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A New Design of Sydney's Frontport Check-in System

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Abstract: This paper proposed a scheme design for Sydney's frontport check-in system, which completes check-in and baggage drop-off at Sydney's Circular Quay, and transports the baggage to Sydney Kingsford Smith Airport by waterway, and provided a strengths, weaknesses, opportunities and threats (SWOT) analysis of Sydney's frontport check-in system. Using the process method of quality management, the frontport check-in process was divided into three sub-processes: baggage consignment, baggage packing and transportation, and airport baggage handling. The eight key elements of each sub-process such as input, output, resources, and methods, etc. were discussed, the key factors influencing the cost of baggage transportation were analyzed, and the cost control measures such as adopting economic speed, reducing fuel consumption of the main engine, improving the ship loading rate, and raising loading and unloading efficiency were proposed. At the same time, two different types of baggage transportation ships and other parameters that affect the cost such as the number of berths, ships, lifting machineries, and the yard area were analyzed and calculated through calculation cases. This scheme is a beneficial addition to the existing in-town check-in system.

Keywords: check-in; baggage drop-off; SWOT; scheme; process; cost

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1. Introduction

In-town check-in (ITCI for short) means that passengers can check in their baggage outside the airport and in designated places in the city. It reduces the burden of passenger travel, saves passengers' time in queues and check-in at the airport, improves the customer experience, and achieves "freehand travel"; on the other hand, it also avoids airport congestion, and expands the accessibility and service area of the airport and stimulates the use of public transportation.

At present, the ITCI system is mainly focused on air-rail/air-road intermodality. The research on the structural framework of air-rail/air-road intermodality system, appropriate baggage collection locations, passenger demand prediction model, baggage consignment mode, etc. has been carried out, and applied in some airports such as Hong Kong, Switzerland, and Japan, and has achieved certain results.

Air-rail intermodality has the high requirements for both infrastructure and technology, and high investment is required in the early stages, so it can only be feasible with a large number of passengers. Highway connectivity is better, but the cost is higher due to the limited number of passengers and the congestion in the city. Therefore, air-waterway intermodality can be developed by airports which have waterway transportation conditions, to reduce urban congestion and air pollution, and give full play to the advantages of low cost of waterway transportation. The main research scope of ITCI system can be expanded from air-rail/air-road intermodality to air-waterway intermodality, so as to further improve the research on the ITCI system.

In this paper, Sydney's Circular Quay and Kingsford Smith Airport were taken as the research objects. The strengths, weaknesses, opportunities and threats (SWOT) of implementing Sydney's frontport check-in system through air-waterway intermodality was analyzed, the waterway transportation scheme of Sydney's frontport check-in system was developed, including baggage consignment, baggage packing and transportation and airport baggage handling, etc., and some measures were put forward such as using economic speed, improving the loading rate of ships, loading and unloading efficiency, and reducing the yard area and the number of berths and ships on the route, etc. to decrease the transportation cost of baggage.

1.1. Research Status of ITCI Systems

So far, the importance of ITCI has been widely recognized by academic circles and most of the current research focus on air-rail intermodality systems. Stark, J. et al. (2008) studied the issue of high quality seamless intermodality for passenger travel using different transportation hubs (such as railway stations, airports, and ports), and analyzed the relevant passenger services to support intermodality. These services include intermodal baggage handling, such as door-to-door service, check-in at local train or bus stations, pre-check-in, and self-check-in; these services all provide baggage transportation services [1]. Liu, W. and Ouyang, J. (2015) built the logical architecture framework of the air-rail intermodality system based on the function of air-rail intermodality, which contains seven subsystems. This paper focused on the integrated ticketing system and baggage handling system, and considered that baggage handling system is a big advantage of air-rail intermodality. In order to ensure transportation safety, the baggage undergoes a second security check after arriving at the airport [2].

Tam, M.L. (2007) believes that air-rail intermodality can relieve road traffic congestion. Based on the historical data of the Hong Kong International Airport, a multinomial logit model has been established. The analysis results show that the fare of the Hong Kong Airport Express is the key to whether passengers will choose to use it. In addition, the number of passengers and baggage will also have an impact. Hong Kong's successful experience lies in discounted fares and the complementary services exclusively for airport railway users, including the free connecting services, in-town check-in service, and porter service [3].

Van Zundert, H.C.W. (2010) believes that baggage check-in has multiple forms of service, and the four-stage method can be used to analyze the most suitable location for passenger baggage transfer. The four stages include environment scanning, developing concepts, evaluating concepts, improving, and detailing. Based on this, a logistics network with four service areas was designed to perform baggage collection services. Different areas use different logistics methods and calculate the cost of baggage collection in different areas. The results show that the best service depends on the comparison of service charges and investment. Although baggage check-in service is necessary, the safety of baggage transportation and service price still needs further study [4].

Some scholars' research takes the railway station as an ITCI service point; for example, Yu, M. (2008) used the process identification method of quality management to decompose and study baggage delivery service of air-rail intermodality. She divided the baggage delivery service into three types: remote baggage delivery service, no remote baggage delivery service, and compromise strategy, and evaluated the process, prerequisites, and implementation possibilities of different types of baggage delivery services [5]. Yeung, H.K. and Marinov, M. (2017) analyzed the current baggage transfer services in some other countries or regions, such as Hong Kong, Switzerland, and Austria, and also mentioned the British Virgin Bag Magic and Bangkok ITCI services that were stopped due to environmental issues, and then conducted an analysis of the technical characteristics of Newcastle Central Station, and found several baggage collection points that may be suitable [6]. Brice, D. et al. (2015) proposed a newly designed system to carry traveler's baggage between the Haymarket in Newcastle-Upon-Tyne and Newcastle Airport by using a pendulum freight train. The new system was simulated and verified with SIMUL8 [7]. Therefore, there is a cooperative relationship that exists between airlines and railways, which will promote the integration of airlines and railways, not only to meet customer needs but also to solve airport congestion. In addition, air-rail intermodality involves multiple stakeholders, all of whom have their own motives [8–11].

However, some scholars believe that air-rail intermodality is difficult. Grimme, W. (2007) summarized the prerequisites for the implementation of the German air-rail intermodal transport, as well as the characteristics and advantages of this service, and specifically explained that seamless travel can be provided in the form of integrated ticketing and baggage handling. At the same time, he also believes that the air-rail intermodal transport has high requirements for infrastructure and technology, and the initial investment is large. Only a large number of passengers using the service can make the air-rail multimodal transport feasible [12].

Lythgoe, W.F. and Wardman, M. (2002) researched the demand forecasting model for connecting railways to airports, and considered the main disadvantages of air-rail intermodality to be that the connectivity is not as good as that provided by roads, and outbound passengers are far more sensitive to the service fare and service quality to and from the airport by rail than inbound passengers [13]. Noordzij, C. (2012) believes that the four standards for the successful implementation of remote CI (check-in) and BD (baggage drop-off) services are passenger use, aviation industry cooperation and support, the functionality of CI and BD, and the availability of space. On this basis, the framework is designed to assess a service location's feasibility—and to determine a "best" functional process. It was concluded that trains are most likely unsuitable for using this service, while P3 services (long-term parking lot in Schiphol) and door-to-door pick-up service can only be determined by estimation [14].

