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Advanced algorithms for improved baggage handling

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Abstract

According to SITA, customer satisfaction in airports depends heavily on the quality of baggage handling and the speed of delivery. However, baggage handling infrastructure is both costly and extremely space-consuming; hence, it is necessary to use the resources optimally. In this paper, we are presenting strategies for optimizing baggage processes in airports for **outbound baggage** and **inbound baggage**. O**utbound baggage** is defined as baggage checked-in locally at curbside, transported to the airside by the baggage handling system (BHS), where it is sorted to a chute (lateral). Based on a case study, we introduce the idea of shifting the assignment strategy of chutes from a *conventional build* to a more handler-friendly *compressed build*. This is achieved without extending the baggage infrastructure, but by using advanced optimization methods to allocate chute(s). **Inbound baggage** is baggage terminating in the airport after the reclaim by the passenger**.** For **i**nbound baggage, the process is different and based on batches. The paper is presenting an idea of how to use an optimized algorithm to allocate reclaim belts in the offloading facilities while improving the experience for passengers in the reclaim hall. The case studies are based on examples from Copenhagen Airport.

Introduction

Air transportation is a rapidly growing industry, and with increased passenger volumes, airports will have to use their infrastructure in an optimized manner[1]. Furthermore, the costs and complexity of baggage infrastructure and airports being an industry with daily-, weekly- and seasonal peaks are contributing to the need for optimization[2]. Optimizing baggage handling is not only crucial for capacity reasons but also to maintain and improve passenger satisfaction, where especially passenger waiting times by the reclaim carousel is playing an important role. A study by SITA[3] shows that the positive emotions of passengers drop to below 54% if waiting time at reclaim belts is exceeding 30 minutes. If the waiting time is below 10 minutes, the positive emotions of passengers are more than 88%. Many industries have benefited from using mathematical algorithms in combination with improved processes to optimize the utilization of infrastructure, reduce costs, and increase customer satisfaction. In a study, Syltevik et al. [4] are showing that there are opportunities to improve efficiency in the airport industry by introducing lean methods, and they encourage future exploration of these opportunities. Even though some airports have introduced algorithms for assignment of chutes and reclaim belts [5,6] , we believe, in line with Syltevik et al. [7], that there is still much room for improvements in the airport industry. Since the flow from curbside to the flight rarely is optimized optimally across the different actors. The case study in this paper is from Copenhagen Airport that has a BHS system, with traditional conveyors, tilt tray sorters, line-based EBS, and laterals. The findings in the article are most relevant for this BHS infrastructure. Airports with different technologies e.g., ICS, rack-based EBS, may find other bottlenecks and challenges.

Processes

In general, there are three main baggage processes, namely, departures (outbound), arrivals (inbound), and transfer (inbound/outbound). The focus of this paper is on departures and arrivals. Departures are the process from check-in to the chute, especially assignment of chutes to flight and the length of the allocation, and for arrivals from off-loading to the reclaim belt. The transfer process is a hybrid between arrivals and departures, where arriving flights are assigned to an off-loading transfer belt, after off-loading of the baggage they are injected into the system as locally departing baggage. From a process view, there are similarities between departures and arrivals. For example, both processes are limited by the fact that processing in advance is not possible. Hence, it is not possible to produce to stock, as in the production processes of physical goods, to smooth out variations in demand.

The process for departures starts in check-in, where a bag-tag is attached to the baggage, and a baggage source message (BSM) is created. After baggage screening, the next step is sorting the bags to chutes where the ground handlers are taking over executing the make-up process. When bags are checked-in early, bags are stored on Early Baggage Storage (EBS) until they are released for sorting to the chutes. See figure 1 for an illustration of the timeline. In many airports, there is a fixed number of chutes assigned to a ground handler, who then is allocating chute(s) to each flight based on preferences and historical allocation.

Arrivals are following a different process where bags are brought from the flight to an off-loading station by the ground handler. Here the ground handler is off-loading the baggage, and the BHS will transport the bags to a racetrack. The allocation of arrival belts is taking place close to the time when the flight is on-block to direct passengers to the correct reclaim hall and belt.

