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Intermodal connection management with passengers' trajectories

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Abstract

In the course of an intermodal journey, there are varying compensation policies covering topics like missed connections, delays or denied boarding on the intra-modal level. The risks of an inter-modal journey usually lie with the travellers. This study examines how an integrated solution can be offered with the focus on transfer situations for air passengers commuting by public transport. For this purpose, in a first step, the concept of the digital twin is transferred to the traveller, creating a virtual image of his journey, the so-called passenger trajectory. In the second step, scheduled departures and arrivals are blended with these passenger trajectories, resulting in a detailed service demand for all relevant infrastructures and means of transport. The third step is data enrichment with real-time information and forecasts that keep track of demand. Digitisation of passengers' trajectories, system wide information exchange and real-time based situational awareness improve resource utilization as well as intermodal connectivity.

Keywords: intermodality; connectivity; passenger management; priorities

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1. Introduction

In the course of a journey, mode changes regularly take place in which the service providers and the industry-typical regulations usually change along with the type of vehicle. Thus, in addition to the vehicles used in a combined rail and air travel, the compensation policies for missed connections, delays or denied boarding in the case of overbooked capacities differ. Intermodality is also made more difficult by the increased diversity of the modes' process landscapes, particularly at their modal changes. The risks of an intermodal journey usually lie with the travellers, and there are only a small number of genuine intermodal products, such as Lufthansa Express Rail. How meaningful a coordinated product world of different transport operators could be is examined in this study on the basis of the transfer situations for air passengers arriving or departing by train. For this purpose, in a first step, the concept of the digital twin is transferred to the traveller, creating a virtual image of his journey, the so-called passenger trajectory. In the second step, the departures and arrivals from the timetables and schedules are blended with these passenger trajectories, resulting in a detailed service demand for all relevant infrastructures and means of transport. Data enrichment with real-time information (actuals) and forecasts keeps track of demand and may serve as management input.
Thus, with detailed knowledge of the demand curve of critical infrastructures, these infrastructures can be adapted to accommodate actual demand at an early stage. In the study, stochastically occurring disturbances are applied to the timetables in order to depict a realistic dynamic of real operations outside the model boundaries. The resulting variations in process duration can have an effect on the achievement of the intended connections, in particular the intermodal connections which are not managed in today's world. Knowing these time-critical intermodal nodes enables stakeholders to make knowledge-based decisions and thereby satisfy customer needs. We present a performance indicator known as the Boarding Score which describes the quality of traffic handling from the perspective of intermodality.
Using the Boarding Score, traffic management can specifically influence the performance of a traffic node. In addition, the prioritisation concepts for aviation by Grunewald et al. (2018) designed to create a fully rule-based system that does not rely on situation-based decision-making across stakeholder boundaries are transferred to passengers. Using the example of a simulated airport, we show the effects of stochastically occurring deviations on the travel plans of the passengers concerned and contrast them with combinations of prioritisation scenarios in which deviations from schedules are not only stochastically disturbed, but are specifically influenced.

1.1. Structure of investigation

This paper transfers the idea of prioritising flight movements on the runway to the passenger area. To this end and in order to provide an overview, the airside prioritisation procedure is once again presented and the associated effects are outlined. We then describe how prioritisations could be applied to passengers in order to correspond with airside prioritisation. In order to gain an initial impression of the overall impact of traffic on passengers, we have extended the purely airside simulation model to include a generic airport landside. We limit ourselves to the consideration of departing passengers and evaluate the way in which connections are ensured. For this purpose, the non-prioritised case serves as a benchmark, in which passengers are always treated in order of their arrival. Based on the findings gained in the simulation, we outline further application possibilities and discuss practical implementation strategies for the introduction of passenger-side prioritisation concepts.