Toal, J. and Marinov, M. (2019) studied the realizing check-in system through trains, but major changes in this system will cause the price to rise, which will prevent passengers from choosing this method. Then he presented four design schemes that meet the design standards, and analyzed their limitations, and finally concluded that the potential for an on-board check-in and bag drop facility by train is realistic, and the cost can be reduced [15]. There are still some problems that hinder passengers from using the air-rail service, including the form of baggage handling, coordination of timetables, compensation for baggage delays, and whether they can obtain door-to-door services [16–19]. In summary, the existing literature mainly focused on realizing a ITCI system through rail transit.

1.2. Comparison of Existing ITCI Systems

Airports in some countries or regions have adopted different strategies to implement ITCI systems according to their own situation, but some of them failed, such as Frankfurt Airport in Germany, Amsterdam Airport in Netherlands, Heathrow International Airport in the UK, etc., while some have been more successful, such as Hong Kong International Airport, Narita Airport in Japan, Seoul Airport in South Korea, Taoyuan Airport in Taiwan, Geneva Airport in Switzerland, Los Angeles International Airport in United States, and so on, as listed in Table 1 [20–25].

Currently, almost all ITCI systems are connected to the airport through metro rapid transit, trains, and buses, and very few are transported by waterways. For example, passengers can check-in themselves and their baggage at the cruise terminals in Los Angeles. In addition, Los Angeles can also provide this service by road. The service locations include the convention center and two main bus terminals.

Table 1. Comparison of in-town check-in (ITCI) systems at different airports.

Item		Airports					
		Hong Kong	Narita	Seoul	Taoyuan	Geneva	Los Angeles
Service tools	Rail or road transportation	√	√	√	√	√	√
	Waterway transportation						√
Service area	Baggage drop-off service outside the airport	√	√	√	√	√	√
	Security check			√	√		
	Entry and exit inspection			√	√		
Service objects	Specific airlines	√	√	√	√	√	√
Service hours	In the same day			√			√
	One to two days in advance	√	√		√	√	
Restrictions on baggage	Limited	√	√	√	√	√	
	Unlimited						√
Special regulations		√			√		√

In conclusion, the current research on ITCI system mainly includes the system model, calculation method, service mode, etc., which is mainly applied to air-rail intermodality, with both successful cases and failure cases. However, there are few reports on air-waterway intermodality, so the design of an ITCI system for air-waterway intermodality is exploratory.

2. SWOT Analysis of Sydney's Frontport Check-in System

Surrounded by the sea on three sides and with developed waterway transportation, Sydney has the unique geographical advantage of air-waterway intermodality. Therefore, in addition to connecting Kingsford Smith Airport by train or road, Sydney can also connect the airport by waterway. Sydney's Circular Quay is the main waterway transport hub and a large interchange station for ferries, buses, and trains.

Currently, Sydney's train network consists of nine different train lines, and three of these train lines and multiple bus lines can reach Circular Quay. There are many famous attractions around Circular Quay, such as the Sydney Opera House, Harbour Bridge, the Royal Botanic Gardens, and so on. There are hotels and inns in and around the area, and the passenger flow is large. Therefore, setting up a check-in system at Circular Quay that connects to Kingsford Smith Airport by waterway will realize the airport service function previa, which is convenient for passengers to achieve "freehand travel" after going through a check-in and baggage drop-off service. As a basic and public resource, Circular Quay is closely combined with aviation to bring a new mode of transportation organization, which can optimize the allocation of aviation resources, increase the attractiveness of the airport to passengers, enhance the image and service quality of airlines, help the development of Sydney's transportation and economy, and strengthen the competitiveness of the entire city.

The Sydney's frontport check-in system refers to the establishment of a check-in system at Sydney's Circular Quay, which enables the airport service function to be moved to Circular Quay, so that passengers and baggage can be separated in advance, and the baggage can be transported to Kingsford Smith Airport by waterway.

The analysis of strengths, weaknesses, opportunities and threats (SWOT) of implementing Sydney's frontport check-in system through air-waterway intermodality are listed in Table 2.

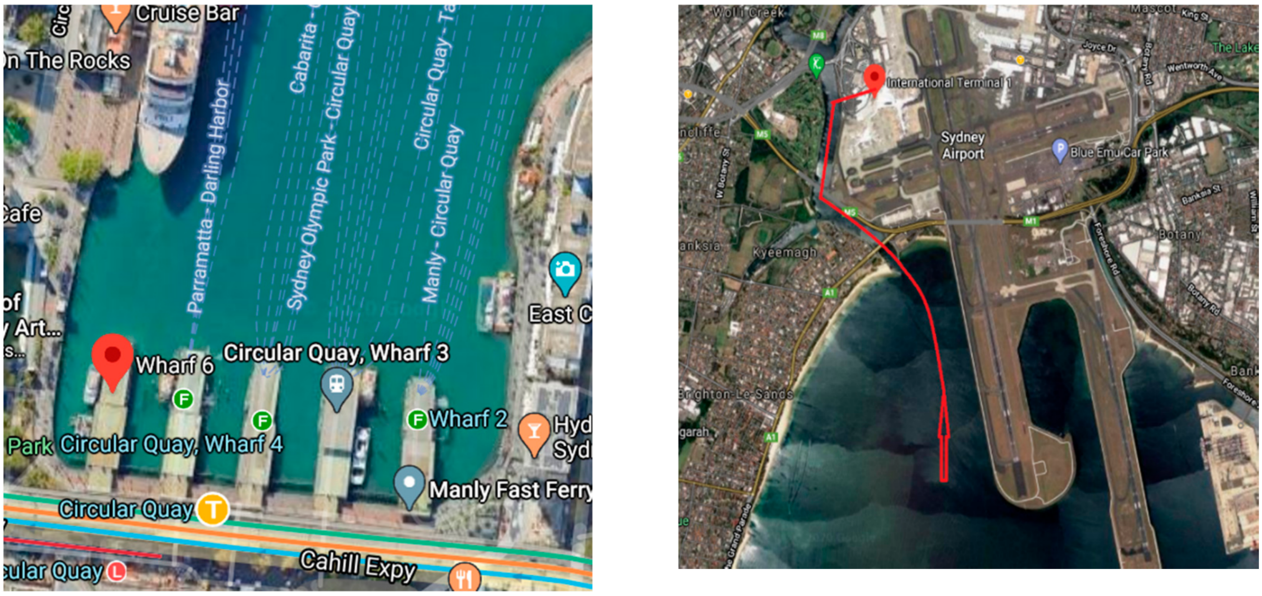
Table 2. Strengths, weaknesses, opportunities and threats (SWOT) analysis of frontport check-in system.