Furthermore, both processes need a close corporation between ground handlers and airports, and both processes are repetitive. There are, however, also differences. The average duration of the process for departing baggage is longer than for arrivals. The intensity of bags when a flight arrives is higher, as it is a batch-based process. Arrivals are seldom allocated to more than one resource (reclaim belt), whereas a departing plane is often using more resources (chutes).

The remainder of this paper studies how we can optimize the baggage handling system (BHS) to support the departure and arrival baggage process in the best possible way. We first introduce concepts from Lean management of processing and then apply these concepts to improve the departing baggage handling and the arrival luggage handling. Both studies are complemented by successful case studies from Copenhagen Airport.

Litterature and theory

Lean strategies for Push and Pull

A *lean* strategy is a strategy that improves processes through the removal of waste[8]. Even though lean strategies have received much attention in many industries, there has not been a similar breakthrough in the industry of airports[9]. In their literature review Syltevik et al.[10] is arguing that this might due to an industry misconception that lean strategies only can be applied in manufacturing and *"resistance to change."* Furthermore, they argue that lean might have the potential to improve efficiency in airports. In their book, *Lean Thinking* Womack & Jones[11] introduced seven types of waste that occur in processes, e.g., storage, transportation, and over-processing. With the LEAN philosophy as the point of departure, many tools and methods have been developed that can help organizations to remove waste, and thus improve quality and customer satisfaction[12]. One of the ways is replacing push- with pull in the processes. In a push process, the materials are pushed through the process from one step to the next, without an actual demand being present downstream. The opposite of a push process is a pull process, where the materials are released from one step in the process to the next upon an actual downstream demand, i.e., the product is first released from process A to process B upon a signal from process B[13],[14]. Scholars in supply chain management, are researching so-called *leagile* approaches. The term is covering a method where the lean approach is working in tandem with an agile strategy, but separated from each other by a decoupling point[15]. Melan[16] argues that processes for services and products have similarities of transformation, feedback control, and repeatability. What is additionally characterizing service processes is the degree of customer contact, that services are intangible, that they cannot be produced in advance and that the consumption is close to the time of the production.

Allocation of baggage chutes

Abdelghany et. al.[17] were some of the first to consider scheduling of baggage handling facilities using a greedy strategy. Frey et. al.[18] presented a decomposition heuristic to balance the workload in the outbound baggage process in Munich Airport. Bart and Pisinger [19]used a greedy randomized adaptive search procedure (GRASP) to schedule outbound luggage handling in Frankfurt Airport. However, these papers only study the baggage handling facility, and do not consider the whole supply chain.

Allocation of baggage belts

Scheduling of reclaim belts has recently been studied in a few papers: Barth[20] present a mixed-integer-programming model for optimal assignment of incoming flights to baggage belts. Results for Frankfurt airport are reported. Frey et. al. [21] study the baggage infeed process at the airport's airside and the reclaim process at the airport's landside, presenting results on real-world scenarios from Munich Airport.

Departing baggage – conventional, compressed and batch build

The outbound baggage handling covers the process from bags arrive at the check-in counters to the handling facilities. The process of outbound baggage is starting at the curbside in the check-in counter. Here passengers are showing up before departure to check-in their bags. In the check-in process, there is a push from the passenger into the system. Many airlines have check-in and bag drop that are open, for example, up to 24 hours before departure. The show-up pattern of the passengers is, in this way, to a certain extent, unpredictable. The check-in service of baggage can first be produced when the passenger is present. For airports, early check-in is beneficial as the security check of passengers can take place as soon as passengers are checked-in. It is minimizing the risk of late passengers for the airlines and is also having a positive impact on the turnover in the airports' commercial units.

