**Conference contribution :**
Loskot, P. (in press). *Towards dissociation of passengers and baggage.* Transportation Research Procedia,

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

International Conference on Air Transport – INAIR 2018

# Towards dissociation of passengers and baggage

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**Abstract**

Dissociation of passenger travel and baggage delivery is being considered as one of the radical innovations in future air transport. This paper elaborates on this idea to identify potential benefits as well as implementation challenges. It is argued that complete end-to-end dissociation involving also the air segment is critically dependent on dissociation provided first in the ground segment. The end-to-end dissociation is likely to lead to full outsourcing of baggage services outside airports to the 3rd party providers while treating baggage as cargo at airports. Even though large scale dissociation may be challenging or less beneficial, the situation appears very different at smaller scales. In order to obtain initial assessment of baggage volumes expected in the ground segment in a large metropolitan area, arrival and departure flight data from 4 major London airports were used to infer the baggage flows between these airports and the Greater London area. Our analysis estimates that the required baggage transport and processing capacity is as large as 100's of bags per hour per a baggage distribution center in the city. This capacity can be reduced by at least 30% provided that the baggage flow variations are suppressed by exploiting temporary storage facilities.



*Keywords:* baggage dissociation; baggage service; data analysis; London airports; parcel delivery network

## 1. Introduction

The new IATA resolution 753 which came into effect last June created a major milestone towards improving baggage services at airports, IATA (2017). It is now required that all baggage handling steps are recorded and all the involved parties held accountable. In addition to these efforts to improve the efficiency of airport services and the passenger experience which are driven through a series of IATA innovation programs, there are also other more

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futuristic outlooks at the future of air transport. One of these future concepts envisions a complete dissociation of passengers from baggage, Loskot (2015). The dissociation of baggage from passenger travel has been discussed in various forums and baggage working groups as a prospective strategy to radically innovate travel services. The ultimate goal is to offer the end-to-end or door-to-door baggage-free journey from the point of departure to the final destination. Thus, the complete dissociation would occur within both the ground and air segments of the passenger journey. Whilst the dissociation in the ground segment is already being offered in areas about some large airports, the dissociation involving also the air segment and its consequences on the system design and operations remains mostly unexplored to this day. It is mainly due to the complexities and challenges which are quickly arising as a result of the proposed fundamental change in the baggage delivery service.

Recently, new economic models have been emerging to exploit increasingly interconnected systems and processes. The underlying idea of these X-as-a-Service (XaaS) economic models is to pool and then share the existing infrastructures to deliver services with much more optimized efficiency and flexibility. In case of Transportation-as-as-Service (TaaS), also known as Mobility-as-a-Service (MaaS), the public and private transportation services in urban areas are combined to provide the seamless passenger travel experience as well as effective goods delivery services, Goodall et al. (2017). In air transport, the XaaS concept emerged as Baggage-as-a-Service (BaaS). The BaaS is currently offered by several large airlines in some urban areas to provide luggage deliver service for their passengers to the airport. Moreover, the airlines normally deliver delayed luggage directly to the passengers, if their luggage did not arrive to the destination airport on the same flight with them. However, such services are rather small scale, and not comparable with BaaS expected to be offered as a standard service to all or most of the passengers. In addition, the main difference between BaaS and the full baggage dissociation is that the former currently focuses only on the dissociation in the ground segment, usually for selected type of passengers whereas our reasoning about baggage dissociation is more general, and aims at large scale widespread adoption, and also embraces dissociation in the air segment.

The complete end-to-end dissociation of passengers and baggage would raise the BaaS concept to a new level. In fact, the complete dissociation may change the notion of baggage as it is understood today. When baggage is delivered end-to-end independently from travel of passengers, such baggage delivery becomes akin to a parcel delivery. The parcel delivery services are now well established after they evolved over several past decades, Cetiner et al. (2010). Some of the key problems considered in optimizing the parcel delivery services are choosing the locations of hubs, distribution and sorting centers, and scheduling the delivery vehicles and their routes, especially for the last-mile delivery. Following the MaaS concept, traditional logistics networks can be extended to support online retailing, Xing (2011). Consequently, traditional parcel delivery and logistics networks for goods delivery can be adopted to also support baggage delivery. In fact, it is unlikely that the airlines and airports would have enough resources to build completely new baggage distribution networks. It is a lot more effective to exploit the existing infrastructures for parcel delivery and upgrade these networks to comply with the requirements and needs of the air transport industry. This may even eventually lead to complete outsourcing of baggage delivery services to the 3rd party providers while the air transport companies would treat baggage as cargo.

