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LOADING OPERATION EFFICIENCY FOR INTERNATIONAL AIR EXPRESS AT A SPOKE AIRPORT

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Abstract. Loading operation efficiency at airports plays an indispensable role in international air express service performance. The authors comprehensively examined the priorities of factors that affect loading operation efficiency for air express services at Taoyuan International Airport in Taiwan. The reviewed results from surveying practical experts using a rank pair-wise comparison (RPC) revealed that load factor and load planning consistently ranked higher and more crucial among 15 elements regardless of flight properties. Long-haul services to the North American hub were most concerned with inventory control of unit load devices (ULDs). Regional feeder services attached importance to the ground operations workforce as well. Feeder services for cross-continental deliveries additionally focused on the arrangement of apron bays. The authors used the TOPSIS, i.e., technique for order preference by similarity to ideal solutions, to evaluate flights by three freighter types. Considering that the studied company performed more consistently on the top crucial factors, the sub-criteria that belong to the negative subset and are affected by the external units played a dominant role in these evaluated flights.

Keywords: loading operation, efficiency, air express, spoke airport, rank pair-wise comparison (RPC), unit load devices (ULD), TOPSIS.

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Introduction

International air express provides door-to-door services worldwide. Every sector in the operation chains runs against time, from pickup to final delivery. One of the critical factors in express service is the aircraft loading operation procedures at airports. Based on a safe operation environment, effective loading performance entails expending the least time loading cargo onto aircraft and the least amount of resources by carrying as much cargo as possible. Aircraft loading operation efficiency, which is affected by many factors, affects the efficacy of air express services.

According to the report of Boeing (2022), international express markets experienced an average rate of 7% per year in the recent decade. Shares of international air cargo traffic kept rapid growth with a double-digit percentage, even at 21% in 2021. The particular service properties cause the number of airlines that can provide global express businesses to be limited. However, a few operators formed a high market competition because of higher growth tendency. Park et al. (2009) explored the importance of affected factors for air delivery services in South Korea. Besides prices, accuracy and promptness that require the support of logistical resources and operative management were critical factors. To strengthen service offerings and enhance the competitive situation, a strategic joint venture might provide synergistic benefits to cooperative partners (Baxter & Srisaeng, 2018). On the other side, domestic markets were gradually deregulated to confront the increasing requirement of competition and cooperation (Aarhaug & Fearnley, 2016; Liu & Kang, 2015). Regardless of what kind of operating scopes or schemes, customer loyalty is as important as in air passenger markets to this business-to-business (B2B) freight transportation market (Tsai et al., 2021).

Freighter capacities are the most important resource supply in the air cargo and logistics community. Besides air express, all-cargo airlines and combination carriers also operate dedicated freighters. Airlines operating freighters generated 90% of cargo revenues in the industry (Boeing, 2022). An essential topic discussed is maintaining the healthy performance of cargo shipping for freighter flights with efficient shipment loads (Budd & Ison, 2017; Merkert et al., 2017). Air express companies greatly depend on operating hub-and-spoke networks with various freighter types to cover a variety of market scales (O'Kelly, 2014). Previous research has focused on hub centralization because of intensive flights and the advantages of network economies (Lakew, 2014; O'Kelly, 2014). Big air integrators normally operate multiple-hub systems within and between individual continents (Malighetti et al., 2019a, 2019b). Deployment of different aircraft types has created these complicated transport patterns and various network tiers, as well as the dynamics of shipment flows. Some studies have examined flow distribution patterns within a hub-and-spoke network (Tan, 2011; Yan et al., 2006, 2008) in the international air express field or mainland China's domestic markets (Yildiz & Savelsbergh, 2022). The proposed models in these studies could also determine shipment consolidation and distribution at hub-and-spoke airports for container and less-than-container loads. Several studies (e.g., Tang, 2011; Yan et al., 2008) have proposed models to decide the best solution for applying resources. Even companies that lacked cargo aircraft provided a hybrid service model to combine rental belly capacities (Xu et al., 2016; Yu et al., 2017). The works of shipment delivery management and constructing transport networks for own freighters became more complex.

Airport loading operations for international cargo deliveries have similar procedures, but some details treat differently because of shipment items. All-cargo and combination airlines handle freight, while air express companies mainly transport parcels and documents. Feng et al. (2015) reviewed extant studies on air cargo operations from the practical perspectives of airlines, freight forwarders, and terminal service providers. Certain elements affected airport operation performance, e.g., improving load factors, allocating cargo space allotments, resource management of terminal staff, shipments tendered, dangerous goods control, cargo routing, packing validation, etc. According to Brandt and Nickel's (2019) literature reviews, extant studies have focused on individual airport operation procedures using various operational research techniques. The main topics of air cargo loading include aircraft configuration, build-up scheduling, air cargo palletization, and weight and balance problems.

Most air cargo shipments are built into unit load devices (ULDs), mainly containing containers and pallets, for loading onto the appropriate deck positions in aircraft. Inventory control of ULDs is concerned with equipment provision for loading operations (Lu & Chen, 2012). ULDs' assemblies in a load plan affect not only the available capacities of loaded freights, the performance of which reflects on every flight's load factor, but also ULDs' repositioning (Lu & Chen, 2011). Containers' contours and pallet stacks' flexibility affect the appropriate use of equipment capacity. When selecting ULDs, one must consider three-dimensional scales, weight limits, stacking stability, shipments' varying characteristics, and mixed build-up among various items (Chan et al., 2006; Paquay et al., 2014). While ULDs are loaded onto aircraft, allotment of ULDs must consider the aircraft's interior contours, weight limits, and the resulting position of the aircraft's center of gravity (CG). Such decisions entail gauging the aircraft's weight and balance (W&B). These conditions comprise loading constraints (Larsen & Mikkelsen, 1980; Limbourg et al., 2012; Vancroonenburg et al., 2014) that must be considered in the objective function of maximizing cargo transport profits (Brosh, 1981) or shipment loads (Mongeau & Bes, 2003). The arrangement will be more complicated when multiple flight legs are a factor (Lurkin & Schynes, 2015) or when combined with ULD selection (Dahmani & Krichen, 2016).

Airport export operations played an interface and conversion role, from landside transport to airside switch. The cargo operations for combination carriers' flights have affected on-time performance significantly and were even tied to revenues from passengers (Lange, 2019). As mentioned earlier, previous research has examined partial functions at airports (Brandt & Nickel, 2019) but rarely has examined the integration of overall procedures. Szabo et al. (2022) focused on increasing airport operation efficiency by measuring handling times, suggesting changes, and re-measuring to improve individual steps, e.g., equipment position before aircraft arrival, staff deployment, and moving routes for ground handling equipment.

The hub systems typically become a core issue in extant research on air integrators while rarely focusing on spoke roles. Spoke airports, like peripheral nerves, require to feed shipments to hub operations on a vast network system with the right amounts, types, and service priorities. Aircraft loading operations at the spoke airports are indispensable in supporting consolidated functions. However, limited research focused on the factors affecting loading operation efficiency, especially for international air express business operation details.

The authors aim to clarify the essential factors that affect freighter loading efficiency at a spoke airport in the context of international air express. In particular, various operating characteristics might cause different priorities on factors. Such practical details have not been explored in previous research. This topic can be evaluated through different dimensions of aircraft loading procedures. Each aspect took into account the attributed considerations to assess efficiency in detail. This study investigated experts from a studied air express company serving Taoyuan International Airport (IATA code: TPE) in Taiwan to construct a hierarchical evaluation framework. A rank pair-wise comparison (RPC), which stemmed from the analytic hierarchy process (AHP), was applied to evaluate relative weights among factors for their ranks on three selected freighter types, MD11F, B767F, and B777F fleet. This study also compiled flights of these three types to compare their loading efficiency using the technique for order preference by similarity to ideal solution (TOPSIS). Although TPE operates as a spoke point with multiple feeder functions in the complicated network of the studied company rather than a hub with consolidation and sorting procedures, these proposed methodologies can be generalized to most airports with similar functions. The obtained results can also be a valuable practical reference for express services in other airports.