After check-in, bags are transported on the BHS to the sortation facilities. Here the bags are loaded into containers, pallets, or carts for the final transportation to the aircraft. If the handling of an outbound flight has not started, the bags are stored in the early baggage storage (EBS). The handling facilities can be organized decentrally (close to the parking position of the departing aircraft) or centrally (in a baggage factory). In both cases, each flight needs to be assigned one or more chutes where the bags can be unloaded from the baggage handling system to the so-called make-up process. Sortation strategies with varying chute opening times are a) *conventional method* b) *compressed build* and c) *batch build*.

The *conventional method* is a method with a relatively long and fixed duration, from the chute is opening, and until it is closing. In this process, there is a push from check-in through the process to the chute. The consequence is that the long and fixed duration of chute opening time is generating waste for the ground handlers, with low production rates per minute. Moreover, it results in sub-optimal utilization of the infrastructure, as shown in figure 1.

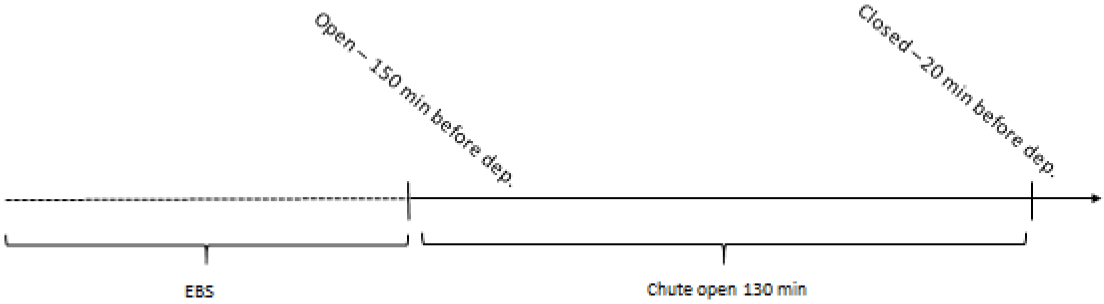

Figure 1: Example of the Conventional Process - using 130 mins. chute opening

An alternative to the conventional method is compressed build. The idea is to reduce the duration of opening time in the chutes by balancing the length of chute opening times against EBS loads, using the BHS infrastructure more optimally. It is based on a principle that most bags are sent to EBS before they are released to the chute. The idea is to decouple the push from check-in by the EBS allowing a more lean operation in the chute with higher productivity. The productivity of the ground handlers is improved, with a higher intensity of bags during the chute opening time compared to the conventional process. It is still a process based on a push from EBS to the chute, but if staffing from handlers in the make-up process is sufficient, the make-up process will generate a pull since there is a continuing need for the next bag in the chute.

Furthermore, reduced chute opening times are enhancing the utilization of the BHS infrastructure. The use of the BHS infrastructure is different than in the conventional process. It requires careful planning of chute opening times that have to be sufficient to handle the baggage volume of the flight. As EBS overflows have to be avoided and there should be adequate time to empty lanes and transport baggage to the chute before closure.

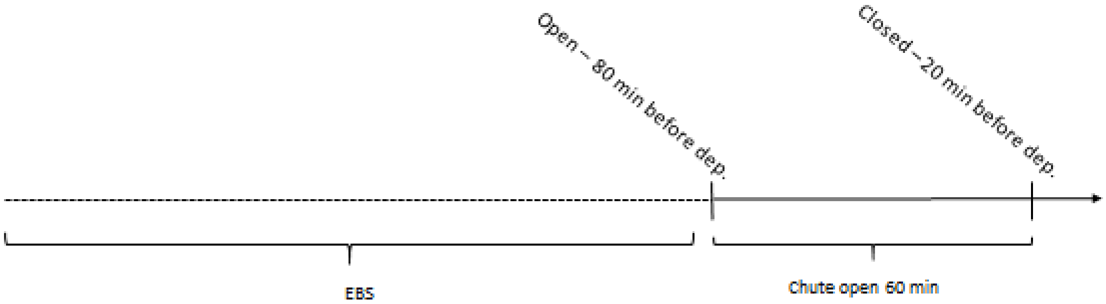

Figure 2: Example of Compressed Build, with minimized chute opening time

Batch build is the last strategy discussed in this paper. It is an approach where all bags are directed to EBS. Here they are pulled by the ground handler whenever a batch is ready. Similar to compressed build, the baggage is pushed into the process check-in, EBS decouples the push. Batch build is requiring more of the BHS infrastructure, as the EBS should be able to produce batches. A conventional line based EBS infrastructure is not ideal for supporting the process since the EBS should be located close to the chute to have a responsive structure. Furthermore, the make-up working station is different for batch production, and floor space is needed around the working station for empty and filled equipment.