In the sequel, we first discuss a high level concept of baggage dissociation to outline main challenges and potential benefits. The ground baggage distribution networks are examined as a key enabling strategy of the end-to-end dissociation. We then specifically focus on assessing the volumes of luggage being delivered between 4 main airports in London, UK, and the Greater London area. The airports considered are: Heathrow (ICAO code EGLL), Gatwick (EGKK), Luton (EGGW) and Stansted (EGSS). We use actual arrival and departure data reported at these airports collected over one week in July 2016. The arrival and departure data are combined with other data on airports and aircraft types including passenger statistics and the distribution of baggage weights in order to estimate the baggage flows in terms of the number of luggage pieces and the actual luggage weights which are being delivered hourly and daily between these airports and the Greater London area. Since the data we used are available for free, there is no guarantee on their accuracy, and occasionally some data fields were missing. The missing data were either excluded or sensibly replaced. Our philosophy was to assess the minimum baggage volumes which are normally observed rather than dimensioning the system for the maximum baggage volumes which can be expected in the near future. Such approach allows us to obtain initial evaluation of feasibility of baggage dissociation. Our results reported for the case of London can be used to understand whether there is enough capacity in the current system to support baggage dissociation. Although such analysis is far from a comprehensive feasibility study, it is the first important step which will inform further reasoning about baggage dissociation, and hopefully also stimulate further discussions. Our conclusions assuming data for Greater London are likely to be valid also for other large urban areas with one or more airports such as Amsterdam and Paris. Moreover, to our best knowledge, there are currently no research papers addressing the problems of end-to-end baggage dissociation, even though there are a few papers on smaller scale implementations of BaaS, van Zundert (2010).

The rest of this paper is organized as follows. The basic concept of baggage dissociation is discussed in Section 2 in order to understand its main benefits and challenges. Section 3 considers the current parcel delivery networks in order to understand how these networks could be used for baggage delivery to and from the airports. The quantitative study for the case of London airports is presented in Section 4. Conclusions are drawn in Section 5.

## 2. End-to-end baggage dissociation

The baggage dissociation can be considered in a broad sense or in a strict sense. The baggage dissociation in a broad sense is assumed within only the ground segment. In particular, luggage is collected at passenger premises by a 3rd party courier company, delivered to the airport and then checked in on behalf of the passenger. It allows the passenger to undertake a hassle free trip to the airport. The main challenge of such service is to prevent unauthorized tampering with the baggage contents during its delivery. This issue can be partly mitigated by a high resolution 3D X-ray screening of baggage at the airport during check in. Upon arrival to the destination airport, a similar baggage home delivery service can be requested by some passengers. The home delivery does not have the problem with safety and security of baggage contents, however, the challenge is the customs inspection of baggage contents, if the reconciliation occurs outside the airport, for example, at a hotel. In both cases, the passengers and their luggage travel on the same flight, even if it consists of multiple legs operated by different airlines.

The strict sense baggage dissociation aims at end-to-end baggage delivery independently of passengers, i.e., including the air segment. The key challenge is violation of the current IATA General Conditions of Carriage for passengers and baggage which demands that passengers and their baggage are put on the same flight with a few defined exceptions. The solution to this issue can be to improve the baggage screening sensitivity at the departing airports to guarantee the baggage contents safety and security. Alternatively, we can consider dedicated flights for delivering only baggage without any passengers on board. These strategies may provide new revenue generating opportunities by optimizing baggage and cargo aircraft loading with differentiated baggage services, or to design new generation of passenger-only aircraft which would be much lighter, faster and fuel efficient, Kircher (2015).

The widespread adoption of baggage dissociation is facing the following challenges:

- Even though a complete dissociation can be generally considered only at selected airports, airport terminals, flight routes, or for some type of passengers, the current vision is concerned with large scale adoption where the baggage dissociation becomes a norm rather than an extra service.
- The new IATA rules are required to govern the dissociation whether it is implemented locally or at a large scale.
- There is need for a new infrastructure as well as to define the associated processes in order to support the dissociation. This is likely to incur significant capital expenditures and further increase the system complexity.
- At present, there appears to be no economic analysis of baggage dissociation. For instance, it is unclear how to cover additional operational and capital costs arising from new baggage dissociation services, and whether these additional expenses can outweigh the offered benefits. Thus, there is a need to develop new business models not only to support, but to sustain the dissociation.
- The baggage dissociation could be completely outsourced to the 3rd party providers who would then request baggage as a cargo (BaaC) delivery from the airline companies.
- The passengers may collect and drop off baggage at suitable points throughout the city. This creates additional handovers between the passengers and the couriers actually delivering baggage to or from the airport. It increases the system complexity as the handovers of baggage ownership and accountability need to be clearly defined.
- The dissociation must be completed by reconciling passengers with their luggage at a given point in time and space. This may turn out to be particularly difficult when the dissociation is enabled also in the air segment.
- The passenger expectations about baggage dissociation services may be vastly different. For example, at present, it is unclear how much baggage reconciliation delay different type of passengers would be willing to tolerate.