1. Loading practices for air express

The procedures for export operations at airports begin with estimating types and quantities of required ULDs. Simultaneously, downtown consolidation centers consecutively pass messages on shipment collection to airport operation units. Airport load controllers must consider possible loads for different resources, including dwelled and transfer ULDs, to provide a warehouse with build-up works as a reference. Meanwhile, load planners need to continuously monitor the aircraft's W&B status for laden ULDs ready to move to the aircraft side. Ramp operation speed and safety depend on the ground handling workforce and equipment arrangement. The sequence of loading ULDs onto aircraft must follow assigned positions on the deck marked on the load sheet. As shown in Figure 1, operation efficiency for air express depends on several factors for the whole process at a spoke airport.

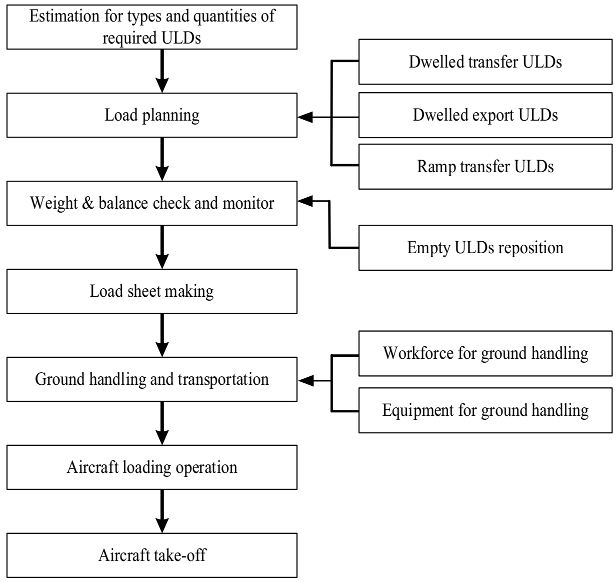

Figure 1. Export operation procedures at a spoke airport (source: compiled from the practice by this study)

1.1. ULD preparation

ULDs include multiple pallets and containers to fit the contours of main decks and lower compartments of various aircraft. Preparing ULDs for an individual flight requires selecting appropriate types and quantities of ULDs to seize maximized shipment stacks. Table 1 provides possible ULD assemblies on freighter types from the studied company deployed at TPE. However, air express freighters prefer to use more containers to rapidly build up parcels and documents before the late cut-off time. Pallets with build-up flexibility in height are only prepared for reserved heavy freights that must be delivered to the warehouse early.

The ULD inventory and repositioning problem is always a topic with a managed challenge. Long-term imbalances between export and import shipments can elicit shortages or excess empty ULDs at an airport. Sufficient quantities and appropriate types for deployed freighters can ensure export operations' reliability. In particular, a long-haul service with less frequency has a more difficult time replenishing or repositioning ULDs for used large aircraft; thus, the settings on safety stock levels for each ULD type become a crucial management factor.

Another possible factor that affects the aircraft loading operation is ULDs' airworthiness. Frequent use of ULDs might deform the bottom of the pallets or cause abrasion outside the containers, even loose bottom corners of ULDs. Preparing appropriate, sufficient, and airworthy ULDs is essential for effective airport cargo operations.

1.2. Load planning in considering weight and balance

Air express shipments comprise many different items and delivery priorities. The most important task is to aggregate and select various feasible loaded ULDs to ensure maximized allotments for each flight's capacity. Load planners must consider reserved export, ramp transfer, dwelled export and transfer ULDs, and their delivered priorities to make an appropriate load plan within a rush hour. Notably,

Table 1. Assemblies of used ULD types for deployed freighters at TPE (source: the studied company)

Freighter	MD-11F				B767F				B777F			
Main Deck	(C)AMJ/(P)PMC×26				(C)AAD/(P)PAG×22 + AYY×3				(C)AMJ/(P)PMC×27			
Lower Compartment	Forward		Aft		Forward		Aft		Forward		Aft	
	(P) PMC/ PAG	(C) AKE	(P) PMC/ PAG	(C) AKE	(P) PMC/ PAG	(C) APE	(P) PMC/ PAG	(C) APE	(P) PMC/ PAG	(C) AKE	(P) PMC/ PAG	(C) AKE
ULD Assembly	0	18	0	14	0	16	0	14	0	18	0	14
	1	14	1	10	1	12	1	10	1	14	1	10
	2	12	2	8	2	8	2	6	2	12	2	8
	3	10	3	4	3	4	3	2	3	10	3	4
	4	6	4	0	4	0	–	–	4	6	4	0
	5	2	–	–	–	–	–	–	5	2	–	–
	6	0	–	–	–	–	–	–	6	0	–	–

this plan concerns the allotted deck positions for ULDs and the departing flight's W&B.

Weight specifications are one of the crucial factors concerning aircraft flying safety. The gross weight of a serving aircraft comprises its operating empty weight (OEW), payload, and fuel weight. The estimated weights before every flight's departure – e.g., zero fuel weight (ZFW), take-off weight (TOW), landing weight (LW), etc. – cannot exceed its serving aircraft's maximal regulation. Except for an unchanged aircraft's OEW, weights of lifting payloads and added fuel for flights will change. The amount of added fuel must ensure that the flight is completed safely, while lifting payloads concerns loading performance. Fuel consumption performance keeps a positive relationship with the aircraft's gross weight, which changes during the flying process because of fuel decreases. Loaded weights are only alterable items once any weight specification is violated. These complicated relationships require professional planners to ensure exactness before every flight's departure.

All the weight specifications mentioned above conformably act on the aircraft's CG and must remain within a specific range based on the mean aerodynamic chord (MAC) during the journey for flying safety (Manshadi & Saghafi, 2018). CG for zero fuel weight (ZFWCG) is the CG's position in considering an aircraft's weight without calculating fuel weight. CG for gross take-off weight (TOWCG) implies the position of CG for an aircraft's weight at the take-off stage. These two items must be planned into the safe scope of W&B because of fuel consumption during flying until landing. This safety guarantee depends on the balance of allotment of payload weights on board. Furthermore, to acquire better fuel consumption at the take-off, climbing, and cruising stages, planners usually set the CG slightly behind the act point of lift force to reduce adjustments to the tail wings to increase tail downforce.

Most forward and aft spaces on freighters are typically designed for special ULDs with a specific size, e.g., the AYY or SAA containers for a B767F, to increase loadable capacity. Higher priority or specific dangerous shipments are built into ULDs to load onto aircraft first with the final off-load sequence while considering bump-off cargo. Amid the loading operation, fixing these special ULDs will affect efficiency. The load sheet al.o requires remarking these ULDs and alerting the captain.

1.3. Resources for safe ground handling

ULD build-up functions with air express shipments require a larger workforce than with combination and all-cargo airlines because the late cut-off time policy increases the urgency of operations at airports. Limits on the working area's capacity cannot accommodate overly large workforces and equipment, e.g., X-ray machines and conveyer belts while maintaining build-up speed. Yet, rapid and exact load planning can accelerate build-up efficiency.

Express airlines usually contract with a ground-handling company for ULD loading and unloading operations at a spoke airport to save money instead of employing their own crew. A team of ULD operations comprises supervisors, loader operators, transporter drivers, and operating guides for the main deck, forward and aft compartments, and the bulk hold. Airlines also assign company supervisors to monitor ground operation tasks. Providing the required workforce ensures smooth operation procedures to unload and load ULDs for all flights.

Loading equipment plays a critical role, along with the workforce, in ground operations between the cargo warehouse and aircraft sides. Different dollies for various ULDs, tractors for dolly tugging, lifting loaders for moving ULDs, and belt loaders for conveying bulk cargo also affect the whole apron operation for each flight. Furthermore, the arrangement of workforce and equipment sometimes needs to consider freighters' parked positions in proximity to the warehouse.

