistical operations based on a causal model. Int. J. Oper. Prod. Manag. 21 (1/2), 254–267.

Verwijmeren, M.A.A.P., Tilanus, C.B., 1993. Network planning for scheduling operations in air cargo handling: a tool in medium term goods flow control. Eur. J. Oper. Res. 70 (2), 159–166.

Wang, R.T., 2007. Improving service quality using quality function deployment: the air cargo sector of China airlines. J. Air Transp. Manag. 13 (4), 221–228.

Zhang, A., Zhang, Y., 2002. Issues on liberalization of air cargo services in international aviation. J. Air Transp. Manag. 8 (5), 275–287.

Please cite this article in press as: Rezaei, J., et al., Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight, Journal of Air Transport Management (2016), http://dx.doi.org/10.1016/j.jairtraman.2016.02.006