- The end-to-end dissociation requires careful advance planning. This process may be easily disrupted by unpredictable changes in the passenger travel plans, whether they are deliberate or unintentional.
- The baggage dissociation and its independent delivery will affect other associated services such as the customs at the destination country, and the financial insurance to provide the agreed level of service.

The challenges of dissociation have to be balanced against the following anticipated benefits:

- A hassle free travel to and from the airports encourages the use of public transport which would relieve the current curb-side congestion at many busy airports. This may also improve the passenger experience which is often stated as the main reasons why to consider baggage dissociation.
- The opportunity to develop new light, fast and fuel efficient aircraft which can reduce travel times by a large margin, and which can also reduce the boarding and the aircraft turn-around times at the gate.
- The opportunity to renovate airports with passenger only and baggage only terminals in order to improve their passenger and baggage handling capacity and efficiency.
- The opportunity to route baggage directly to the destination airports while avoiding baggage transfers at the intermediate hubs which is usually one of the most demanding baggage handling operations, and thus, the main source of delayed and lost baggage.
- Baggage delivery can be reconsidered as extending the current parcel delivery services. This would remove the distinction between baggage and parcels, so baggage delivery would be truly independent from whether the passengers actually undertake the journey or not.

There is another line of reasoning about baggage dissociation which may be quite useful. As the initial step, we may consider baggage dissociation in the air segment as our primary objective. Thus, the passenger would arrive to the airport with their luggage, however, luggage is put on a different flight. Since the passengers and their luggage are likely to arrive to the destination airport at different times, it significantly complicates the baggage reconciliation. It may require either sufficient luggage storage capacity at the destination airport, if luggage arrives before the passenger, or to move the reconciliation off the airport to the passenger's final destination in order to avoid the need for passengers to await their luggage at the airport. Therefore, the off-airport luggage reconciliation with home distribution is inevitable, provided that we assume the air segment dissociation. Once luggage distribution is offered at the destination airport, it is sensible to offer a similar service for luggage collection and delivery to the departing airport. Hence, dissociation in the air segment drives dissociation in the ground segments.

Our aim in this paper is to obtain a high level estimate of the scale of baggage dissociation and handling which can be expected in the ground segment assuming a large metropolitan area of Greater London served by 4 major airports. The metric to be evaluated is the expected number of luggage to be collected from and delivered per hour to each of the 12 baggage processing centers evenly located throughout the city. The assumptions made in our analysis provide a lower bound on such luggage volumes. The volumes obtained are likely much larger than the capacity of available in the current ground distribution networks. Since parcel delivery networks are already large scale and well established, we will first consider these networks and how their structure can be reused to build similar networks for high baggage volume delivery in the urban areas.

## 3. Ground distribution networks for baggage

Many distribution networks share common problems and design issues. In particular, the constraint delivery capacity may create congestion which is perceived by service users as sudden and significant delay of the service provided. Improving network management to better utilize the available resources to suppress the congestion increases the network complexity which in turn reduces its resilience to unpredictable disruptive events. The reduced resilience then raises new security issues, and the service disruptions lead to larger and more profound economic and social consequences. The scalability issues to provide a distributed service in many network nodes require hierarchical network topology with central hubs and last-mile service provisioning at the network edges. Although it is relatively easy to add more nodes to the network at its edges, increasing the hub capacity to support the added nodes is much more challenging. Providing network services in areas with high density of users (per infrastructure) is economically much more viable than in other less populated areas. In addition, the transport capacity of many networks is not constant, but it often varies significantly over the course of day. The time varying capacity can be exploited by scheduling deliveries to later times, if such delays can be tolerated. There may be also instances when the delivery is misplaced or lost.

More importantly, even though many of these issues have been somewhat mitigated to various extents by the use of digital technologies and the Internet, the laws of physics limiting the performance of distributed services in general distribution networks are unavoidable by any means. Since the main focus of this paper are the ground distribution networks for baggage delivery to and from the airports, we first review well established parcel delivery networks which are used extensively within the national economies. We can then reuse design principles of these networks to devise a network topology for baggage delivery networks in the ground segment.