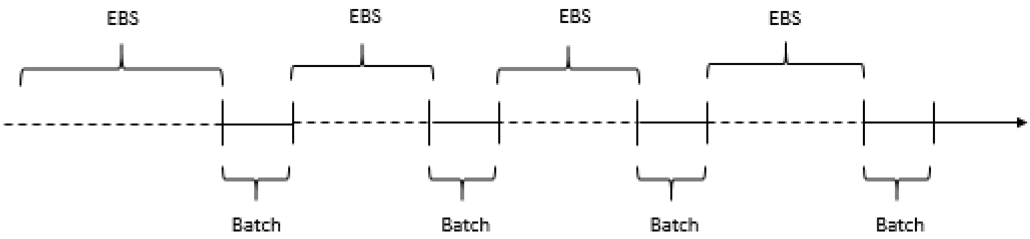

Figure 3: Batch build, with interplay between EBS and batches.

Case study: Improving Chute Allocation in CPH

In 2019 CPH airport, together with The Technical University of Denmark - DTU and the software company Qampo developed an advanced scheduling algorithm for outbound luggage handling. Due to the currently ongoing construction and replacement of BHS machines in CPH airport, the airport had to reduce their facilities from two baggage handling factories to one single factory while at the same time seeing annual growth in departing flights. Furthermore, process focus, efficiency, and optimization are at the core of CPH's strategy.

Until then, CPH was running a *conventional method* for the outbound bags. Typically, a short-haul flight in Copenhagen Airport (CPH) will be assigned a chute 2 1/2 hours before departure, while a long-haul flight will be assigned a chute 3 1/2 hours before departure. Depending on the baggage volumes or whether sub-sorting for the final destination is requested, from 1 to 8, chutes may be needed for handling the bags. The outbound baggage process planning is then to assign the requested amount of chutes to each flight in the required time interval, such that a number of operational constraints are satisfied. These constraints may include handler preferences (e.g., location close to the aircraft), adjacency of chutes for a given flight, compatibility with container heights, etc. To ensure a robust solution, and for the ground handler to execute the process, it is needed to add buffer time between flights at each chute, typically in the order of 15 minutes, to ensure that there is time to unload all bags.

Some initiatives were launched to transform the strategy from the conventional method to compressed build. The first step was to be better at predicting the demand for chutes for each flight. It was to standardize the products, i.e., the number of chutes and the duration of opening of the chute. By using big data analysis and regression methods, flights were clustered into some groups with a similar profile (narrow/wide-body, long/short-haul, charter/route, etc.). Flights in each group had the same demand for resources in the baggage factory. It gave a more fair distribution of resources and made it easier to schedule the requests by having a set of predefined" packages."

The next step was to stimulate the sharing of facilities between handlers. Each handler historically had their segment of the baggage factory with access to the corresponding chutes. Shared areas were introduced to optimize the utilization of the facilities, where all handlers could use the chutes. Fortunately, the ground handling companies had complementary demands. Handlers with mainly charter flights needed many chutes at the weekend, while handlers with mainly business flights had a high demand on working days. In this way, the shared area could absorb the peak demands for each handler at different times, leading to an overall better distribution of the load.

Finally, an advanced scheduling algorithm based on guided local search[22] was developed by Qampo to schedule the outbound baggage handling facilities. The scheduler supports the handlers in assigning the right amount of resources to each flight and provides an overview of all facilities. The scheduler provides a master plan with a feasible schedule of all flights. The ground handlers can afterward adjust it according to their specific needs as long as they stay within the allocated resources. For instance, they can have individual agreements with the carriers, or they prefer to have a higher manning at each chute to shorten the opening times.