Strengths	Weaknesses
1. Large volume 2. Little pollution 3. Low energy consumption 4. No traffic jams, no stop on the way, can go directly to the airport wharf 5. Modification difficulty is small 6. Low initial investment 7. Low technical requirements 8. Lower operating and maintenance cost 9. Available existing infrastructure (wharfs, berths, etc.)	1. Long distance 2. Slow speed 3. Fewer service locations 4. Small coverage area 5. A long time is needed in advance (the interval between the check-in time and the flight departure time)
Opportunities	**Threats**
1. Make full use of geographical advantages 2. Passengers have the opportunity to appreciate the sea scenery 3. The rapid growth of service demand	1. Affected by the weather

It can be seen from Table 2 that although both waterway transportation and rail transportation can provide the same services to the same customer group, the former has irreplaceable advantages. The most prominent advantage is that there is no traffic congestion and no stop in waterway transportation. It is not necessary to transform the existing railway system in Sydney, which can avoid traffic chaos, technical difficulties, and high costs. At the same time, it can also make full use of the geographical advantage of Sydney being surrounded by sea on three sides to open up the voyage route from Circular Quay to Kingsford Smith Airport, make maximum use of the existing wharfs, berths and ships, realize mixed loading of passengers and cargos, and enhance passenger flows. The increase of passenger flows can also effectively drive the economy and tourism of Sydney's central business district around Circular Quay. According to the statistical data of the number of departing passengers from 2009 to 2018 [26,27], it is predicted that by 2025, the number of passengers will reach an annual growth rate of 4.07%. The statistical data of Kingsford Smith Airport display that the amount of baggage will be a very large based on an average of 1.2 pieces of baggage per passenger. Faced with the huge market demand and the superior location of Sydney, the S-O (Strengths—Opportunities) strategy should be chosen to give full play to the advantages and competitive potential of waterway transportation, grasp the opportunities, and eliminate or weaken its disadvantages, which is the key to the success of Sydney's frontport check-in system scheme.

3. Scheme Design of Frontport Check-in System

The scheme of Sydney's frontport check-in system starts with passengers arriving at Circular Quay for check-in, and ends with baggage arriving at the airport wharf and finally entering the airport baggage handling (Circular Quay and the airport wharf are shown in Figure 1).



(**a**) (**b**)

Figure 1. The starting and ending points of the frontport check-in system: (**a**) Wharf 6 of Circular Quay is the starting point, hereinafter referred to as Circular Quay; (**b**) The airport wharf of the Cook River is the ending point, hereinafter referred to as the airport wharf.

It is different from traditional air service in which passengers need to bring their baggage to the airport to check in. The early separation between passenger and baggage can improve the comfort and convenience of passenger, but significantly extend the baggage service chain.

Circular Quay would not only provide check-in services, but would also carry ordinary passengers who bring their own baggage to the airport. Passengers who use the frontport check-in system can take a ship for free at any time with a payment voucher; other passengers can also board the ship at their own expense. This can fully implement the mixed loading of passengers and cargo or LTL (less than truckload) cargo transportation, which can maximize the loading rate of ships. Similarly, passengers arriving at the airport can also choose to reach Circular Quay by ship, but the airport wharf would not provide a baggage check-in service. The flow chart of the scheme is shown in Figure 2.

The scheme of frontport check-in system assumed conditions is shown as the following:

1. The starting point of the scheme is at wharf 6 of Circular Quay, and the ending point is at the airport wharf of the Cook River that connects to terminal 1 of Sydney Kingsford Smith Airport (as shown in Figure 1).
2. The airport wharf is located at the right end of the airport's runway No. 34. This wharf does not provide check-in and baggage drop-off services.
3. The ship is divided into passenger and cargo areas.
4. The structural dimensions of the baggage container are designed according to the requirements of the single baggage, the size of the ship hatch, and the space of the storage compartment.
5. The service time is 6:00–20:00, which is only applicable on the day of the flight, and the check-in time is at least 4 h before the departure time.

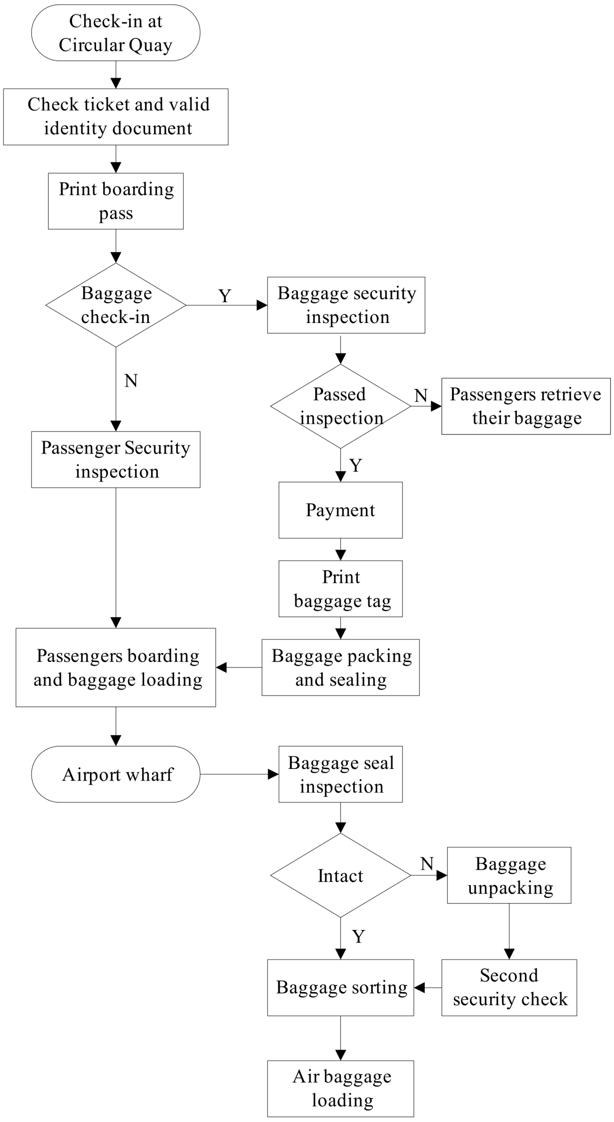


Figure 2. The flow chart of the scheme.

3.1. Analysis of the Implementation Process of the Scheme

The implementation process of frontport check-in system can be divided into three sub-processes: baggage consignment, baggage packing and transportation, and airport baggage handling. Because the implementation of frontport check-in system involves many participants and management links, the whole process becomes very complicated, so the implementation process of the scheme needs to be analyzed in-depth, and the aviation quality management system standards are used for research here.

The aviation quality management system standard (AS9100:2016) is the standard for the aerospace industry based on the requirements of the ISO9001 quality management system, and now widely used in aviation industry enterprises. The "process method" of the quality management system is used to analyze and manage the interrelated processes in the scheme as a system, which helps the implementation, evaluation, management, and improvement of the scheme, and achieves the expected results effectively and efficiently. The process method clarifies the various processes in the system and the interaction among them by analyzing the eight key elements of each process. These eight key elements of the process include inputs, outputs, resources, owners, implementers, evaluation indicators, risks and opportunities, and main methods, procedures and technologies. Among them, input and output are two endpoints of the process, and the output of one process is usually the input of another process. Two or more interconnected and interacting continuous processes can also belong to one process, out of which a gapless process system is formed. Therefore, according to the requirements of the aviation quality management system standard (AS9100:2016), the analysis of implementation process of the frontport check-in system based on the process method is shown in Figure 3.