The parcel delivery networks have strictly hierarchical topology, Baumung (2015). The consolidation centers or points (CP) and distribution stations (DS) are required for achieving the delivery efficiency of delivery vehicles. They are located within the area of distribution or delivery centers also referred to as last-mile sub-networks. The sorting centers (SC) act as gateways for parcel delivery to and from the distribution centers. The sorting centers are interconnected via a network of long-haul transportation links and hubs. The last-mile sub-networks are usually in operation throughout the day from early morning hours until late afternoon or evening, the long-haul transportation networks to deliver parcels between the distributions centers are used mainly overnight.

The parcel delivery networks are often designed in at least two subsequent steps. In the first step, the decision is made on the number and location of the network hubs (sorting centers and distribution stations). The parcel flows are then optimized in the second step. The parcel service in a typical country in the Western Europe relies on 10's of sorting centers, 100's of delivery stations, and 1000's of delivery vehicles in order to obtain the capacity of 100's of millions of parcels delivered annually. Fortunately, the underlying optimization problems are usually linear, so they can be solved efficiently even in such large scales. These optimization problems are parametrized by large number of variables, and constrained by a number of limitations and requirements. These include the number and size of vehicles and their availability, the type and nature of customer demands and whether they can be predicted, the throughput of surface roads, and other constraints related to various fixed and variable costs. The objectives of these optimizations can become easily conflicting which gives rise to various trade-offs. For instance, minimizing the service costs is usually possible at the expense of service quality such as the delivery delay. The high-level objectives then translate to more specific implementation requirements such as the required number of vehicles, the total distance travelled during the delivery, and the number of customers visited in each delivery trip.

Inspired by the parcel delivery networks, the envisioned network for baggage delivery is depicted in Fig. 1. The baggage delivery through airline networks requires the use of baggage handling systems (BHS) at all airports. These systems may be modified in the future, for example, if baggage is delivered as cargo in the standardized ULD (unit load containers) consolidated by the 3$^{rd}$ party couriers outside the airports. The baggage distribution network will require at least two-tier topology. The BHS at airports would perform the first level sorting of arriving baggage towards the appropriate baggage sorting centers (BSC) outside the airport. The BSC can be shared among multiple airports, and perform the second level sorting. The BSC may also provide longer term storage of baggage which would not otherwise be available at BHS. Note that no baggage is routed directly between BHS, but always through BSC. Thus, baggage to other cities would be routed via the BSC sub-network. There can be other tiers after the BSC, however, here, we consider that the BSC feed directly to local baggage delivery stations (BSC) for the last mile delivery. The links between BHS and BSC, between different BSC, and between BSC and BDS are assumed to have large transport capacity, for example, they can be realized as dedicated routes with high speed train or trucks. The BSC are distributed throughout the city to provide the service coverage of the whole area. Note that BDS are connected only via BSC, and never directly. The end-to-end baggage delivery service also requires defining the admissible service end-points such as homes, local shopping malls and stores, post offices and hotels.

The baggage distribution network can naturally consolidate baggage collection throughout the city to create aggregated baggage flow for delivery to the airport. In this case, the bags can be collected from the passenger premises, or from drop-off points established in public locations such as post offices and shopping centers.

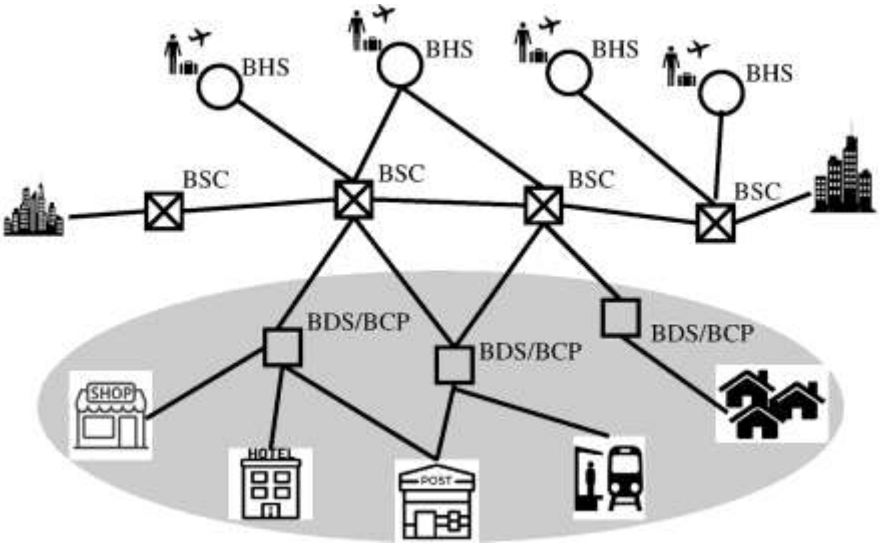


Fig. 1. A layout of the baggage collection and distribution network.