The scheduling algorithm makes it possible to decouple the push from the check-in counters by using the EBS intelligently, providing wide windows for the passengers. Moreover, the baggage handling is run leaner, having all bags for a given flight arriving in the chutes within a relatively short interval and at chutes close to each other. In this way, the approach is moved from the conventional method with a fixed chute duration to closer to compressed build.

A further study[23], of the EBS showed that the demand curve for EBS often is complementary to the demand curve for chutes. Figure 4 depicts the amount of bags in the EBS at each time of the day, while Figure 5 shows the demand for chutes. For instance, from 5:00 to 8:00, there are almost no bags in the EBS, while the demand for chutes is high. From 8:00 to 10:00, we see the opposite behavior by having many bags in the EBS and a smaller demand for chutes. From 14:00 to 18:00, both the EBS and the chutes are heavily loaded, but the EBS is not using the full capacity.

This observation makes it possible to optimize the process even further. When the demand for chutes is at the top, the opening time of the chutes can be reduced, resulting in more bags in the EBS. In other words, we can use a *compressed build* to decrease the demand for chute-hours and increase the efficiency of the handlers.

On the other hand, when the demand for chutes is low, we can run a *conventional build.* The opening time of the chutes can be extended if desired, hence, in reality, using the chutes as early baggage storage. It relieves the EBS and might have other benefits as well.

In the afternoon, when both the EBS and the chutes are heavily loaded. There might be an option to use the spare capacity in the EBS to run *batch build*, to increase performance. The latter strategies are not implemented in practice, and whether it is possible to do on a larger scale with current infrastructure is questionable. However, the potential is considerable and is an area of future studies and exploration.

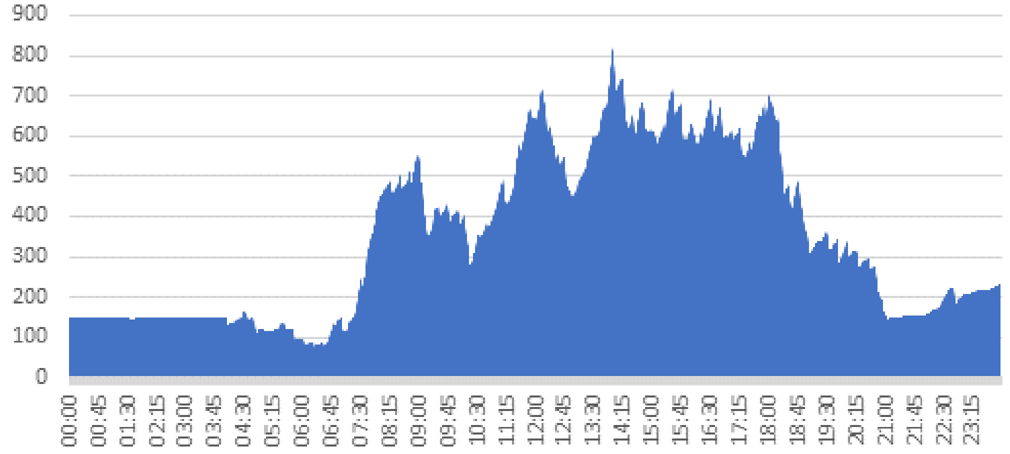

Figure 4: EBS Volume Profile during a busy day (measured in bags).