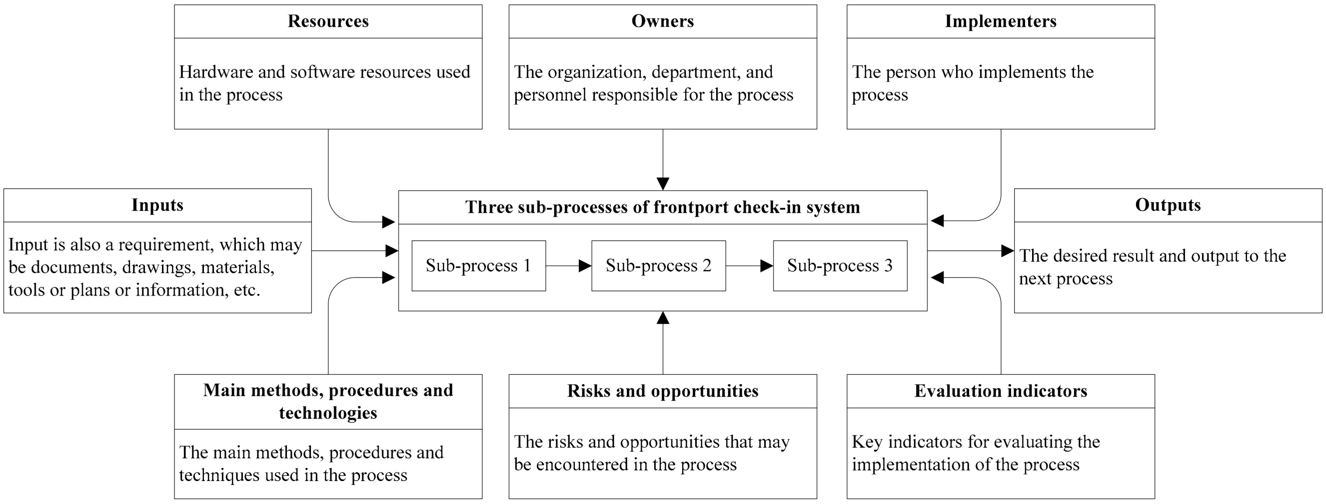


Figure 3. The analysis of implementation process of the frontport check-in system.

Figure 3 shows that the output of sub-process 1 is the input of sub-process 2, and the output of sub-process 2 is the input of sub-process 3. The sub-processes are interlinked to form the frontport check-in system. The specific contents in the eight key elements of the process method of quality management have some similarities in the 3 sub-processes of the frontport check-in system, but there are also some differences. For example, the inputs of sub-process 1 is passenger information and baggage; the input of sub-process 2 is the security-checked baggage, and the input of sub-process 3 is the baggage containers delivered to the airport. These steps are manifested in different stages for the baggage.

3.1.1. Sub-process 1: Baggage Consignment

Sub-process 1 refers to passengers bringing their baggage to Circular Quay and check-in, as shown in Figure 4.

In Figure 4, baggage consignment sub-process is composed of three modules: identity confirmation, baggage security inspection, and fees payment. It has the functions of handling the boarding pass, baggage tag, payment voucher for baggage consignment and electronic information, etc. The baggage consignment sub-process is completed at the check-in area of Circular Quay, which is the starting point of the frontport check-in system. The check-in area consists of check-in counters, baggage yard, conveyor belts and baggage containers, and so on. Its main functions include check-in, baggage collection and transportation, passenger transportation, recovery of empty baggage containers, and LTL transportation. The main functions of airport wharf are basically the same as Circular Quay, but there is no check-in function.

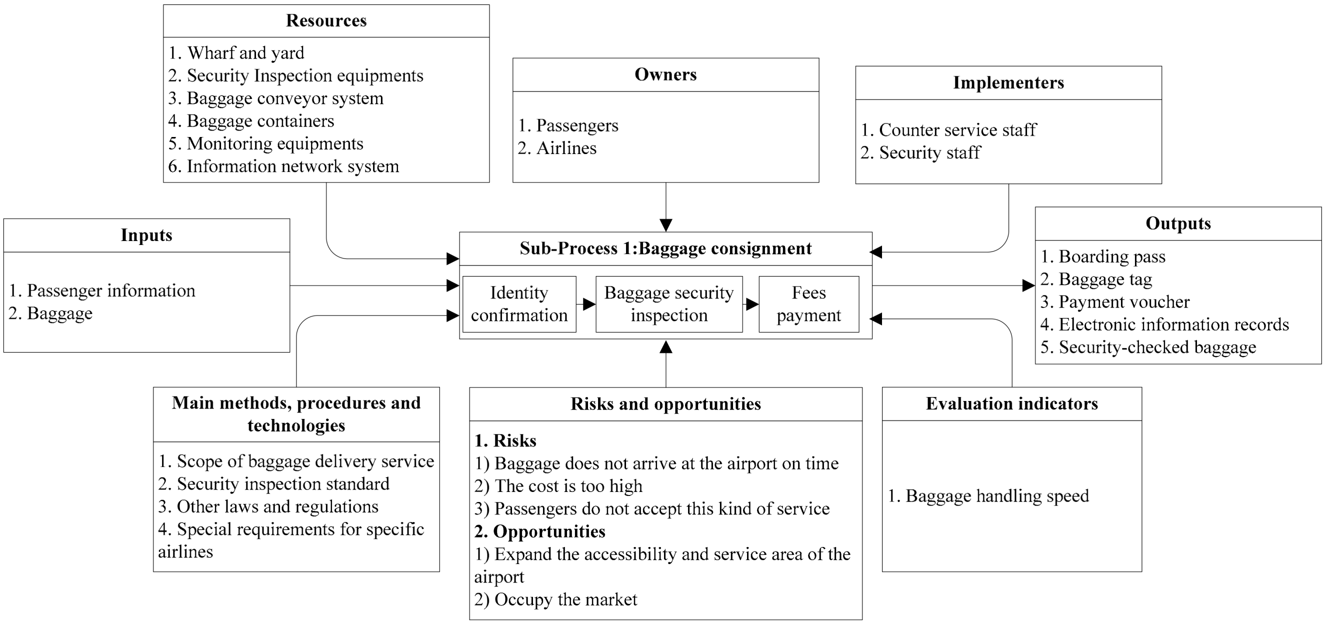


Figure 4. Baggage consignment sub-process.

The specific modules are analyzed as follows:

(1) Identity confirmation

Passengers can arrive at Circular Quay at least 4 h before the flight departure time on that very day, and check in at the check-in counter after confirming their identity information.

(2) Baggage security inspection

After passengers hand in their baggage, the baggage needs to go through security inspection. The baggage confirmed as safe will be accepted by the frontport check-in system and transported to the baggage yard through the conveyor belt, and sorted according to the flight information, and then wait for packing. The baggage confirmed as being unsafe would be rejected or subject to the next step of inspection.

(3) Fees payment

Passengers can pay the baggage consignment fee after the baggage is accepted, and leave after printing the boarding pass, baggage tag, and payment voucher. Passengers can track the status of the baggage at any time through the internet. They can also take a ship to the airport wharf at any time with the payment voucher.

3.1.2. Sub-Process 2: Baggage Packing and Transportation

Sub-process 2 is the follow-up link of sub-process 1, it refers to putting the sorted baggage into the baggage container and loading it onto a ship, then transporting it to the airport wharf. This sub-process is shown in Figure 5.