1.2. Airside prioritisation scenario

On the airside of our generic, simulated airport, there is a form of resource allocation that is very different from today's standard. All planned traffic, which is to be handled on a mixed operations runway, is grouped according to priority. Analogous to Grunewald (2016) there are two strategically allocated priorities 1 and 2, which were assigned to flight movements within the slot allocation system. Priority 1 flights have priority over priority 2 flights. In our example, the priorities have been assigned alternately in each case, so that there are about the same number of aircraft movements with each of the strategically allocated priorities. In real life, the allocation of such priorities would require economic interaction, such as a resource market, which will not be further modelled here. Instead, we use the demand created by simplification in its given structure. The airside prioritisation process aims to increase efficiency of resource use. As shown in the underlying preliminary work, this could be done through an incentive-based system. In such a system, there is not only a market-based strategic allocation of prioritised slots, but also a final prioritisation based on actual demand, i.e. the desire to use the runway. This checks whether the requesting aircraft has arrived at the resource being regulated within a defined punctuality window. Requesting aircraft within the punctuality limits retain their strategically allocated priority (i.e. 1 or 2). Aircraft requesting too late are shifted down the queue and slotted in behind the originally allocated priorities. An aircraft with priority 1 that makes a late request is assigned an effective priority 3, and a late requesting aircraft with priority 2 is assigned an effective priority 4. The ranking of priorities is therefore "1 before 2 before 3 before 4". Early arrival at the regulated resource presents a special case. It, too, is sanctioned with a downgraded priority, although an upgrade mechanism would be appropriate here in order to avoid unreasonable rigidity. If a requesting aircraft arrives too early at a resource that is in high demand and a long waiting period leads to the originally scheduled service time being reached while waiting, then the original priority should apply from this moment at the latest, since the resource was made available on schedule. In contrast to this, delayed take-up always leads to the resource (the slot) being missed and the only way to enable servicing is to renew the resource allocation. Overall, the priority system outlined above results in a service sequence on the runway that tends more towards serving aircraft with high priority in the event of a shortage and distributes required waiting times to lower-ranking customers. In addition, balancing the punctuality of the system incentivises punctual movement, as a lack of punctuality will lead to a downgrade in priority. The last point in particular leads to a qualitative reduction in deviations from the schedule due to the "pricing" of the airport's own lack of punctuality. In accordance with the principles of queuing theory, the variability in the arrival of requesting aircraft is thus reduced, which essentially has a positive influence on queuing performance.

1.3. Landside prioritisation scenario

Taking airside prioritisation as the basis, we are able to achieve planned differentiation of the service classes of the aircraft operating at our generic airport. Assuming that the two classes 1 and 2 are strategically assigned alternately (theoretically there could be any number of further classes), this has an impact on expected punctuality. Flights with a strategically allocated Priority 1 will tend to be more punctual than those with Priority 2 as they will be less affected by fluctuations in runway capacity. Priority 2 flights, on the other hand, will be expected to be less punctual. This applies equally to arrivals and departures, since in both cases slots are required for the shared runway and timing is based solely on the sequence created by the sorted queue. Regardless of the economic allocation model, it is evident that Priority 1 flights have higher productivity than Priority 2 flights, as with lower waiting times they have to spend fewer resources overall, for example for actual waiting for service and for buffer times required in flight plans to avoid unreasonable delays. This economic advantage is a unique selling point of those higher-priority flights and the question arises how this advantage could be used for passenger processes and thus possibly for maximisable ticket revenues. We propose a response here with two appropriately differentiated service levels. Passengers booked for a Priority 1 flight could be allowed to arrive at the airport nearer to scheduled departure time than those booked for a Priority 2 flight. The current system already imposes these kinds of appearance deadlines for travel, but they only differentiate according to the type of flight and the expected average process duration (e.g. domestic vs. international flights); however they apply equally for all passengers who fulfil these characteristics. Today's system also differentiates based on the booking class (economy, premium economy, business, etc.) and separate infrastructures are sometimes provided for these classes. For example, it is common to see separate security stations offering service levels differentiated according to booking class. However, this is done primarily for comfort reasons in order to justify the pricing of airline tickets. In our case, however, available parallel security stations should be used to prioritise passengers according to their flight (and not the booking class).