Airlines regulate operating procedures primarily to ensure the safety of all workers and equipment, ensuring rapid and unhindered ramp operations without any accidents. For example, a tail grounded because of the wrong loading sequence or neglecting safety procedures will damage the aircraft severely. To avoid head tipping, aircraft-side operators must follow the exact loading procedure or use appropriate accessories, e.g., nose tethers, tail stands, and ballast pallets.

1.4. Load performance

For airlines, a freighter's load factor is an intuitive load performance. The narrow definition of *load factor* is the ratio of the actual cargo weight in tons to the aircraft's maximal available payload. The maximally available payload may be the aircraft's maximal loaded weight for a trip within the range allowing for full payload or less than full payload for a journey longer than the threshold range.

On-time performance is another vital measure for air express operations. The scheduled time can have different standards, e.g., times of aircraft pushback or the closure of the last cargo door. The latter might be more objective because the pushback allowance typically depends on the air traffic tower's ground control.

Another indicator is the loads for bumping off to the warehouse, i.e., the laden ULDs not loaded onto the aircraft as planned. Off-load reasons might include loading limitations, the detoured bottom of pallets and containers, the collapse of stacking, etc. These off-load ULDs are dwelled to wait for late flights, just like a service failure, increasing operation time and cost.

The aforementioned operation content seems pretty complicated for judging the importance of affecting factors, so a professional and integrated evaluation is necessary. Furthermore, it requires clarifying whether express operators' performance follows the significance of affecting factors or whether other critical possibilities exist.

2. Methodologies

From a realistic perspective, so many factors affect air express export operations that a systemic scheme is required to conduct an analysis comprehensively. This study investigated expert opinions to construct an analytical framework and applied an RPC concept (Lu & Liu, 2014) to evaluate the relative weights of critical factors for different freighter types. Considering that experts have suggested using some numerical indices as data to represent the assessed positive and negative sub-criteria, TOPSIS (Hwang & Yoon, 1981) is an appropriate tool for evaluating the loading efficiency of air express freighters for export operations.

2.1. Research design

The authors proposed a research design, as provided in Figure 2, to meet our research needs. According to the examination of practical operations and literature review of previous efforts, this study first constructed an analytic hierarchy to model the essential evaluation elements. Practical experts from the studied company helped ensure the appropriateness and validity of the main dimensions and attributed factors to evaluate loading efficiency for air express at TPE. The criteria and sub-criteria in the framework comprised the compared entities to design a questionnaire for the RPC. More invited practitioners from the studied company responded to their opinions in the distributed questionnaire on the relative importance between criterion and sub-criterion levels of different freighter types. The RPC operation combined experts' opinions to decide sub-criteria weights for each selected aircraft type. Following the experts' suggestions, this study identified the indices of collectible data corresponding to all sub-criteria. These data for different freighter types evaluated loading efficiency among involved flights using TOPSIS. The following two subsections describe the concept of RPC and TOPSIS and their operation steps.

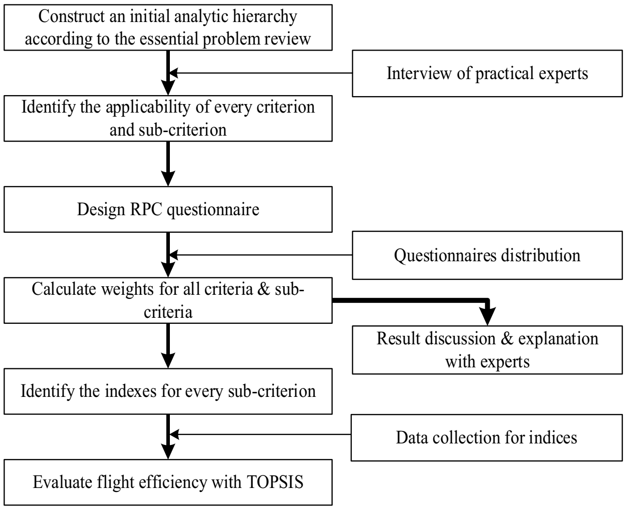

Figure 2. The research design framework

2.2. RPC concept

Constructing an analytic hierarchy is the basic scheme for multi-criteria decision-making problems. An AHP aims to measure relative comparisons among decision factors and evaluate possible alternatives if needed. The hierarchical framework comprises the ultimate goal, evaluated criteria, attributed sub-criteria, and possible alternatives. One can allocate relative weights, which might be examined through experts' group decisions, for criteria being assessed and attributed factors. Furthermore, if alternatives are required to be ranked, the performance evaluation of all options on all decision sub-criteria needs to be measured further.

The pair-wise comparison among entries under a common attribute is the core of executing an AHP. A matrix, or pair-wise comparison matrix, presents the compared results between every two entries in which the values of symmetrical elements in this matrix are reciprocal. The linear algebra calculation can decide the relative weights for every entry. Typically, the pair-wise comparison results follow the perfect transitivity property, i.e., the value of Entry *a* compared with Entry *b* is equal to the multiple between the value of Entry *a* compared with Entry *c* and the importance of Entry *c* compared with Entry *b*. An AHP allows deciders to present a little variety on this property, yet satisfy an acceptably consistent level.

The traditional AHP operations require comparing every two entries for all responding attributes, such as criterion level, same attributed factors in sub-criterion levels, and all alternatives (Saaty, 1980). However, some drawbacks have been experienced in executing an AHP to collect opinions from a large group of respondents. First, too many comparative entries generally render the respondents, particularly those without experience in pair-wise comparison, unable to discriminate the relative weights necessary to reach the acceptable level, e.g., the number of comparisons is $(n^2 - n)/2$ for n entries. Second, response inconsistency occurs when respondents encounter entries with closer perceived relationships. This phenomenon might be that respondents do not rank their priorities in advance. Furthermore, an overly complicated framework that lists too many pair-wise comparison queries can be chaotic for respondents as they write down their opinions. Thus, respondents' original views might be distorted because of repetitive questions to reach a minimum consistency.

Lu and Liu (2014) proposed an RPC approach to overcome the mentioned drawbacks of the traditional pair-wise comparison method. This approach asks respondents to express the priorities of the involved entries and subsequently assess the relative weights for two consecutive ranks. The number of pair-wise comparisons is $n - 1$ for n entries. This operation holds the perfect transitivity property for all comparisons, but the compared results might be enlarged than the original setting measure scales. For example, three elements are compared with Likert 5-point scales for importance. The rank comparing results are 5:1

Table 2. Adjusted ranges between consecutive linguistic variables (source: Lu & Liu, 2014)

Measure Scales	Number of evaluated entries (n)							
	2	3	4	5	6	7	8	9
1 ~ 5	1	0.166667	0.032258	0.006410	0.001280	0.000256	5.12E-05	1.02E-05
1 ~ 7	1	0.125000	0.017544	0.002500	0.000357	5.1E-05	7.29E-06	1.04E-06
1 ~ 9	1	0.100000	0.010989	0.001219	0.000135	1.51E-05	1.67E-06	1.86E-07

and 4:1 for three priorities. By the transitivity rule, the importance between the first and last elements will be 20:1 over the original 1 to 5 measure scales. The largest compared range, 25:1, can be transformed into the set scale, 5:1, and keep the original pair-wise comparison relationships for elements. Following Table 2, 20:1 transforms into the 1 to 5 scales will be 1 + 0.166667 × (20 − 1) = 4.1666733 and 25:1 being 5, respectively. Therefore, one can elicit an RPC matrix with complete consistency using the transitive rule, scale adjustment, and reciprocal principle. This approach is appropriate for collecting opinions from experts unfamiliar with pair-wise comparison.

After collecting experts' opinions, the whole execution process in this study proceeded as follows:

Step 1: Construct all respondents' pair-wise comparison matrices using the following RPC steps (Lu & Liu, 2014).