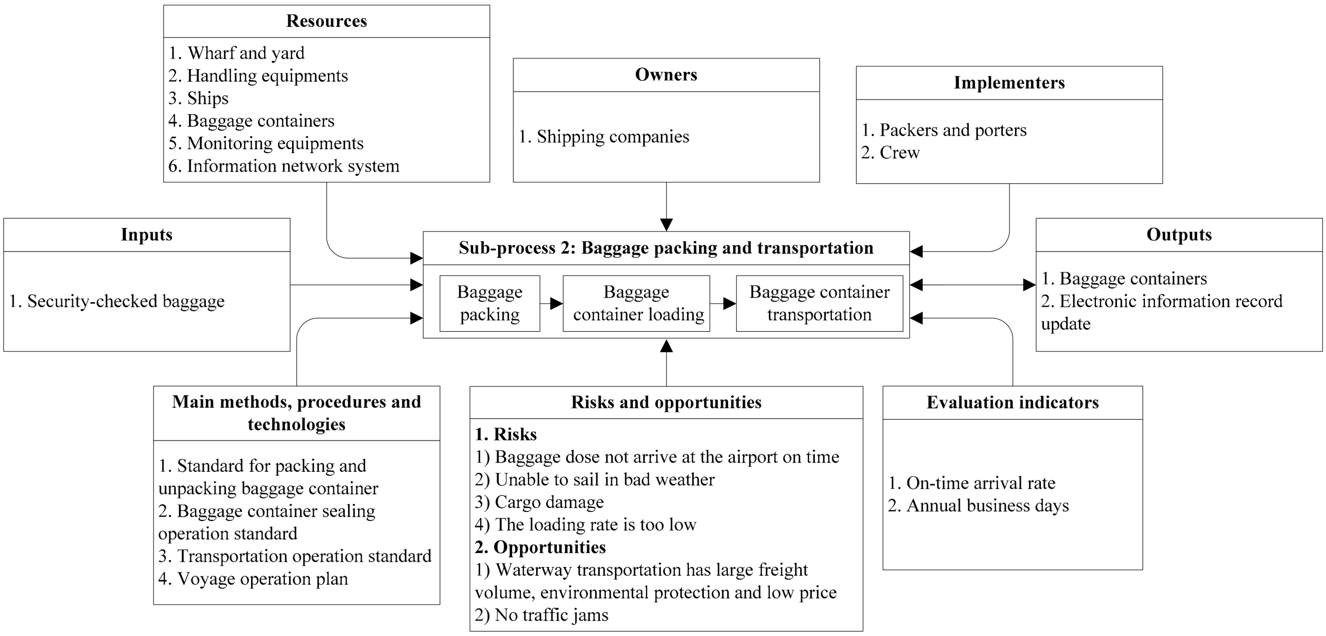


Figure 5. Baggage packing and transportation sub-process.

As can be seen from Figure 5, the sub-process of baggage packing and transportation consists of three modules: baggage packing, baggage container loading, and baggage container transportation. It has the function of transporting security-checked baggage by waterway to the airport wharf and updating the relevant electronic information record.

The specific modules are analyzed as follows:

(1) Baggage packing

In order to avoid the dropping of baggage caused by the wind, waves, and acceleration or deceleration of ships during waterway transportation, and also load and unload the baggage conveniently, the baggage has to be manually placed in a special container, and for safety reasons, the baggage container should be lead sealed.

(2) Baggage container loading

Baggage containers would be loaded on the conveyor belt between the berth and the ship, and sent directly to the baggage yard. In order to ensure the voyage operation plan such as the loading efficiency, ship mooring time and the daily shipping frequency, the baggage containers should wait at the berth until the ship arrives.

(3) Baggage container transportation

The ship departs from Circular Quay and has no stopover on the way to the airport wharf. After unloading the baggage containers and disembarking passengers, loading the empty baggage containers and embarking passengers to be returned, the ship then sails back to Circular Quay to complete a round-trip voyage (That is, from Circular Quay to the airport wharf, then back to Circular Quay). The ship transportation process can be divided into 4 stages.

Stage 1: Ship moors at Circular Quay to complete unloading of empty baggage containers and loading of heavy baggage containers, as well as the disembarking and embarking of passengers (T_c is the mooring time of the ship at Circular Quay).

Stage 2: Ship departs from Circular Quay, and then reaches the airport wharf (T_{ca} is the sailing time from Circular Quay to the airport wharf).

Stage 3: Ship moors at the airport wharf to complete unloading of heavy baggage containers and loading of empty baggage containers, as well as the disembarking and embarking of passengers (T_a is the mooring time of the ship at the airport wharf).

Stage 4: Ship departs from the airport wharf, then reaches Circular Quay, which takes time (T_{ac} is the sailing time from the airport wharf to Circular Quay).

In the case of the fixed route distance, ship type, ship speed, and loading and unloading efficiency, the round-trip voyage time is fixed.

3.1.3. Sub-Process 3: Airport Baggage Handling

Sub-process 3 is the follow-up link of sub-process 2, it refers baggage containers being transported to the airport wharf, and then entering airport baggage sorting system after checking the integrity of the seal. This sub-process is shown in Figure 6.

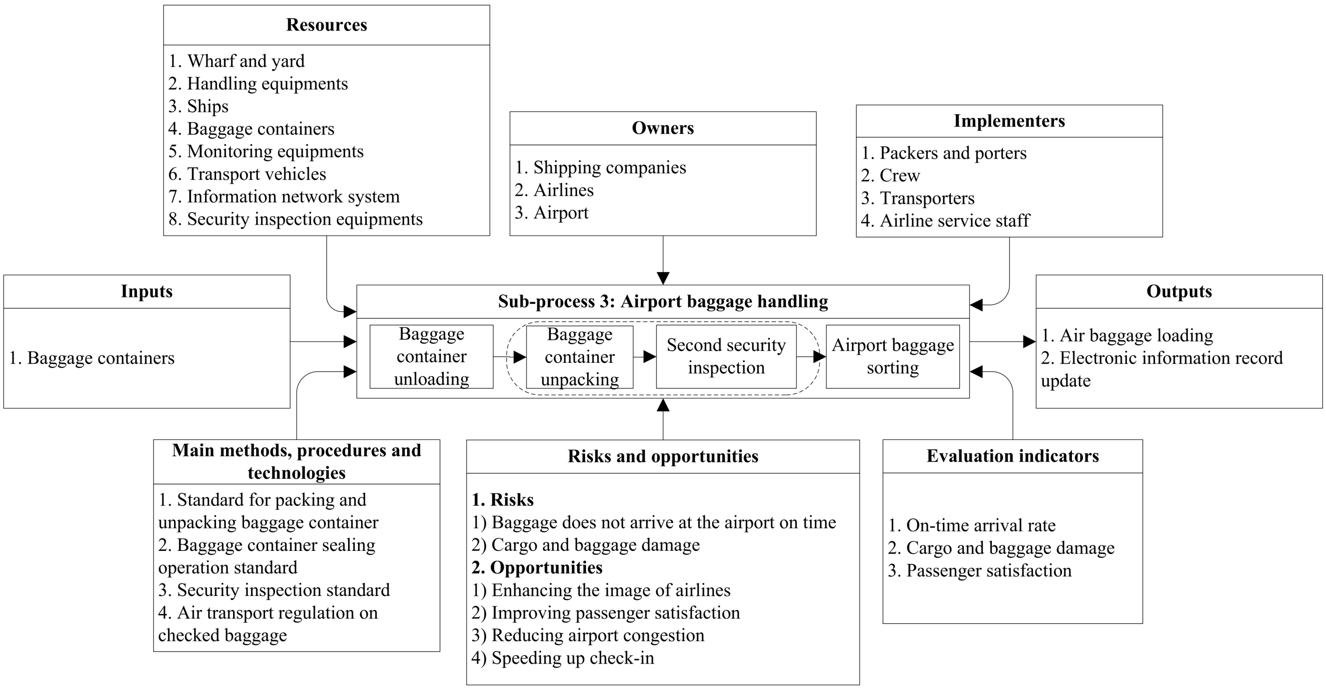


Figure 6. Airport baggage handling sub-process.