Passengers with priority 1 flights are therefore assumed to have a spread around arriving at the airport with less time to spare before their flight than passengers with priority 2. There is a mental paradox in arguing that arriving earlier in the case of priority 2 flights does not help if these flights tend to be more delayed. In fact, a Priority 2 flight *may* be delayed, but it does not have to be. However, timing the scarce resources in passenger handling according to priorities is essential for the functioning of product differentiation. In our example, the security check is operated with two different service levels. The security check in our generic airport model consists of eight check lanes in each of the four terminals, which are served from two sides. Passengers of a priority 1 flight wait for service separately from passengers of priority 2 flights. Waiting places vacated in front of a control lane are given to priority 1 passengers first. The disadvantage of dedicated infrastructures is that when they are experiencing less heavy usage, they cannot be used for servicing lower priority customers and thus operate less efficiently; physically separating only the queues rather than physically separating the control lanes means that we avoid this disadvantage. The passengers of a Priority 1 flight reporting closer to their departure time may expect rapid completion of pre-flight activities due to their prioritised service at the time-critical security control infrastructure. The larger buffer time that priority 2 passengers should plan for in order to be considered as reporting on time will be taken up by the longer service times which may be required. At the end of the day, it is advisable to influence the distribution of the arrival of travellers by means of conditions and/or incentives in such a way that both customer groups achieve comparable connection rates despite different service levels. By connection rate here we mean the boarding score, a term which we coined to describe the percentage of outbound passengers who have actually caught their flight (i.e. arrived at the gate in good time before the actual off-block).

2. The passenger trajectory

The concept of trajectory management, which is applied here in a more specified form, was introduced in Engler et al. (2017) to record passenger travel chains. The object trajectory here is the passenger trajectory and is illustrated using the example of departing passengers for the area within the airport. On the basis of the flight plan used, based on real data from Gatwick Airport and the aircraft using it, a suitable number of passengers was determined for each flight departure. This total demand of each departure was then applied to individual generic passengers. Each passenger starts in the simulated world with his arrival at the airport terminal. The corresponding milestone is OPAT. A passenger's OPAT was determined from a triangular distribution which is different for priority classes 1 and 2 and indicates the passenger's arrival before the scheduled off block time (SOBT).

Table 1: Variables of triangular distributions for airport arrival before departure

	PRIO 1	PRIO 2
max	120 minutes	180 minutes
peak	60 minutes	90 minutes
min	20 minutes	45 minutes

Within the airport terminal, departing passengers pass through a sequence of milestones that mark their arrival at a process location and the end of their service at this location. In the model, the usual process item "border control" was omitted, since this depends on the location of the airport and the destination of the flight. In our simplified model all passengers successfully arrive at the airport, and entering is not a separate process (although it could be if this area were already subject to restricted access). The next process point is check-in which, however, may already have been completed virtually (remotely). Now follows security control reordered by us. Passengers who reach the waiting area (this milestone is represented by “actual outbound passenger at security time, AOPST") are served according to service level and leave this area correspondingly faster or slower (milestone "AOCST", see table 2). Upon arrival at the gate ("AOPGT") it is decided whether the passenger has arrived on time and caught his flight ("AOCGT"), or whether the gate has already closed and the plane has been missed. Only the actual values of the milestones are used in our simulation. Since the simulation is also used for researching active management procedures, further milestone characteristics exist. For example, there are values for each milestone for expected times, which are estimated values and marked with the prefix "E" instead of "A".

Table 2: Departure passenger milestone definition within terminal

milestone	milestone description
AOPAT	actual outbound passenger at airport entrance time
AOCAT	actual outbound (passenger) checked at airport entrance time
AOPCT	actual outbound passenger at check in time
AOCCT	actual outbound (passenger) checked at check in time
AOPST	actual outbound passenger at security time
AOCST	actual outbound (passenger) checked at security time
AOPGT	actual outbound passenger at gate time
AOCGT	actual outbound (passenger) checked at gate time

3. Results of the simulation

Table 3: Quality of service measures for departing passengers at security control

scenario	indicator(s)	number [1]	average [hh.mm]	std. dev. [hh:mm]	max [hh:mm:ss]	min [hh:mm]
pax equality						
	all	49,568	00:25	00:36	02:19	00:01
	all & OK	41,765	00:13	00:21	02:16	00:01
pax prio						
	all	49,568	00:23	00:41	03:34	00:01
	PRIO 1	24,281	00:06	00:05	00:24	00:01
	PRIO 2	25,287	00:39	00:53	03:34	00:01
	all & OK	44,388	00:11	00:18	02:39	00:01
	PRIO 1 & OK	24,164	00:06	00:05	00:24	00:01
	PRIO 2 & OK	20,224	00:17	00:25	02:39	00:01