- Using the transitive rule, calculate the values for other nonconsecutive comparison elements with the consecutive comparison results.
- Adjust the values for these elements according to the scale adjustment rule in Table 2.
- Fill in the values for other matrix elements according to the reciprocal principle.

Step 2: Combine all respondents' pair-wise comparison matrices, the elements of which are the geometric means of all corresponding values in all respondents' pair-wise comparison matrices.

Step 3: Calculate the relative weights for entries in all tiers with these matrices using the average of normalized columns approach, as in Equation (1), in which a_{ij} is the matrix entry with n entries.

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \forall i = 1,2,..,n \tag{1}$$

Step 4: Distribute the overall relative weights for all sub-criteria.

Step 5: Rank the priorities for all sub-criteria with the overall relative weights.

2.3. TOPSIS

Although the traditional AHP can rank the importance of alternatives, one may confront the decision problem with additional specific properties. For example, some selected factors for loading operation efficiency in this research bring positive or negative effects for the ultimate goal. Most factors can use continuous numerals to quantify the measured results for the evaluated flights. Still, using the pair-wise comparison concept to solve this evaluation will become rather complex than the exploited approach, TOPSIS. The TOPSIS approach appropriates evaluating alternatives with multiple quantified factors that include positive (i.e., benefit) and negative (i.e., cost) influence. It aims to find an option closest to the defined positive ideal solution (PIS) and furthest from the defined negative ideal solution (NIS). The defined PIS can be the maximal values of benefit criteria and minimal values of cost criteria, and vice versa for the defined NIS.

Following the steps proposed by Hwang and Yoon (1981), the implementation of TOPSIS for a given matrix $X = [x_{ij}]$, with assigned rates to n criteria, indexed by j, and m alternatives, indexed by i, with a weighted vector $w = [w_j]$ for the sub-criteria is described as follows.

Step 1: Normalize evaluation matrix $R = [r_{ij}]$ using Equation (2).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \forall i = 1,2,..,m; \; j = 1,2,...,n\,. \tag{2}$$

Step 2: Construct weighted decision matrix $V = [v_{ij}] = [w_j \times r_{ij}]$.

Step 3: Define the PIS (V^+) and NIS (V^-) and determine their ideal solutions using Equations (3) and (4).

$$V^+ = \left\{v_1^+, v_2^+, ..., v_n^+\right\} \;;\; v_j^+ = \max_j \; v_{ij}; \tag{3}$$

$$V^- = \left\{v_1^-, v_2^-, ..., v_n^-\right\} \;;\; v_j^- = \min_j \; v_{ij}. \tag{4}$$

Step 4: Calculate the distances to the PIS and NIS – i.e., S_i^+ and S_i^-, respectively – for every alternative using Equations (5) and (6).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2} \quad \forall i = 1,2,..,m; \tag{5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad \forall i = 1,2,..,m. \tag{6}$$

Step 5: Compute the closeness coefficient with the ideal solutions for each alternative using Equation (7).

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+} \quad \forall i = 1,2,..,m\,. \tag{7}$$

Step 6: Because $0 < C_i^+ < 1$, rank the preference orders of alternatives as decreasing C_i^+.

3. Investigation of factor weights

The proposed evaluation framework's ultimate goal in this study is to evaluate freighter flights' loading efficiency. This study then executed a sampling investigation of the studied company for affected factors and exploited the RPC to calculate the comparative importance of evaluated factors. In considering the properties in serving different routes for three types of freighters, the results included data on MD-11F, B767F, and B777F.

3.1. Investigation of analytic hierarchy

This study compiled the main dimensions from the previous literature (Brandt & Nickel, 2019; Chan et al., 2006; Fen & Shen, 2015; Lange, 2019; Manshadi & Saghafi, 2018; Mongeau & Bes, 2003; Szabo et al., 2022; Vancroonenburg et al., 2014) and examined the practice of aircraft loading for express freighters at TPE. Then, a framework comprising five preparative criteria and 15 attributed sub-criteria was prepared for review by six practical experts in our focus group. All these experts have over 20 years of experience in loading operation works of different freighter types, including ramp operations and W&B. Through a sufficient explanation, experts all understood the original definitions of criteria and sub-criteria. Accordingly, these senior practitioners expressed their opinions on the factors affecting the freighter loading efficiency.

As shown in Figure 3, the five criteria include ULD uses, cargo load planning, aircraft weight and balance, resource utilization, and operational performance. Except for operation performance receiving 83.3% agreement, the other four criteria were agreed upon entirely. Nine sub-criteria

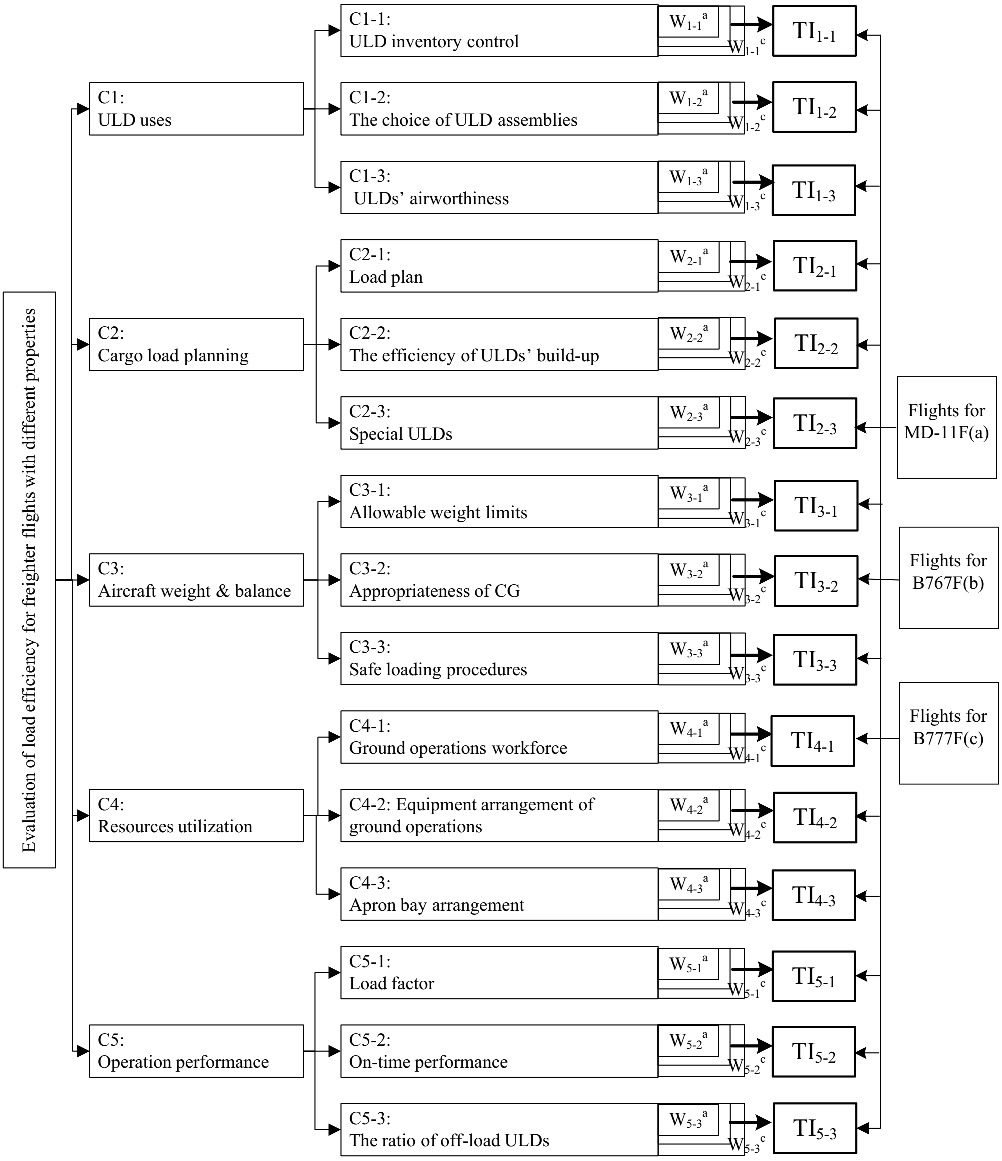

Figure 3. The evaluation framework

ultimately indicated agreement, while five factors obtained 83.3% agreement, and the left one received 66.7% agreement. Among them, one expert suggested minor modifying the meanings of factors. Only two experts advised deleting the sub-criterion of the ratio of off-loading ULDs (C5-3). Considering that most of the focus group agreed with the whole framework, this study modified the definitions of factors, as the experts suggested, to design the distributed questionnaire as the original hierarchical structure.