As can be seen from Figure 6, the sub-process of airport baggage handling is composed of four modules: unloading, unpacking, secondary security inspection of baggage containers, and the airport baggage sorting system. It has the function of loading baggage on the plane and updating relevant electronic information records.

The specific modules are analyzed as follows:

(1) Baggage container unloading

After the ship arrives at the airport wharf, baggage containers are unloaded from the ship through the conveyor belt and transported to the baggage yard, waiting for the next step. At the same time, the empty baggage containers would be loaded on the ship, transported back to Circular Quay in the next voyage, and re-entered into the packing operation.

(2) Baggage container unpacking and second security inspection

The unloaded baggage containers must be checked for the integrity of the lead seal. If the lead seal is intact, the baggage containers will be directly sent to the airport baggage sorting system; if the lead seal is damaged, the baggage containers must be unpacked and all baggage in the containers would be subjected to a second security check, and then sent to the airport baggage sorting system.

(3) Airport baggage sorting

The baggage containers on the same flight that do not need to be unpacked can be directly transported to the baggage collection conveyor after passing the airport baggage sorting; the unpacked baggage must be re-sorted and packed after second security inspection, and then according to the flight information would be transferred to the baggage collection conveyor and transported to the baggage loading point to complete air baggage loading.

3.2. Cost Control Analysis of the Scheme

As the operator, the main goal is to make a profit, and as a passenger, whether to use the service depends on the comparison between the inconvenience of carrying baggage and the service cost. Therefore, the cost reduction is a win-win for both operators and passengers.

There are many ways to classify cost. Here, cost is divided into voyage cost and non-voyage cost. The voyage cost (that is, variable cost) refers to the cost of a ship's round-trip voyage (That is, from Circular Quay to the airport wharf, then back to Circular Quay), which is directly related to the distance and cargo volume, usually including a fuel fee, port usage fee, the cost of using or purchasing baggage containers, ship repair and insurance costs, etc. The non-voyage cost (that is, fixed cost) refers to relatively fixed expenses that are not affected by the specific distance and cargo volume, such as the purchase and depreciation of ships, new wharfs, berths and yards, etc., and can also be called the fixed cost. The key to reducing the transportation cost is to control the voyage cost. Because the transportation from Circular Quay to the airport wharf conforms to the "four fixed" characteristics, the route, docking point, shipping schedule, and freight rate are relatively fixed, which is important for liner transportation.

Liner transportation has the advantages of providing large cargo volumes, low costs, reduced pollution, etc. However, the waterway distance from Circular Quay to the airport wharf (about 44 km) is three times that from Central Station to the airport. The baggage transportation from Circular Quay to the airport wharf, which relies solely on long distance and slow speed, will easily cause problems such as idle cabins, low utilization rates, and high transportation costs. In addition, fuel fees account for the large proportion of ship transportation costs, which can generally reach 30% to 35%. When the fuel price is high, it can reach 50% of ship transportation costs. Therefore, reducing fuel consumption is an important factor in controlling costs, and adopting economic speeds to reduce the fuel consumption of main engine can be used. At the same time, the method of adding LTL cargo or mixed passenger and cargo can be used to increase the ship loading rate and decrease the transportation costs.

3.2.1. Adopting Economic Speed to Reduce Main Engine Fuel Consumption Cost C_g

(1) The fuel consumption cost of the main engine at rated speed C_g

In ship operation, the fuel consumption of main engine is an important part of the voyage cost. The fuel consumption of main engine is related to the displacement, speed, and fuel consumption rate of the ship, which can be expressed as:

$$G = gPT_s = gT_s\frac{\Delta^{\frac{2}{3}}}{C}v^3 = g\frac{S\Delta^{\frac{2}{3}}}{C}v^2 \tag{1}$$

where,

G: The fuel consumption of main engine for a round-trip voyage, kg;

g: The fuel consumption rate, kg/(kW·h);

P: The continuous power of main engine of the ship, kW; $P = \frac{\Delta^{\frac{2}{3}}v^3}{C}$, where Δ is the displacement of the ship, t;

v: The rated speed of the ship, kn;

C: The ship coefficient (also called naval coefficient), C = 150∼200;

T_S: The sailing time of a round-trip voyage at rated speed, $T_s = T_{ca} + T_{ac}$, $T_S = S/v$, h;

S: The voyage distance of a round-trip voyage, n mile.

It can be seen from Equation (1) that the fuel consumption of the main engine is proportional to the sailing time T_S and the speed cubic v^3; when the voyage distance S is constant, it is proportional to the speed square v^2:

The fuel consumption cost of main engine C_g can be expressed as:

$$C_g = \lambda G = g\lambda \frac{S\Delta^{\frac{2}{3}}}{C} v^2 \tag{2}$$

where,

C_g: The fuel consumption cost of the main engine for a round-trip voyage at the rated speed, AUD;

λ: Fuel price, AUD/kg.

(2) The fuel consumption cost of main engine at economic speed C_g'.

The speed at which the unit transportation cost is the lowest is usually called the economic speed. The economic speed is lower than the rated speed, which can be estimated by the empirical Equation (3):

$$v' = 1.84 \left(\frac{P}{\Delta}\right)^{0.237} \sqrt{L} \tag{3}$$

where,

v': Economic speed of the ship, kn;

L: Length between vertical lines of the ship, meters.

The fuel consumption cost of main engine at economic speed is expressed as:

$$C_g' = \lambda G' = g T_s' \lambda \frac{\Delta^{\frac{2}{3}} v'^3}{C} = g\lambda \frac{S\Delta^{\frac{2}{3}} v'^2}{C} \tag{4}$$

where,

C_g': The fuel consumption cost of the main engine for a round-trip voyage at economic speed, AUD;

T'_S: The sailing time of a round-trip voyage at economic speed, $T'_S = S/v'$.

Under the same conditions of g, λ, Δ, and C, the fuel consumption cost of main engine at economic speed is lower than that of the main engine at the rated speed, and then the reduction rate of the former compared with the latter is:

$$\eta = \frac{C_g - C_g'}{C_g} = \frac{\lambda G - \lambda G'}{\lambda G} = 1 - \frac{v'^2}{v^2} \tag{5}$$

where,

η: The reduction rate of the fuel consumption cost of main engine at economic speed compared to the cost of main engine at rated speed.

(3) Voyage cost C_v

The voyage cost of a ship is inversely proportional to the loading rate α and the average total loading and unloading efficiency β; when the voyage distance S is constant, it is proportional to square of the speed. For the convenience of analysis, the cost irrelevant to the speed in the voyage cost can then be classified into C_o, and then the voyage cost C_v can be expressed as:

$$\begin{gathered} C_v = C_o + C_g' = C_o + kv'^2 \\ C_v \propto \frac{1}{\alpha}, \frac{1}{\beta}, v^2 \end{gathered} \tag{6}$$

where,

C_v: Voyage cost, referred to as the cost of a round-trip voyage of ship, AUD/a round-trip voyage;

C_o: The cost of the voyage cost which has nothing to do with speed, AUD/voyage.

k: The fuel consumption coefficient of the main engine related to the speed, $k = f(g, T_s, \Delta, C, \lambda)$, AUD/ ($v^2$·voyage).

When the voyage distance is fixed, the fuel consumption is close to the square of the speed. Using economic speed can greatly reduce the power of main engine, reduce the fuel consumption cost, and reduce the voyage cost.