*"all": total demand of departing passengers; "OK": number of actual departing passengers (arrival at boarding gate before closure); "PRIO 1" ("PRIO 2"): passenger with priority 1 (2) at security check queue

In our trial, we have a total passenger demand for departing flights of 49,568 passengers. In the reference case, where there is no passenger preference in the simulation but the passengers are served strictly according to FIFO, 41,765 passengers catch their flight. Almost every fifth passenger misses his flight and we have to admit that we have exaggerated the scenario a bit. Airside this is a very busy scenario and we have now induced even tighter timing in the terminal with the values for triangular distribution which are purely assumed values and cannot be directly derived due to a lack of real models. However, the high number of stranded passengers serves as a basis for illustrating the prioritising procedure, which is effective in cases such as this where resource scarcity is particularly acute. On average, passengers wait 25 minutes at security for service, with the value showing a wide spread. Passengers who arrived at the gate in time ("OK") in the end on average had to wait only 13 minutes. Since service takes place strictly according to FIFO, a large portion of the passengers simply had no fair chance.

The initial reaction to prioritising passengers at the security lane according to PRIO 1 and PRIO 2 flights is that it must lead to an even greater lack of fairness and we must confirm that these were our own expectations before the experiment, especially by recognizing our previous studies as for example described by Grunewald and Popa (2014). There we had a unique distribution for all incoming passengers, but now we changed it for dedicated arrival times depending on one’s flight priority. Nevertheless, under the chosen circumstances and boundary conditions, a significantly better average result can be presented. Instead of the 41,765 passengers in the reference scenario, 44,388 passengers now catch their flight. The missed flight rate drops from just under 16% to a good 10%. Of the PRIO 1 passengers almost all reach their flight and a majority of the PRIO 2 passengers as well. Controlling the timing of the scarce resource of security control has thus led to improved overall performance, which has essentially given priority to those whose departure is in the near future. Since the passengers arrived at the airport with different lead times depending on the PRIO category of the flight, prioritisation of the PRIO 1 customers leads to this result. It is also helpful that the scarcity of airside resources, which was also generated by a compressed flight plan, leads to delayed departures. We have assumed that these delays can still be used for boarding, so the plane has not yet gone off block and the gate remains open until then.

4. Simulation environment

The generic airport simulation model developed in the Optimode.net project and described by Milbredt et al. (2018) was used for the simulation of the different prioritisation variants, and extended by the prioritisation algorithm.

An essential feature of the model used is the modular design of the generic airport. This means that recurring process points such as check in desks or security lanes can be integrated into the model in various forms. This type of modelling allows a very simple scaling of the generic airport from a small regional airport to a continental hub.