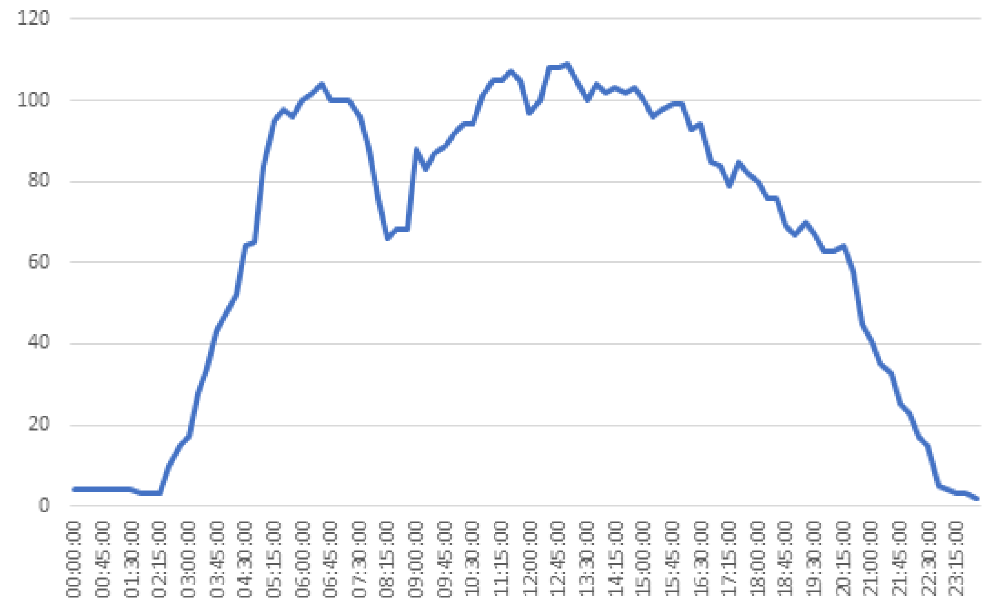

Figure 5: Aggregated maximum chute demand (measured in number of chutes) per 15 minutes in a planning period for all handlers.

Arriving baggage – conventional, compressed and batch build

Arriving luggage – a method to improve allocation

The process for arriving baggage is of similar importance as the allocation of chutes. The process is starting when a flight arrives on the stand. Here the ground handler is emptying the plane and transporting the baggage to the off-loading area in the baggage hall. Baggage can either be bulk loaded or containerized. In the off-loading area, the ground handler is parking at allocated to an off-loading belt. The problem is here to assign incoming flights to belts in the baggage reclaim area. Many airports are maximizing preferences, leading to uneven utilization across reclaim belts[24]. From each reclaim belt, there is a corresponding unloading station in the baggage factory, connected by a conveyor belt. This conveyor belt can function as a buffer between the off-loading station and the racetrack if the racetrack is full of bags, illustrated in figure 6.

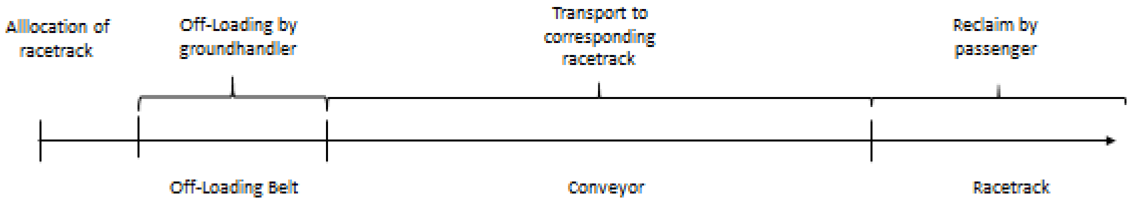

Figure 6: Arrival process

The process is a batch process, where each train with carts/containers is a batch. Depending on the baggage volume on the flight, there might be more than one train with containers/carts per arrival. It is considered valuable to generate a pull from the off-loading belt, to secure that the ground handler smoothly can off-load the baggage without stop/go conditions or similar. When the ground handler is off-loading the first baggage of the flight, a first bag time stamp is registered, and as soon as the ground handler has finished the off-loading, a last bag timestamp is recorded. Passengers' emotions have correlations to the speed of baggage delivery[25]. Hence, the task for airports and ground handlers is to minimize first- and last bag delivery times.