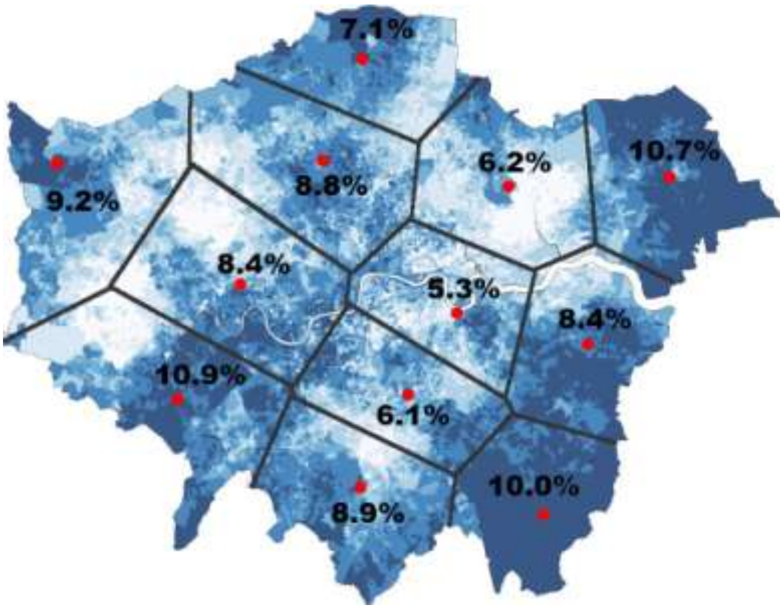


Fig. 2. Example of 12 distribution centers and estimated population sizes of the corresponding distribution districts in a Greater London area.

In order to assess the locations and the required number of DBS in the last-mile baggage sub-networks, we assumed the population density data in Greater London from the UK Census 2011 report, Census (2011). In particular, every pixel in the map shown in Fig. 2 represents a certain population density up to 100%. Knowing that the total population of Greater London in 2016 was 8,174,000, we can calculate the population sizes in specific geographical areas with the pixel-level resolution. We assumed 12 BDS in total which are placed in the areas with the largest population density, and somewhat uniformly spread throughout the area. The boundaries between the last-mile distribution areas, each containing exactly 1 BDS, are shown as black lines and red points in Fig. 2, respectively. The percentage values next to each BDS in Fig. 2 indicate the fraction of the overall population living in that area. It is then fair to assume that, at least initially, we can assume that the number of terminating passengers arriving to and departing form the Greater London area is proportional to these values. More accurate analysis would need to take into account other passenger statistics such as the fraction of business vs. leisure passengers, domestic vs. foreign passengers, and the length of stay; all these data are available in the report, CAA (2016).

## 4. Case of London airports and Greater London

Our aim is to assess the amount of baggage which is delivered hourly between selected London airports and the Greater London area. The basis for our investigations is the arrival and departure flights data and several other supporting datasets. The arrival data consist of flight number, aircraft type, IATA/ICAO code of the departing airport, and the times of departure and arrival. The departure data records flight number, aircraft type, IATA/ICAO code of the destination airport, time of departure, and scheduled time of arrival. These data were collected for EGLL, EGKK, EGGW and EGSS London airports over one week in July 2016. These data can be combined with other datasets to obtain the following information:

- The airline type – regular or low-cost carrier (LCC) – can be extracted from the flight number using a dataset of airline codes. We were unable to reliably detect non-scheduled (i.e. charter) flights, although it is possible to identify likely instances of such flights.
- The aircraft type was combined with the dataset containing, among other, the information about the typical and maximum (high-density) number of seats. This gives an upper bound on the number of passengers arriving. However, we also used estimated passenger load factors (PLF) to obtain more realistic passenger numbers.
- The flight time is simply the difference between the departure and arrival times. The complication is that the arrival and departure times are given in the local time zones which need to be first converted to the same time zone such as UTC, or the time zones of one of the airports considered.
- The haul type – short (< 500 km), medium (< 5000 km) and long (> 5000 km) – is obtained assuming a lower bound on the travelled distance calculated from the GPS coordinates of the departure and destination airports.
- The route type – domestic, European and non-European – is mapped from the database of airports which also includes information on countries and continents in which the airports are located in.