3.2. Questionnaire design and sampling

A questionnaire was designed for rank pair-wise comparison with seven-point measuring scales from 1 for the same importance between two elements to 7 for the former being extremely important than the latter. According to the proposed analytic hierarchy, respondents should make pair-wise comparisons of one criterion and five sub-criterion levels for each freighter type. For each RPC, respondents gave the sequence of importance for the evaluated elements, then expressed the importance level for each consecutive element pair. Table 3 provides an example for comparing three sub-criteria under criterion C1 for MD-11F. As the remark, respondents can rank three sub-criteria first and then tick the adaptable relative importance levels for two consecutive factors. These measures vastly decreased the traditional comparison times for three aircraft types and reached the purpose of pair-wise comparisons.

Although other air express companies operated at TPE, their flight functions were not as comprehensive as the studied company. The questionnaires were therefore distributed to practical experts belonging to one company. After inquiring about the response willingness, 15 male technicians, almost one-third of the total employees in this field, responded to questionnaires from April 1–30, 2019. Twelve had more than 20 years of experience, and the other three had less than ten years. Since work rotation arrangement, they have ever handled aircraft loading operations and W&B for all three freighter types. These experts could express opinions on different freighter types; thus, all the questionnaires were effective.

3.3. Factor priorities

Air express flights at a spoke airport must consolidate parcels, documents, and freight to support hub operations. At TPE, the studied company deployed three types of freighters to implement shipment feeding roles. The MD-11F fleet mainly ships large freight and rapid express cargo to the Anchorage airport (ANC), the hub flying into North America from Asia. The B767F fleet primarily operates flights to the Asian hub, Hong Kong (HKG), for regional services in Asia. The B777F fleet mostly loads cargo to Osaka (OSA), the North Asian hub, to consolidate shipments into Europe and America.

The opinions of 15 experts on three types of freighters were transformed into their pair-wise comparison matrices following the calculation steps mentioned in Section 3.2. As in Table 2, the adjusted range for the criterion level should be 0.0025 because of five entries with seven measuring scales. Every sub-criterion comparison in the same criterion should use 0.125 to scale adjustment because of three elements with seven measure scales. After using the reciprocal principle to fill up other entries for respondents' matrices, combining the same elements in the pair-wise comparison matrices from all expert opinions with the geometric means could form the final comparison matrices of the group decision. Figure 4 compiles the results from criteria and sub-criteria priorities for the three freighter types following Equation (1).

Cargo load planning (C2) was the most crucial of the five criteria for all three types. The measure of ULD uses (C1) ranks second for MD-11F, but aircraft W&B (C3) for the other two types. These first two criteria all share percentages of over 40%. An ideal load plan (C2-1) can drive efficient build-up works of ULDs and a smooth operating procedure, particularly for regional services. Load factor (C5-1) is crucial in planning the whole load operation, no matter what service type. This index reflects freighter operations' actual performance. Various factors can affect each flight, e.g., weather conditions, flying distances, and, of course, load control. However, inventory control for ULDs (C1-1) was relatively significant among all sub-criteria for the trans-Pacific services of MD-11F. The workforce for ground operations (C4-1) and apron bay arrangement

Table 3. Question item design for three sub-criteria in C1 for MD-11F

Please compare the importance of the following three sub-criteria in C1 for MD-11F:
(You can *rank them first* and *then tick an adaptable relationship between consecutive items*)
C1-1: ULD inventory control; C1-2: The choice of ULD assemblies; C1-3: ULDs' airworthiness

1st Sub-criterion	7	6	5	4	3	2	1	2nd Sub-criterion	7	6	5	4	3	2	1	3rd Sub-criterion
	EI	HI	VI	I	MI	LI	SI		EI	HI	VI	I	MI	LI	SI	

Note: EI: extremely important; HI: highly important; VI: very important; I: important; MI: moderately important; LI: slightly important; SI: same (equally) important.

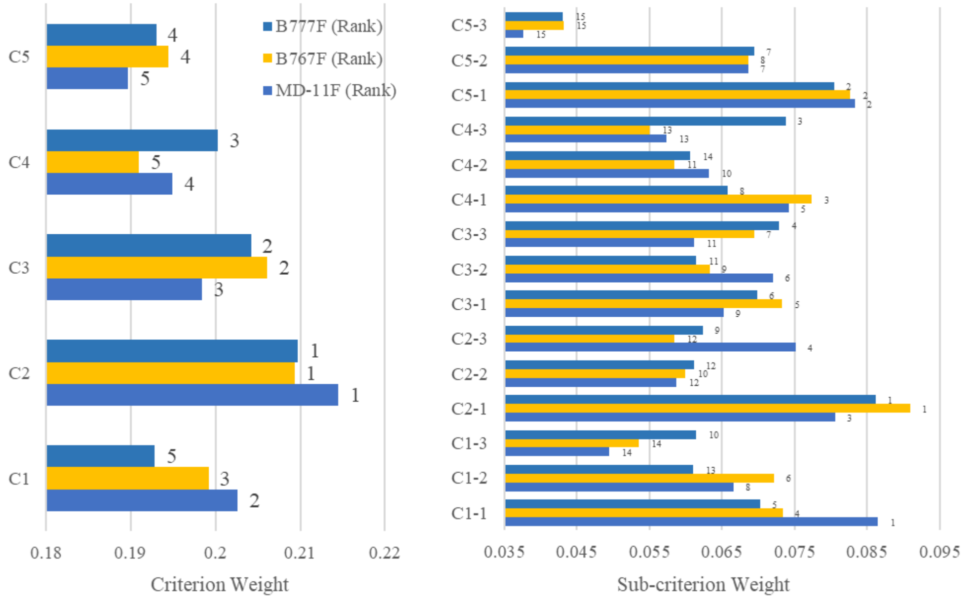

Figure 4. Weights and ranked priorities of factors for different freighters

(C4-3) were also vital for two regional services, B767F and B777F, respectively. Criteria C4-3, C2-3, and C1-1 were the top three factors for gaps among the three service types, with the largest and lowest weights of the three types all over 0.015. From criterion C2-3, the attached importance of handling special ULDs of MD-11F was higher than the other two aircraft types.

From expert explanations, the evaluated results might be related to the flight characteristics listed below.

1. MD-11F for trans-Pacific services. Many ULDs planned to transfer to ANC on these flights were left at TPE to wait for the next flights. This regular phenomenon magnified the importance of cargo load planning. In particular, these early flights also required more time to build up containers in the morning. Effective ULD inventory control could allocate shipments more efficiently, with different sizes and diversified properties shipped to North America.
2. B767F for feeding the Asian hub. These flights' limited capacities always made a large number of dwelled ULDs. ULDs' destinations on these flights are at Asian airports. A detailed and prompt load plan was essential for these flights, with consolidation functions at the Asian hub. The workforce for ground operations played a relatively vital role in these flights.
3. B777F for feeding the North Asian hub. B777Fs, executing the latest departure flights daily, typically received leftover ULDs from the other two services. Allowances for load planning time and preparation to conduct aircraft loading were the most limited because shipments' destinations might be countries in Europe, Asia, and/or America. The flexible function to fly to the North Asian hub led operators to be concerned about aircraft parking bays to avoid any mistake in night operations because of a slack countermeasure with overly far distances from the warehouse.