3.2.2. Increasing the Average Loading Rate of Ship α

The ships can be divided between the passenger and cargo cabins to load passengers and cargo separately. The cargo cabins have the priority to load baggage containers, and baggage conveyor belts, forklifts, and other lifting and handling machineries are used to transport baggage containers into the cabins and place them in the position where it is easy to load and unload. The remaining cargo cabins are used to load LTL cargo. The average loading rate of ship α should be increased as much as possible to reduce cost. At the same time, it should be noted that the arrival of baggage is not evenly distributed. The maximum number of baggage arrivals within a certain counting time will cause the maximum loading rate of ship α_m, which will affect the choice of ship type.

3.2.3. Improving Loading and Unloading Efficiency β

The improvement of loading and unloading efficiency can decrease loading and unloading costs, reduce the ship's mooring time at the wharf, and improve the ship's transportation capacity. Therefore, when baggage containers are loaded or unloaded on the ship, they should be stored centrally; according to the actual situation, it is important to select the appropriate loading and unloading machinery and technology, and to try to increase the volume of one-time loading and unloading to reduce cost.

In actual operations, although economic speed can save fuel, it will increase the round-trip voyage time of the voyage, affect the shipping frequency, the loading rate of ship, the number of ships, and the arrival time of the baggage, which will reduce the efficiency. Therefore, it is not that the slower the speed, the more economical the vehicle, but instead important to find a better economic speed range, which reduces the energy cost without reducing the transportation efficiency.

4. Calculation Case

The goal of the scheme is to achieve the lowest cost based on the on-time baggage arrival. In addition to using the economic speed, reducing the fuel consumption of main engine, and increasing the ship loading rate, it also requires that the number of new infrastructure construction and allocated ships are the smallest number possible, and that ships do not need to wait for berths when they are docking.

Assumptions are as follows:

(1) The ship type on the route is the same.

(2) Regardless of ship course and loading rate, the one-way sailing time of the ship is the same (i.e., T_{ac} = T_{ca}). Circular Quay and the airport wharf use the same numbers and types of lifting machinery, and ignore the ship's docking time and other auxiliary production times (i.e., T_{a} = T_{c} = loading and unloading time).

(3) The number of berths at both wharfs is the same. There is only one berth at Circular Quay and the airport wharf.

(4) The arrival of baggage for check-in is subject to a Poisson distribution, with a confidence of 99%.

(5) The daily shipping frequency F of Circular Quay is divided into three situations: 8 times, 10 times, and 14 times, and the shipping intervals are respectively 2 h, 1.5 h, and 1 h.

(6) Baggage size and weight restrictions: the baggage size is less than 28 inches (that is, the sum of the length, width, and height of the baggage is less than 158 cm), and the weight of each baggage is limited to 30 kg. If the ULD (Unit Load Device) is used

in air freight to load baggage, the model is LD3 (dimensions: upper bottom/lower bottom length × width × depth = 200.7 cm/156.2 cm × 153.4 cm × 162.6 cm), an LD3 can transport an average of 30 pieces of baggage at 900 kg per container.

(7) The number of ships on the route only refers to the number of ships that have been put into operation, excluding standby or emergency ships.

(8) Baggage can arrive at the airport on time without missed flights.

4.1. Passenger Forecasting

Passengers are the service objects of a frontport check-in system, and the number of passengers using the service will directly affect the number of pieces of baggage, ships, berths, yard areas, loading and unloading efficiency, shipping frequency and ship type selection, and so on. These factors ultimately affect the design and operation cost of the frontport check-in system.

Here, three quantitative methods (trend extrapolation, causal analysis, and gray system model) were used to predict the number and annual average growth rate of departure passengers at the Sydney Kingsford Smith Airport in the future, with the forecast period from 2019 to 2025. Among them, the trend extrapolation method and the gray system model GM (1,1) use the statistical data of passengers departing from 2009 to 2018, and Causal analysis uses statistics from New South Wales' state GDP from 2009 to 2018 (using chain measurement) [26,27]. The forecast results of the number of departing passengers are listed in Table 3.

Table 3. Forecast results of the number of departing passengers.

Model		Equation	Fitting Degree	Predictive Value of 2025
Trend Extrapolation	Binomial method	$Y = 5.67496E + 03X^3 - 3.42675E + 07X^2 + 6.89736E + 10X - 4.627709E + 13$	98.46%	27,702,272
	Trinomial method	$Y = 1.212261E + 04X^2 + 4.618879E + 05X + 1.63467E + 07$	98.13%	35,377,085
Causal Analysis	Linear regression	$Y = -4{,}020{,}846.351 + 44.363\ X$	98.30%	26,154,022
Grey system	GM (1,1)	$Y(t+1) = 581{,}251{,}069.15127e^{0.02955t} - 564{,}795{,}917.15127$	99.11%	27,149,671
Average predictive value				29,095,763
Average annual growth rate of forecast results				4.07%

According to Department of Infrastructure, Regional Development and Cities, 35.1% of passengers travel on business, for short times and less baggage needed; 27.1% of passengers travel on vacation, for longer times and more baggage needed. According to statistics from the Sydney Kingsford Smith Airport, each passenger carries the average of 1.2 pieces of baggage. Assuming that by 2025, 25% of departing passengers will use the frontport check-in system, then 23,915 pieces of baggage, that is, 798 LD3, a total of 718.2 tons of baggage will be generated every day.

4.2. Baggage Arrival Rules

Due to the small arrival density of baggage, the interaction among passengers is weak, and other interference factors are also less, that is, the arrival flow of baggage is random, similar to the traffic flow. Therefore, it can be assumed that the arrival of baggage follows the Poisson distribution. The distribution function is expressed as:

$$P(X \leq x) = \sum_{i=0}^{x} \frac{m^i e^{-m}}{i!}, x = 0, 1, 2, \ldots\ldots \quad (7)$$

where,

$P(X \leq x)$: Expressed as the probability that the number of baggage arrived is less than or equal to x, X is the number of baggage that arrive within one counting time t;

t: Counting time, it refers to the interval time of shipping on the route;

e: Base of natural logarithm, the value is 2.718280;

m: The average number of baggage arriving within one counting time t;

x_{max}: The maximum number of baggage arrival within one counting time t.

4.3. Minimum Number of Berths

The number of berths depends on the ratio of the amount of cargo being loaded and unloaded to the passing capacity of the berth. According to the characteristics of liner transportation, the equation of the number of berths can also be simplified as the ratio of the mooring time of the ship at the berth to the interval time of shipping on the route. Under the fixed loading and unloading efficiency of the berth, if the ship's mooring time is greater than the shipping interval, and the number of berths is 1, then the waiting phenomenon will appear, that is, the ship A is loading and unloading the cargo on the berth, and at the same time, the ship B has arrived at the wharf and waiting berth. There are various measures to solve this problem. Here, we only discuss the impact of the number of loading and unloading machinery on the number of berths. The relationship between the minimum number of berths and the number of loading and unloading machines can be expressed as:

$$\min N \geq \frac{\max(T_a)}{t} = \frac{2x_{\max}/(l * \beta)}{t} \quad (8)$$

where,

N: The number of berths, $N > 0$, $N \in$ integer.

l: The number of loading and unloading machines;

β: The efficiency of loading and unloading machinery, unit: ULD/h.