Case study: Improving arrival allocation in CPH

In the period from 2018 to 2019, CPH airport, in collaboration with DTU and the software company Qampo, developed a new scheduling tool to support the arriving process. As opposed to the departing luggage handling, there is no EBS to decouple the push and pull, only some long convey belts from the unload station to the reclaim belt. They are a buffer if baggage is not picked up by passengers from the racetrack. However, as the bags are introduced to the racetrack in the same order as off-loading, it is not possible to use these conveyors to decouple the off-loading and racetrack completely.

In the studied case, each flight is assigned to one reclaim belt. Since the reclaim belts have different sizes, large airplanes can only be assigned to reclaim belts with a large capacity, while small planes can be assigned to all reclaim belts. If possible, there should be some buffer time between two flights to make the solution more robust. Moreover, it was a clear goal to minimize cases where two flights are assigned to the same reclaim belt at the same time. It is because it complicates unloading operations for the ground handlers while lading to congestions on the passenger side and passengers from both flights pushing to stand in front of the belt.

Furthermore, it was a goal to spread out the flights evenly among the reclaim belts, so the passengers will not be concentrated in one part of the reclaim hall. Finally, CPH has some entrances to the reclaim hall, depending on the stand of the flight. Therefore, it was a clear goal to assign reclaim belts close to the stand of the flight to avoid cross-flow in the reclaim hall.
The arriving passengers request a lean reclaim process, where bags are delivered swiftly, and waiting time in front of the reclaim belt is minimized. The handlers request a process in the unloading hall, such that they can unload the bags as soon as they arrive at the baggage factory. The conveying belt between the two is optimized in a way to create a pull condition. It is up to the scheduling algorithm to schedule and assign the delivery of bags from both a ground handler and passenger perspective.

Results after the first four months of operation are promising. There has been a drop in cases where two flights are to be unloaded to the same reclaim belt at the same time. Moreover, the flights are more evenly distributed across the reclaim belts, avoiding congestions of waiting passengers. Finally, the walking distance of passengers, and hence cross-flow in the reclaim hall, are reduced. The scheduling algorithm has further potential, which can be obtained if improving the first bag/last bag predictions and reduce variance in the underlying ground handler processes.

date	description	flights	quality before	quality now
6. June 2018	average day	372	57%	99%
14. June 2018	most arrivals	405	42%	98%
3. August 2018	most bags	363	11%	98%
4. August 2018	many arrivals, many bags	323	20%	92%

Table 1: The potential quality of schedule for reclaim belts before and after the introduction of the new optimization tool (Rude and Pisinger 2019)[26]. Quality is measured as a percent of flights having no overlap with other flights, i.e., the flights are scheduled alone to a reclaim belt. To reach the full potential (quality now) further should be done to improve predictions of first bag / last bag and the underlying ground handler performance.

Before the project, a machine learning model was installed to calculate the expected first bag and last bag from the flights. The allocation algorithm uses this model to have the expected first- and last bag values. If the bags arrive before the passengers, they accumulate on the belt and block for further unloading. If the bags arrive later than the passengers, the waiting passengers will cause congestion in the reclaim hall. The project has shown that first and last bag predictions of paramount importance to the quality of the allocation. Therefore, avenues for future work includes process optimization and focus on the variance in the underlying ground handling processes to reduce the difference between actual and predicted first and last bag times.

Conclusion

Due to the extremely high construction costs in airports and limited space availability, it is necessary to have a holistic view of the whole process and to exploit complementary demands, to utilize the infrastructure in the best possible way.

The process optimization in CPH airport has shown that the process for inbound and outbound bags can be improved significantly. It requires to think differently about the problem, boundaries, and obstacles.

The airline industry frequently solves bottlenecks in the process by investing in more hardware, but this may not be the best approach, and it introduces new problems. More hardware means longer distances for transportation, and a less responsive setup, resulting in a process which is difficult to control. However, using optimization in collaboration with simulation and machine learning may give a considerably better and more flexible process and higher customer satisfaction.

As stated by Henry Ford: “Thinking is the hardest work there is, which is probably the reason why so few engage in it.”

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