The experts ranked W&B as the second or third most important criterion, but no sub-criterion was listed in the top three critical factors. This result reflects this dimension's general importance, which requires monitoring several detailed works. Another aspect to notice is that air express companies intuitively care about connecting flights on time at the hubs, but this criterion was not highlighted on the questionnaires, possibly because frequent flights deployed from hubs decrease the possibility of missing connections.

4. Flight comparisons

Some factors that affected loading efficiency might be abstract or reverse. Practical experts proposed numerical indices to express these factors so that this study could conduct numerical analysis with the TOPSIS. Meanwhile, flight records for three types were collected courtesy of the studied company to compare the handling stabilities within the same fleet and disparities among the different fleets.

4.1. TOPSIS indices

Table 4 provides the numerical indices that can express the meanings of sub-criteria for the TOPSIS approach. Criterion C1 uses the number of ULDs with various properties to represent its three sub-criteria. Aside from C2-2 and C2-3 using the same approach, C2-1 applies the duration of completing the load plan to express its efficiency. W&B uses loaded weights and distance from CG to represent the first two sub-criteria, respectively. The discrimination of safe loading procedures with Digits 1 and 2 concerns whether or not the operation follows the company's safe or unsafe operation standards. Criterion C4 uses the appropriate quantities to represent available resources. The indices in Criterion C5 follow their definitions. Intuitively, the larger the numeral for a factor benefits more the efficiency is a positive one, and vice versa for a negative factor. The positive (benefit) subset of sub-criteria includes eight factors, i.e., C1-1, C1-2, C2-1, C2-2, C2-3, C3-1, C3-2, and C5-1; the other seven indices belong to the negative (cost) subset.

4.2. Evaluation results

With the cooperation of the studied company at TPE airport, this study collected data on three kinds of freighter flights in operations at the end of 2018, comprising 26 MD-11F flights, 18 B767F flights, and nine B777F flights. Table 5 provides the descriptive statistics of sub-criteria for samples of three evaluated aircraft types. From the average values, MD-11F flights had larger ones on C1-3, C2-3, C4-1, C4-2, C4-3, and C5-3. B767F presented larger values on C2-1, C2-2, C3-2, C4-1, C5-1, and C5-2, while B777F on C1-1, C1-2, C3-1, and C4-2. Sub-criterion C3-3 kept the same values for all flights.

Table 4. TOPSIS indices and their subset attributes

Sub-criteria		Meanings of TOPSIS indices		Subset attributes
C1-1	ULD inventory control	TI$_{1-1}$	The number of ULDs left empty after aircraft departure	P
C1-2	The choice of ULD assemblies	TI$_{1-2}$	The number of ULDs loaded onto aircraft, including the build-up, transferring, and reloaded ULDs	P
C1-3	ULDs' airworthiness	TI$_{1-3}$	The number of ULDs without airworthiness	M
C2-1	Load plan	TI$_{2-1}$	The duration between finishing the load plan and aircraft pushback	P
C2-2	The efficiency of ULDs' build-up	TI$_{2-2}$	The number of ULDs built up at TPE and loaded onto the aircraft	P
C2-3	Special ULDs	TI$_{2-3}$	The number of special ULDs loaded onto the aircraft	P
C3-1	Allowable weight limits	TI$_{3-1}$	Maximal aircraft weight allowed to be loaded	P
C3-2	Appropriateness of CG	TI$_{3-2}$	The distance between the actual CG position and its most forward allowance position	P
C3-3	Safe loading procedures	TI$_{3-3}$	Following the company's existing procedures, i.e., Digit 1 represents a better application than Digit 2	M
C4-1	Ground operations workforce	TI$_{4-1}$	The number of ground operations workers	M
C4-2	Equipment arrangement for ground operations	TI$_{4-2}$	The amount of ground equipment used	M
C4-3	Apron bay arrangement	TI$_{4-3}$	The distance between the assigned parking bay for aircraft and the bay closest to the warehouse	M
C5-1	Load factor	TI$_{5-1}$	Actual cargo load weights divided by the loadable weight capacity	P
C5-2	On-time performance	TI$_{5-2}$	Delay time in minutes for flight departure	M
C5-3	The ratio of off-load ULDs	TI$_{5-3}$	The ratio of the number of off-load ULDs with the maximal number of loadable ULDs	M

Table 5. Descriptive statistics of sub-criteria for samples of evaluated aircraft types

Type (samples)	Statistics	C1-1	C1-2	C1-3	C2-1	C2-2	C2-3	C3-1	C3-2	C3-3	C4-1	C4-2	C4-3	C5-1	C5-2	C5-3
MD-11F (26)	Max.	212.00	50.00	10.00	372.00	22.00	5.00	185510.00	597.00	2.00	15.00	8.00	5.00	1.09	34.00	1.17
	Min.	79.00	41.00	0.00	226.00	6.00	5.00	138000.00	428.00	2.00	15.00	8.00	0.00	0.71	0.00	0.33
	Avg.	150.65	46.54	3.46	275.73	15.38	5.00	161597.31	518.19	2.00	15.00	8.00	2.08	0.87	1.77	0.73
B767F (18)	Max.	201.00	43.00	6.00	340.00	42.00	3.00	125010.00	630.00	2.00	15.00	7.00	5.00	1.03	27.00	0.11
	Min.	79.00	33.00	0.00	340.00	24.00	2.00	118000.00	479.00	2.00	15.00	7.00	0.00	0.75	0.00	0.00
	Avg.	146.33	38.22	2.56	340.00	34.11	2.72	122552.78	546.00	2.00	15.00	7.00	2.50	0.92	2.56	0.03
B777F (9)	Max.	201.00	54.00	6.00	172.00	33.00	4.00	232213.00	637.00	2.00	13.00	8.00	2.00	0.93	10.00	0.85
	Min.	131.00	42.00	0.00	123.00	18.00	4.00	232213.00	452.00	2.00	13.00	8.00	0.00	0.80	0.00	0.26
	Avg.	157.00	48.78	2.67	143.22	24.89	4.00	232213.00	532.11	2.00	13.00	8.00	1.22	0.85	2.11	0.65

According to the TOPSIS processes, records of these flights could be compiled into 26 × 15, 18 × 15, and 9 × 15 matrixes for respective fleets. After normalizing these matrixes as Equation (2), weighted decision matrixes could be formed by multiplying sub-criteria weights evaluated to three freighters. Tables 6 and 7 show the maximal and minimal values for normalization and weighted matrixes for different aircraft types. In Table 6, sub-criteria C3-3, C4-1, and C4-2 had the largest values for all freighter types on average. Besides, C2-3 in MD-11F, C2-1 in B767F, and C2-3 and C3-1 kept the same level. After multiplying weights, C1-1 and C5-2, C2-1 and C5-3, and C2-1 and C5-2 revealed the highest and lowest values on average for the evaluated three fleets, respectively.

The positive and negative ideal solutions (v_j^+ and v_j^-), as shown in Table 8, could be found as the definitions in Equations (3) and (4). The absolute values of gaps between v_j^+ and v_j^- for every factor can present the distances to ideal solutions. ULDs' airworthiness (C1-3) and apron bay arrangement (C4-3) were the other two critical indices, aside from on-time performance (C5-2), at the studied air express company. The ratio of off-load ULDs also indicated a more significant difference with B767F flights. However, other highly emphasized factors' performance discrimination affected final loading efficiency on every flight, but not significantly.