The number of passengers arriving or departing on a given flight is not known exactly (from available public datasets), so we have used the following procedure to estimate it. Our philosophy is that the number of passengers and their checked in baggage is different each time, even on the same flight whereas the timetable of scheduled flights remains unchanged for weeks or months. In many cases, it is possible to find the data about long term averages, and sometimes, also the corresponding variances (or the standard deviations, st.d.). It is then sensible strategy to generate passenger numbers and the corresponding volumes of checked in bags randomly conditioned on the known long term statistics. Since the realistic values are bounded (e.g., the number of passengers by the aircraft seating configuration), and the total checked in baggage weight per passenger by the allowable limit imposed by the airline, the probability distributions should assume finite support intervals. A good candidate distribution would be the truncated Gaussian distribution or the uniform distribution. In our analysis we used the latter distribution, since it is much easier to sample. In particular, for a random variable $X$ with the mean value $m_X$ and the st.d. $s_X$, we assume the uniform distribution over the interval, $(m_X - (\sqrt{12})\, s_X /2,\ m_X + (\sqrt{12})\, s_X /2)$. The values $m_X$ and $s_X$ are reported as, $m_X \pm s_X$. The procedure to generate numbers of passengers and their checked in baggage is described as follows:

- The average PLF values are reported for some airlines, but not for others. The current long term average values seem to be between 70% and 85% for regular airlines, and 80% to 95% for LCC airlines. We used these intervals to generate the instantaneous PLF value for each flight assuming the uniform distribution.
- The number of transit passengers (i.e., those who arrive to and leave the airport in the same aircraft) in comparison to the number of terminating passengers (i.e., those who arrive to or depart from given airport) can be neglected, CAA (2016). On the other hand, the number of connecting passengers (i.e., those who arrive to and leave the airport on another aircraft) can be significant as shown in Table 1, CAA (2016). Furthermore, the percentages of terminating passengers have to be split between the arriving and departing passengers. We assumed the split 51% to 49% slightly biased towards the arriving passengers as reported in the literature.
- The number of passengers considered is further adjusted by the fraction of passengers who terminate their journey in the Great London area. These statistics are reported in the last column of Table 1, CAA (2016).

- The gender of passengers is generated randomly following the statistics given in Table 1 which were calculated from the statistics reported in CAA (2016). Note that the number of females is calculated as the total number of passengers minus the number of males and the children 2-12 years old.
- We assume that the number of checked in bags per passenger is equal to 1, as we did not find any relevant statistics, although the baggage overweight statistics can be found in Table 3 below, Berdowski et al. (2009). The grouping of passengers and the cases of males and females accompanying an infant were ignored.
- The baggage weights were obtained by combining the data reported in Berdowski et al. (2009). These statistics are summarized in Table 2 and Table 3 assuming summer season to match the flight data from July 2016. The baggage weights are generated independently for every passenger.
- Finally, the number of baggage and their weights are accumulated within given time windows as explained next.

Table 1. Percentage statistics of passengers at London airports.

| Airport | Pax type | | Pax gender | | | Terminating at the Greater London area |
|---|---|---|---|---|---|---|
| | Terminating | Connecting | Male | Female | Child (2-12) | |
| EGLL | 63.8±8.1 | 36.2±3.4 | 52.7±5.0 | 45.8±0.0 | 1.5±1.0 | 34.1±5.0 |
| EGKK | 92.4±8.5 | 7.6±1.7 | 50.9±5.0 | 46.9±0.0 | 2.2±1.5 | 37.7±5.0 |
| EGGW | 98.0±8.4 | 2.0±0.5 | 46.5±5.0 | 45.5±0.0 | 8.0±4.0 | 34.2±5.0 |
| EGSS | 94.4±8.5 | 5.6±1.3 | 51.9±5.0 | 47.3±0.0 | 0.8±0.4 | 34.0±5.0 |
| EGLC | 97.9±10.0 | 2.1±0.4 | 58.7±5.0 | 41.1±0.0 | 0.2±0.2 | 81.4±10.0 |
| EGMC | 99.5±10.0 | 0.9±0.2 | 59.7±5.0 | 40.2±0.0 | 0.1±0.1 | 80.0±10.0* |

*value estimated

Table 2. The per passenger baggage weights (in kg) during the summer season.

| Gender | Unconditional | Airline type | | Route type | | | Haul type | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Regular | LCC & Charter | Domestic | Europe | Non-Euro. | Short | Medium | Long |
| Male | 16.9±5.8 | 17±6.1 | 18.5±4.9 | 15.5±5.9 | 16.3±5.7 | 18.3±5.8 | 15.1±6.1 | 16.6±5.8 | 18.7±5.6 |
| Female | 17±5.7 | 17.1±5.9 | 18.3±4.8 | 15.4±5.8 | 16.6±5.5 | 18.3±5.7 | 15.3±5.9 | 16.7±5.6 | 18.7±5.4 |
| Child (2-12) | 14.2±6 | 14.7±6.2 | 14.2±6 | 15.6±6 | 12.7±5.7 | 16.4±5.8 | 10.5±7.1 | 13.6±5.9 | 16.8±5.5 |