4.4. Yard Area

The yard is used to handle packing, unpacking, and storage of ULD. The size of the yard determined by the following factors: the number of ULDs that should be accommodated in the yard, the horizontal transportation, depalletizing and palletizing methods, and loading and unloading technology. The empirical estimation method is used here, and yard capacity is 3.33 times the average ULD number of ships loaded (or unloaded). The design yard area A_y can be expressed as:

$$A_y = 3.3 * \frac{m}{30} * 2.007 * 1.534. \quad (9)$$

4.5. Minimum Number of Ships on the Route

According to the assumption, in order to reduce the cost of infrastructure construction, there is only one berth at Circular Quay and at the airport wharf each, so the number of ships on the route mainly depends on the shipping interval, the round-trip voyage time of the ship, and the loading and unloading efficiency. The minimum number of ships can be expressed as:

$$\min M \geq \frac{\max(T)}{t} = \frac{2\max(T_a) + 2T_{ac}}{t} = \frac{2x_{\max}/(l * \beta)}{t} + \frac{2T_{ac}}{t} \quad (10)$$

where,

M: The number of ships on the route, $M > 0$, $M \in$ integer;

T: The total time of a round-trip voyage, h.

4.6. Calculation

We chose two types of DAMEN Company's road ferry for comparison. The ship type parameters are listed in Table 4 below [28,29].

Table 4. Ship type parameter list.

Dimensions	Unit	DAMEN	
		6819 E3	6014
Length	m	70.7	60.3
Beam	m	20.2	14.0
Depth	m	4.2	6.0
Draught summer	m	2.9	4.5
Deadweight (summer)	t	800	1100
	ULD	889	1223
Speed (at summer draught)	kn	12.0	14.0

The one-way distance from Circular Quay to the airport wharf is 21.6 nautical miles. On average, 798 LD3s are transported to the airport every day. By simulating the law of baggage arrival, according to Equations (7)–(10), we calculated the minimum number of berths and ships, the size of yards, and the average loading rate and maximum loading rate required for different shipping frequencies under the two ship types. The calculation results are listed in Table 5.

Table 5. Calculation results.

Item	Symbol	Unit	Lifting Machinery	6819 E3			6014		
Loading and unloading efficiency	β	ULD/h		40					
Rated speed	v	kn/h		12.0			14.0		
Counting time	t	h		2	1.5	1	2	1.5	1
Daily shipping frequency	F			8	10	14	8	10	14
Average number of baggage arriving within one counting time t	m	ULD		100	80	58	100	80	58
Maximum number of baggage arrival within one counting time t	x_{max}	ULD		124	101	76	124	101	76
One-way sailing time	$T_{\text{ac}} = T_{\text{ca}}$	h		1.8	1.8	1.8	1.54	1.54	1.54
Mooring time at wharf	$T_{\text{a}} = T_{\text{c}}$	h	$l = 3$	2.07	1.68	1.27	2.07	1.68	1.27
			$l = 4$	1.55	1.26	0.95	1.55	1.26	0.95
Minimum number of berths	min N	h	$l = 3$	2	1	1	1	1	1
			$l = 4$	1	1	1	1	1	1
Minimum number of ships on the route	min M	h	$l = 3$	11	9	7	11	9	7
			$l = 4$	8	6	5	8	6	5
Yard area	A_y	m^2		615	492	351	615	492	351
Average loading rate	α	%		11.25	9.00	6.52	8.18	6.54	4.74
Maximum loading rate	α_m	%		13.95	11.36	8.55	10.14	8.26	6.21

It can be seen from Table 5 that when the loading and unloading efficiency is fixed, the more the number of loading and unloading machines, the more the daily shipping frequency, the smaller the maximum number of baggage arrivals within one counting time, and the shorter the mooring time at wharfs, then the number of berths demanded is smaller. When the number of loading and unloading machines is 3 and the shipping frequency is 8 times/day, the ship type 6819E3 requires 2 berths, which do not meet the assumptions. Therefore, the use of appropriate technology and loading and unloading machinery is the key to improving loading and unloading efficiency. The more the daily shipping frequent and the more loading and unloading machinery uaed, the fewer ships will be allocated on the route. However, the average loading rate and maximum loading rate of each ship type under different shipping frequencies are low, which will increase the cost.

According to Equation (5) and the rated speeds of different ship types, the reduction rate of fuel consumption cost of the main engine at economic speed compared with the main engine fuel consumption cost of the rated speed is plotted, as shown in Figure 7:

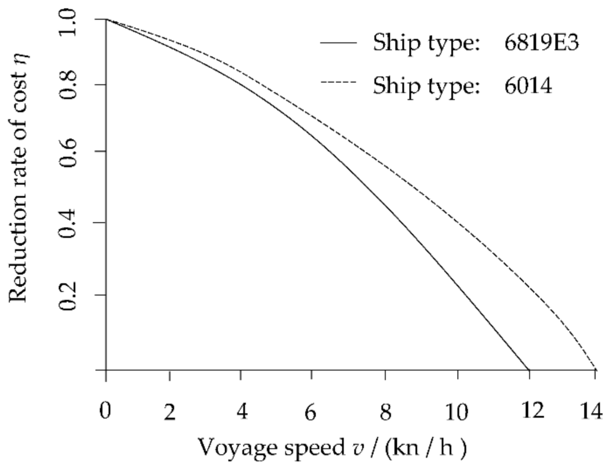


Figure 7. The reduction rate of fuel consumption cost of the main engine under different ship types.

According to Equation (5), it can be seen that the change interval of η is [0,1]. As can be seen from Figure 7, under the same conditions of g, λ, Δ, and C, when the speed is equal to the rated speed, the main engine fuel consumption cost is the largest; at this time, η = 0. When the speed drops, the fuel consumption cost of main engine decreases. The slower the speed, the greater the reduction rate of the fuel consumption cost of the main engine. However, the sailing time will be prolonged, which will have an impact on other factors, such as the number of ships, berths and loading and unloading machines, the daily shipping frequency, and the loading rate of ships, etc. Therefore, it is necessary to choose the better economic speed range to maximize economic benefits. This is the key to the success of the scheme. This part of the content can be focused on future research.

5. Conclusions

In this paper, the strengths, weaknesses, opportunities and threats of implementing the Sydney's frontport check-in system through air-waterway intermodality was studied by SWOT analysis, and then we proposed a design scheme for Sydney's frontport check-in system. In order to achieve the purpose of punctual, safe, and low-cost baggage transportation, the scheme was divided into three sub-processes of baggage consignment, baggage packing and transportation, and airport baggage handling according to the process method of a quality management system, and we suggested to adopt an economic speed to reduce fuel consumption of the main engine, improve the ship loading rate and loading and unloading efficiency, and decrease the number of berths and ships, the yard area, etc. This design scheme is the beneficial supplement and improvement to the existing ITCI system.

This paper mainly discussed the preliminary design scheme of Sydney's frontport check-in system, but the detailed design of this scheme is yet to be studied in depth, including the division of responsibilities, cost sharing and information sharing of many participants, the layout design, and the selection of loading and unloading technology for the airport wharf and Circular Quay, as well as the emergency handling measures for baggage during suspension periods due to the environmental conditions and climate of waterway transportation (wind, waves, fog, etc.).

In addition, reducing the voyage cost is the key to the research of frontport check-in systems. How to choose the most suitable ship type, loading and unloading machinery, and the number of ships, daily shipping frequency, and appropriate economic speed range is the focus of future research.

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