Following the calculations of Equations (5) to (7), as shown in Figure 5, the closeness coefficient, C_i^+, of the best samples for MD-11F and B767F was close, but the best case of B777F was relatively far. The C_i^+ of the worst example for B767F was smaller than the values of the other two freighter types. In the MD-11F category, the average value of C_i^+ for these 26 flights was 0.76336. Flights 16 and 12, ranked first and the worst, respectively, had a gap of 0.54989 on C_i^+. The average value of B767F examples

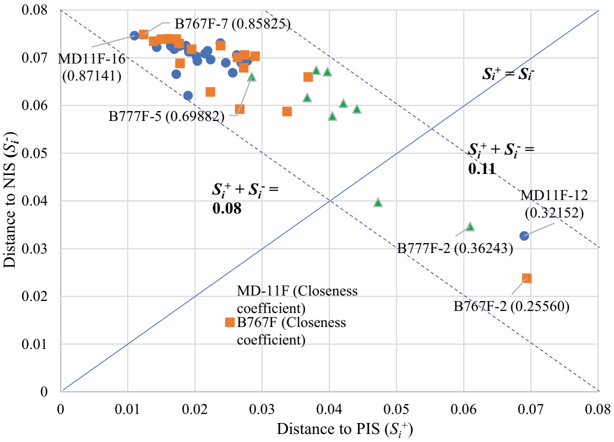

Figure 5. Distribution of distances to PIS and NIS for evaluation flights

Table 6. Descriptive statistics of normalization matrixes for evaluated aircraft types

Type	Statistics	C1-1	C1-2	C1-3	C2-1	C2-2	C2-3	C3-1	C3-2	C3-3	C4-1	C4-2	C4-3	C5-1	C5-2	C5-3
MD-11F	Max.	0.26845	0.21048	0.44194	0.26170	0.27225	0.19612	0.22461	0.22508	0.19612	0.19612	0.19612	0.39043	0.24407	0.97743	0.29722
	Min.	0.10003	0.17260	0.00000	0.15899	0.07425	0.19612	0.16709	0.16136	0.19612	0.19612	0.19612	0.00000	0.16006	0.00000	0.08256
	Avg.	0.19077	0.19591	0.15298	0.19398	0.19038	0.19612	0.19566	0.19536	0.19612	0.19612	0.19612	0.16218	0.19471	0.05086	0.18544
B767F	Max.	0.31536	0.26440	0.41603	0.23570	0.28806	0.25631	0.24040	0.27107	0.23570	0.23570	0.23570	0.42108	0.26233	0.94288	0.55470
	Min.	0.12395	0.20291	0.00000	0.23570	0.16461	0.17087	0.22692	0.20610	0.23570	0.23570	0.23570	0.00000	0.19144	0.00000	0.00000
	Avg.	0.22959	0.23502	0.17720	0.23570	0.23396	0.23258	0.23568	0.23493	0.23570	0.23570	0.23570	0.21054	0.23435	0.08924	0.12327
B777F	Max.	0.42218	0.36796	0.56695	0.39859	0.43474	0.33333	0.33333	0.39698	0.33333	0.33333	0.33333	0.48507	0.36155	0.80845	0.42091
	Min.	0.27515	0.28619	0.00000	0.28504	0.23713	0.33333	0.33333	0.28169	0.33333	0.33333	0.33333	0.00000	0.31158	0.00000	0.12627
	Avg.	0.32976	0.33238	0.25198	0.33190	0.32788	0.33333	0.33333	0.33161	0.33333	0.33333	0.33333	0.29643	0.33295	0.17067	0.32153

Table 7. Descriptive statistics of weighted decision matrixes for evaluated aircraft types

Type (samples)	Statistics	C1-1	C1-2	C1-3	C2-1	C2-2	C2-3	C3-1	C3-2	C3-3	C4-1	C4-2	C4-3	C5-1	C5-2	C5-3
MD-11F	Max.	0.02322	0.01402	0.02188	0.02110	0.01598	0.01474	0.01463	0.01621	0.01200	0.01456	0.01240	0.02241	0.02033	0.06707	0.01122
	Min.	0.00865	0.01149	0.00000	0.01282	0.00436	0.01474	0.01089	0.01162	0.01200	0.01456	0.01240	0.00000	0.01333	0.00000	0.00312
	Avg.	0.01650	0.01305	0.00757	0.01564	0.01118	0.01474	0.01275	0.01407	0.01200	0.01456	0.01240	0.00931	0.01622	0.00349	0.00700
B767F	Max.	0.02314	0.01908	0.02232	0.02143	0.01725	0.01499	0.01763	0.01716	0.01636	0.01824	0.01380	0.02318	0.02169	0.06469	0.02395
	Min.	0.00909	0.01464	0.00000	0.02143	0.00986	0.00999	0.01664	0.01305	0.01636	0.01824	0.01380	0.00000	0.01583	0.00000	0.00000
	Avg.	0.01685	0.01696	0.00951	0.02143	0.01401	0.01360	0.01728	0.01487	0.01636	0.01824	0.01380	0.01159	0.01938	0.00612	0.00532
B777F	Max.	0.02967	0.02243	0.03488	0.03436	0.02655	0.02081	0.02329	0.02440	0.02429	0.02194	0.02022	0.03580	0.02911	0.05614	0.01813
	Min.	0.01933	0.01745	0.00000	0.02457	0.01448	0.02081	0.02329	0.01732	0.02429	0.02194	0.02022	0.00000	0.02509	0.00000	0.00544
	Avg.	0.02317	0.02026	0.01550	0.02861	0.02003	0.02081	0.02329	0.02038	0.02429	0.02194	0.02022	0.02188	0.02681	0.01185	0.01385

Table 8. Positive and negative ideal solutions for three aircraft types

Factor	Subset	MD-11F			B767F			B777F		
		v_j^+	v_j^-	Gap	v_j^+	v_j^-	Gap	v_j^+	v_j^-	Gap
C1-1	P	0.02322	0.00865	0.01456	0.02314	0.00909	0.01404	0.02966	0.01933	0.01033
C1-2	P	0.01401	0.01149	0.00252	0.01907	0.01464	0.00443	0.02243	0.01744	0.00498
C1-3	M	0	0.02187	–0.02187	0	0.02231	–0.02231	0	0.03488	–0.03488
C2-1	P	0.02109	0.01281	0.00827	0.02143	0.02143	0	0.03436	0.02457	0.00978
C2-2	P	0.01598	0.00435	0.01162	0.01725	0.00985	0.00739	0.02655	0.01448	0.01206
C2-3	P	0.01474	0.01474	0	0.01499	0.00999	0.00499	0.02080	0.02080	0
C3-1	P	0.01463	0.01088	0.00374	0.01762	0.01663	0.00098	0.02328	0.02328	0
C3-2	P	0.01621	0.01162	0.00458	0.01716	0.01304	0.00411	0.02440	0.01731	0.00708
C3-3	M	0.01199	0.01199	0	0.01636	0.01636	0	0.02429	0.02429	0
C4-1	M	0.01456	0.01456	0	0.01823	0.01823	0	0.02194	0.02194	0
C4-2	M	0.01240	0.01240	0	0.01379	0.01379	0	0.02021	0.02021	0
C4-3	M	0	0.02241	–0.02241	0	0.02318	–0.02318	0	0.03580	–0.03580
C5-1	P	0.02033	0.01333	0.00699	0.02169	0.01583	0.00586	0.02911	0.02508	0.00402
C5-2	M	0	0.06707	–0.06707	0	0.06468	–0.06468	0	0.05614	–0.05614
C5-3	M	0.00311	0.01121	–0.00810	0	0.02394	–0.02394	0.00543	0.01813	–0.01269