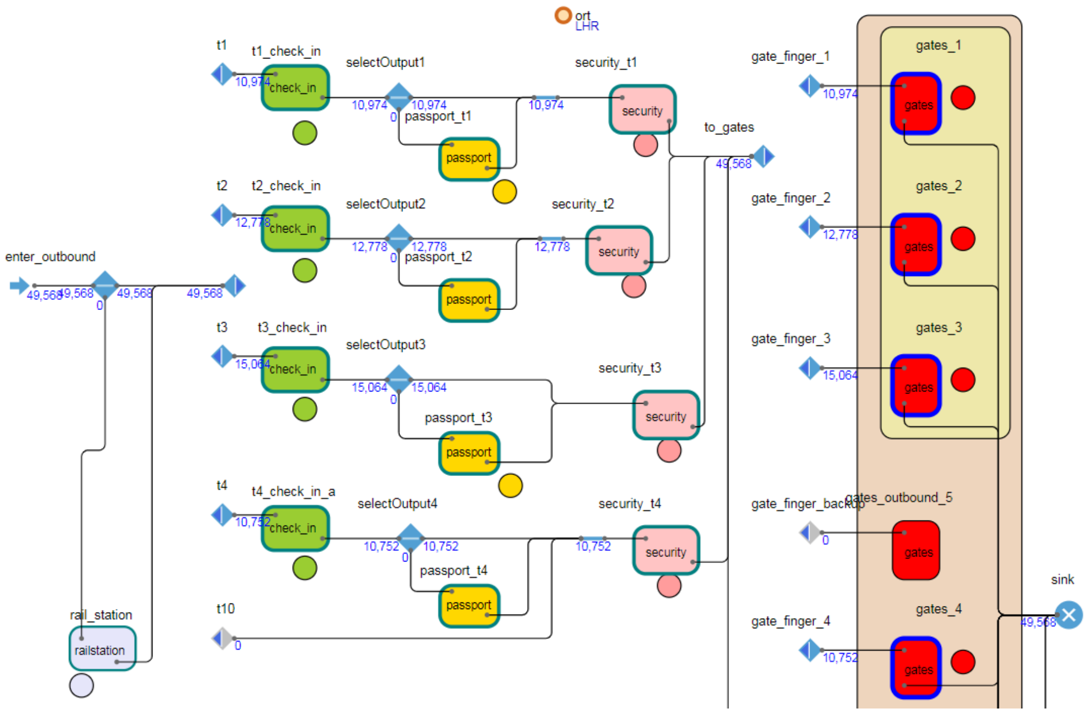

Fig. 1 Modular structure of the simulation scenario

The existing security module with first-in-first-out sequencing and first-class security lane was extended and modelled with flight-related prioritisation.

In this case, each security module consists of 8 security lanes. Strict first-in-first-out applies to the individual security lanes themselves, the capacity of the waiting area of the individual lanes was defined as a maximum of 20 persons. 2 further queueing areas were modelled upstream of these lanes, one area for each prioritisation level, these areas were assigned a maximum (infinite) capacity.

Fig. 2 Schematic structure of the safety check

In these areas, first-in-first-out also applies initially, however, passengers booked on a flight with Priority 1 will be preferred when merging. Passengers who have booked a flight with priority 2 will be processed only if there is no prioritised passenger in the waiting area. There is the possibility of adding in a timeout for passengers; this timeout allows passengers who have been in their waiting area for more than 50 minutes to leave it immediately and be forwarded directly to the security lanes via a bypass. A further virtual waiting area with first-in-first-out was added in the modelling for structuring purposes.

The simulation runs a complete day from 0:00 to 23:59, simulating approximately 50,000 departure passengers spread over 315 flights. The distribution consists of 158 prio 1 flights and 157 prio 2 flights. There are 24,281 passengers who have booked a Prio 1 flight and 25,287 passengers for a Prio 2 flight. Two scenarios are simulated, the first scenario takes place without prioritisation (pax_equality) at the security control and the second scenario uses the described procedure (pax_prio). The time stamps of each passenger's trajectory are recorded in the raw data generated from the simulation. This data can be used to calculate the process times at the service stations and also to determine whether this passenger is available at the gate in time for his flight. The times of the individual passengers aggregated over the service times are used for evaluation.

Table 3 shows the results of these two variants. In pax_equality, out of 49568 passengers, 41765 reported at the gate in time. The average service time at the security checkpoint was 25 minutes with a standard deviation of 36 minutes. In the pax_prio scenario a total of 44388 passengers reached their gate on time. 117 prio 1 passengers reached their gate too late, while 5063 prio 2 passengers would miss their flight.

In addition to the higher total number of "in time" passengers, passengers booked on priority 1 flights in particular catch their flight thanks to the landside prioritisation which is also taking place. In the case of priority 1 passengers, in addition to the significantly lower average service time of 6 minutes, there is also a much smaller standard deviation of 5 minutes, which is also reflected in the maximum value of 24 minutes. Passengers on Prio 2, on the other hand, have an average waiting time of 39 minutes, and also a very high standard deviation of 54 minutes and the maximum value of 3:34.