Table 3. The additional per passenger baggage weight statistics (in kg) during the summer season.

| Gender | With infant | Exceeded permitted bag weight | | | | Group | |
|---|---|---|---|---|---|---|---|
| | | 15 kg | 20 kg | 23 kg | 32 kg | One | More |
| Male | 19.9±7.1 | 14.3±4.5 | 16±5.8 | 18.2±5.5 | 18±5.7 | 16.6±5.7 | 18.2±6.2 |
| Female | 17.2±7.9 | 14.1±4.8 | 16.2±5.6 | 18.3±5.7 | 17.5±5.2 | 16.7±5.5 | 18.2±6.2 |
| Child (2-12) | - | 14.6±6.1 | | | | 13.7±5.8 | 15.7±6.5 |

Table 4. The total baggage counts statistics at selected London airports.

| Airport | EGGW | EGLL | EGKK | EGSS |
|---|---|---|---|---|
| arrivals | 694±59% | 2179±70% | 2645±48% | 1514±62% |
| departures | 870±85% | 1970±81% | 2479±83% | 1462±92% |

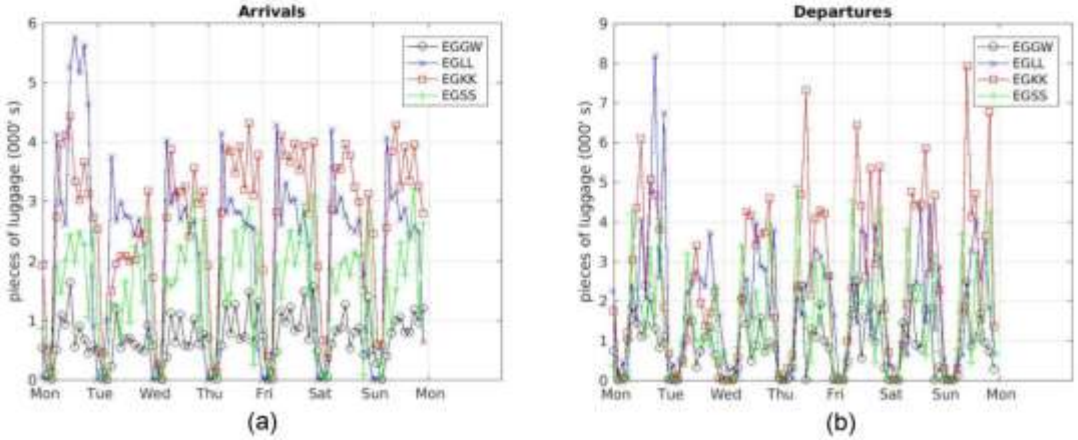


Fig. 2. The estimated number of bags from Greater London arriving to (a) or departing from (b) the selected London airports.

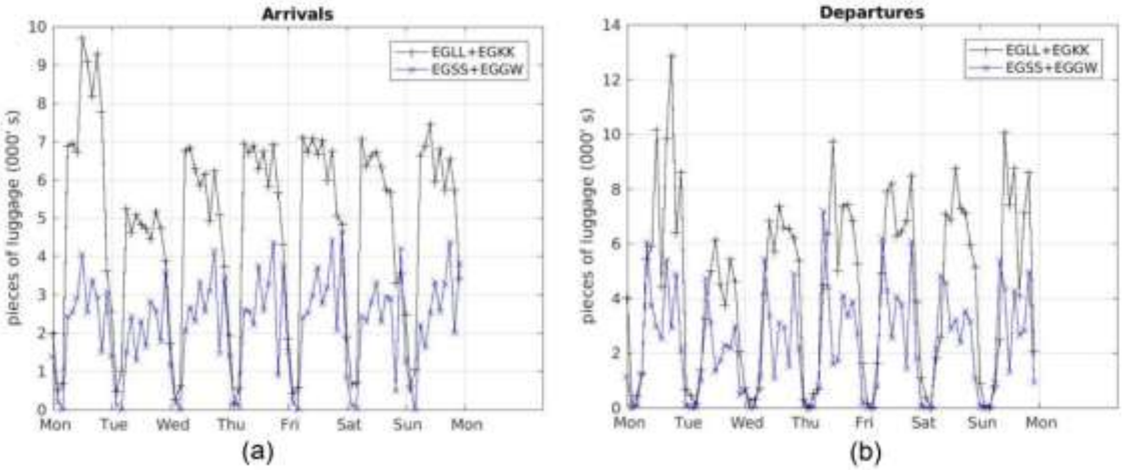


Fig. 3. The merged baggage flows for Greater London from a pair of selected London airports in arrivals (a) and departures (b).