Table 9. Comparisons between the best and the worst flights

Factor	Subset	Trans-Pacific services (MD11F)					Regional collection services (B767F)					Cross-continental collection services (B777F)				
		Factor priority	Flight 16 (best)		Flight 12 (worst)		Factor priority	Flight 7 (best)		Flight 2 (worst)		Factor priority	Flight 5 (best)		Flight 2 (worst)	
			Raw value	Normalization	Raw value	Normalization		Raw value	Normalization	Raw value	Normalization		Raw value	Normalization	Raw value	Normalization
C1-1	P	1	***182***	0.23045	146	0.18487	4	***173***	0.27143	91	0.14277	5	134	0.28145	***144***	0.30245
C1-2	P	8	***50***	0.21048	45	0.18943	6	39	0.23980	***40***	0.24595	13	42	0.28619	***53***	0.36114
C1-3	M	14	2	0.08838	***0***	0	14	***0***	0	4	0.27735	10	**1**	0.09449	2	0.18898
C2-1	P	3	***275***	0.19346	248	0.17446	1	340	0.23570	340	0.23570	1	148	0.34297	***151***	0.34992
C2-2	P	12	***15***	0.18562	10	0.12374	10	31	0.21261	***38***	0.26062	12	18	0.23713	***30***	0.39521
C2-3	P	4	5	0.19611	5	0.19611	12	2	0.17087	***3***	0.25630	9	4	0.33333	4	0.33333
C3-1	P	9	***185,510***	0.22461	160,000	0.19372	5	121,010	0.23271	***123,010***	0.23655	6	232,213	0.33333	232,213	0.33333
C3-2	P	6	526	0.19830	***581***	0.21904	9	**534**	0.22976	479	0.20610	11	***558***	0.34774	545	0.33964
C3-3	M	11	2	0.19611	2	0.19611	7	2	0.23570	2	0.23570	4	2	0.33333	2	0.33333
C4-1	M	5	15	0.19611	15	0.19611	3	15	0.23570	15	0.23570	8	13	0.33333	13	0.33333
C4-2	M	10	8	0.19611	8	0.19611	11	7	0.23570	7	0.23570	14	8	0.33333	8	0.33333
C4-3	M	13	0	0	0	0	13	***2***	0.16843	3	0.25264	3	1	0.24253	1	0.24253
C5-1	P	2	***1.08653***	0.24407	0.75202	0.16893	2	0.98758	0.25080	***1.03093***	0.26181	2	0.79929	0.31157	***0.92749***	0.36155
C5-2	M	7	***0***	0	34	0.97743	8	***0***	0	27	0.94288	7	***0***	0	10	0.80845
C5-3	M	15	***0.91304***	0.23116	1	0.25318	15	***0***	0	0.02857	0.13867	15	0.80851	0.39986	***0.25532***	0.12627

was 0.72961 on C_i^+. Flights 7 and 2 were the best and the worst among 18 flights, with a 0.60265 gap of C_i^+. Among nine B777F flights with an average value of 0.57372 for C_i^+, Flights 5 and 2 had an enormous gap of 0.33639.

Table 9 compares the best and the worst flights for the three freighter types. The better values following the factor attributes are highlighted in bold with italics. Although the scales of different indices appear to have significant gaps, the TOPSIS was conducted for normalization in the first step. From the normalized values of all indices, it is found that the on-time performance (C5-2) gap between the best and the worst flights appeared to be significant compared to the normalization values regardless of any service type. Although this factor's weight was not the most critical, its performance played a dominant role, even when accounting for multiple effects from consequences for all sub-criteria with this company.

In summarizing the findings on factor performance for the studied company, on-time performance was the dominant factor in scrutinizing the reviewed company's loading operation efficiency. The other two significant factors commonly affecting all freighter types were ULDs' airworthiness and apron bay arrangement. They all belonged to the negative set, i.e., the more reduced, the better. Their important ranks fell behind seven, except for parking distances for B777F flights. These three factors should be better managed, with considerable variances for the studied company at TPE.

Meanwhile, the reviewed company could not control these three factors entirely. Flight departure punctuality depended greatly on many outsourcing units' cooperation with ground handling operations, except for necessary document planning works. Of course, the entire procedure might affect export operations' on-time performance, from the cut-off times of receiving downtown to the close of the last door of the aircraft holds. The studied company was required to diagnose critical points that need improvement.

The airport authority handles apron bay arrangements for aircraft standings at TPE. Scheduled flights usually have a fixed parking duration. The arrangement unit of aircraft parking positions preferred to follow the previous plan. However, extraordinary events affecting the arrival status on any flight sometimes could disturb the initial planning. The studied company seemed unable to receive preferred aircraft parking positions for its flights.

Higher ratios of ULDs without airworthiness revealed that ground handling operations might be more careful in the ramp-side works and ULD movements. Air express preferred using containers for documents and parcels with light density to reduce expenses in the build-up handlings. The monitor units of ULD control should realize the reasons for this phenomenon. It might be responsible for TPE's operations and upstream airports that ULDs have ever cycled around.

Conclusions and suggestion

Export handlings of international air express require rapid reflection on the status of shipment pickup. Many details in the delivery process affect the transport chain, including airport operations, regardless of hubs or spokes. Loading operation efficiency at airports, representing the efficacy of interfaces between landside and airside, links the whole connection of tasks across the global network. Previous efforts rarely discussed the support role and importance from spoke airport's perspective. This research sufficiently disclosed the practical functions to support different geographical hubs. This study has examined the factors influencing the loading efficiency of freighter operations at a spoke airport, TPE, that operates feeding services to trans-Pacific, regional, and cross-continental hubs. Airport loading operation efficiency presents abstract meanings to classify affected factors hardly. This study has comprehensively investigated and measured the weights of factors through practical experts using a rank pair-wise comparison (RPC) approach. The cargo load planning dimension was ranked most important. Load factor and load planning consistently were rated highest among 15 critical elements regardless of freighters' service properties. Long-haul services to the North American hub were most concerned with inventory control of ULDs. Regional feeder services attached importance to the ground operations workforce as well. Feeder services for cross-continental deliveries also cared about apron bay arrangement. These findings can assist the studied company in reviewing the airport resource deployment to improve efficiency and extraordinary countermeasure situations.

Furthermore, this study also combined the TOPSIS approach to compare selected flights' loading efficiency with three freighter types. Based on the suggested indices for 15 sub-criteria, the results between the best and the worst flights revealed a noticeable gap in closeness coefficients, but only a few flights appeared extraordinary. This company might be able to handle the critical factors with a caring attitude to reduce the significant influence of evaluated flights. However, on-time performance, ULDs' airworthiness, and apron bay arrangement played commonly dominant roles in distinguishing between these flights' efficiency. On-time performance is a synthesis index to compile many results in export operation procedures. Although it did not attract respondents' higher notice of the importance, this study found its remarkable discrimination from the evaluated cases. The studied company could further examine the reasons for the larger variances in its operating flights to improve their performance, e.g., whether too many ULDs without airworthiness generated longer delays or whether far parking positions of aircraft made it more difficult for the ground handling team to provide in-time support. These findings also provide express companies a valuable reference to concern those factors that cannot be controlled to improve efficiency. Sufficient coordination with the relative units at airports can increase the opportunities to enhance operational efficiency.

Loading operation efficiency is a topic that needs to be monitored long-term with cargo airlines. This study has identified factors affecting an air express company at a spoke airport. The same functional units can follow our procedures to implement proposed measures and improve operations. This assessment can further examine shipment quantity and property changes according to demand characteristics, e.g., peak seasons, weekends, or specific festivals.

This study focused only on the export operations of a spoke airport in the international air express context. Consolidation and redistribution are essential functions in ensuring remarkable air express performance. Hub airports play a critical role in developing these functions, as measures of their loading efficiency are supposed to differ from feeding airports. It would be valuable to clarify the factors affecting transferring efficiency at hubs and evaluate practical cases like the one examined in this study. The proposed evaluation methods can be applied to measures for other freighter flights, companies, and airports.

In the segmentation of air cargo operations, combination and all-cargo carriers operate scheduled direct flights with dedicated freighters for international freight markets. Freight shipments usually are stored in warehouses to await customs inspection. The attributes for measuring loading operation efficiency on freight operations must differ with air express. Future research on this topic may require slightly changing the evaluated factors based on their operation properties.

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Author contributions

Hua-An Lu was responsible for topic conceptualization, methodology, formal analysis, validation, and writing. Chi-Sheng Chung was responsible for compiling practical knowledge, investigation, and data management.

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