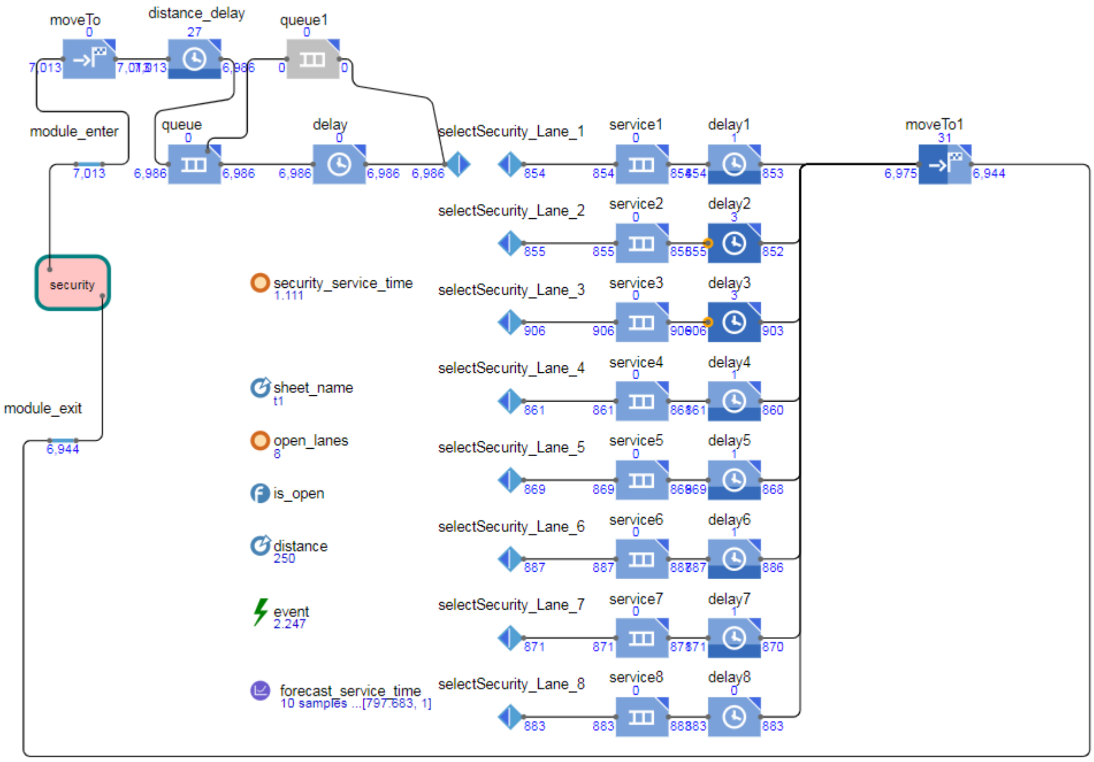

Fig. 3 Modelled structure of the safety check

5. Conclusion and outlook

With an airport model extended to include an airport landside, we have presented how intensified airside priority control could also contribute to an increase in landside performance. The priority-based handling of aircraft taking off and landing on a runway system does not comply with the agreed rules of civil aviation in the first place, and the current legal situation does not permit a transfer of such a system to passenger processes at an airport. Nevertheless, we have used simulations to investigate how the resource efficiency of particularly scarce transport infrastructures could be increased. The diversification of service levels can actually create added value if they are defined transparently from a regulatory point of view and if they are committed to well-fare. On the one hand, there is the clearly incentivising component of allowing aircraft to operate more punctually if this is rewarded in sequencing. The chance to select a level of service may safeguard the connectivity for any modal change in cross modal networks; this feature is not available in today's world that favours one single service level for all with ups and downs depending on capacity and demand variations. The diversification also creates a lever to economically meet the various user demands for availability, flexibility and punctuality of resource provision.

Binding standards have yet to be created for the actual transfer of the prioritisation models to the airport airside and landside. Treating passengers differently according to the priority of their flight (and not their class of travel) as proposed here may have a positive effect on overall performance, but not necessarily. It depends on the actual design of the influencing parameters and how customer behaviour could be controlled. The passenger arrival times used in this simulation, however fictitious they may be, show enormous potential for optimization as long as there is a measurable difference independent of the actual value. The question of the economic model behind airside prioritisation and in ticket sales opens up a wide field for further research - or for pioneering work by the industry. The product differentiation possible today in line with ticketing classes is legally compliant and as fair as it can be, so a different kind of differentiation could equally well arise.

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