The estimated numbers of baggage produced in the arrivals and departures to and from the Greater London area over one week in July 2016 are shown in Fig. 2. In order to reduce the number of data points, the reported values are accumulated over non-overlapping time slots of 2 hours durations. For each airport considered, we can identify the baggage free windows after the midnight every day, however, the durations of these empty windows are not the same. Thus, there are large variations in the number of baggage produced in the course of the day. The mean values and the corresponding standard deviations for the data in Fig. 2 are reported in Table 4 on the previous page. These results indicate that the largest source of baggage to and from the Greater London area is the Gatwick airport. This is quite possible, since as shown in Table 1, the numbers of terminating passengers at Gatwick are about 50% larger than at Heathrow. Moreover, the variability of luggage at the departures seems to be always larger than at the arrivals as indicated in Table 4. Indeed, as shown in Fig. 2(b), there are distinctive peaks during the day for departures whereas there are multiple such peaks of the similar amplitude for arrivals.

Assuming Table 4 and Fig. 2, we can conclude that the number of baggage being sent between the Greater London area and one of the main London airports is of the order of 100's up to peaks of a few 1000's every two hours. The cumulative baggage flows combining 2 airports are shown in Fig. 3. Recall that these baggage flows would be directed to or emanate from a relatively large, densely populated area of Greater London as shown in Fig. 2. Assuming 12 last-mile delivery districts in Fig. 2, the cumulative flow of about, 4,000 (EGKK) + 3,000 (EGLL), 2,500 (EGSS) and 1,000 (EGGW) = 10,500 of arriving bags every 2 hours, would require the BDS/BCP peak capacity of about, 10,500/2/12 ≈ 440 bags/hour during the day. Assuming departures, similar calculations yield the estimated peak capacity equal to, 7,000 (EGKK) + 4,000 (EGLL) + 4,500 (EGSS) + 1,500 (EGGW) = 17,000 of departing bags every 2 hours, or 17,000/2/12 ≈ 710 bags/ hour during the peak hours of the day. While such baggage processing capacities are technically possible, the associated costs required to develop the supporting infrastructure may be overwhelming. More importantly, large variations of incoming and outgoing baggage flows can be reduced to lower the required baggage processing capacity, provided that buffering over 6-10 hour periods can be tolerated.

## 5. Conclusion

We have reviewed the idea of baggage dissociation to enable the baggage free travel of passengers in air transport. We found that dissociation within the air segment requires dissociation in the ground segments, so it is useful to consider the concept of baggage dissociation first for the ground segment as a necessary but not sufficient condition for the complete end-to-end dissociation. The main advantage of considering baggage dissociation in the ground segment only is that it has minimal effect on the existing processes at the airports. The scale of dissociation critically affects its feasibility. Whereas the dissociation at moderate scales, e.g., for certain groups of passengers, can be readily implemented even as end-to-end, the baggage dissociation offered as a standard service to all passengers is rather challenging. The difficulties in implementing large scale baggage dissociation arise mainly due to the need for creating new baggage processing infrastructure with sufficient handling and storage capacity outside the airports where the interests of airports operators were traditionally non-existent. Thus, the involvement of the 3rd parties to achieve baggage dissociation is inevitable. Even though the baggage dissociation services can create significant new streams of revenue, the question is how much of these incomes can be captured by airports and airlines, and how it is going to affect the overall travel cost for the passengers. The pilot projects where baggage dissociation is offered on certain flights is probably a viable approach to understand the cost implications and the passenger attitudes towards these new baggage services.

Our quantitative study to assess the amount of baggage flowing between the Greater London area and 4 main London airports showed great variations in the numbers of baggage observed each hour throughout the day. Our calculations estimated the required processing capacity at every BDS in the city to be as large as 100's of bags per hour. In addition to this processing capacity at BDS, the same order transport capacity would be required between BDS and BSC. These capacities could be reduced by averaging the baggage flows via intermediate storage, especially for the departures. As a final note, even though we considered the problem of baggage dissociation within air transport, such concept is equally applicable in railway transport and may be even necessary in other modern transport systems such as the Hyperloop project where the onboard space for baggage is rather limited.

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