Chapter 12
Airport Logistics Operations

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Abstract In recent years, air traffic has increased dramatically while airport capacity has remained stagnant. This has resulted in congestion problems which degrade the performance of the air traffic control system and cause excessive costs. Despite recent technological advances in the airport airside area, some procedures and operational rules in the landside area are years behind airside capability. In this chapter, a discrete-event system view of airport operations is introduced. The main aspects of delay propagation due to a lack of coordination policies will be illustrated using an Arena© simulation model.

12.1 Introduction

In the air traffic management (ATM) context, the terminal manoeuvring area (TMA) is the most complex subsystem due to the dynamics of the aircraft movements in the airside (conflict-free trajectories) and the scheduling of the airport infrastructure (runway, taxiway, parking, gates) together with the services (ground handling segment). Nowadays, TMAs are the main bottleneck to supporting the future expected increase in air traffic flow capacity. Furthermore, the TMAs are the areas that urgently require operational efficiency improvements in the airport airside and landside operations.

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Airlines are constantly demanding a reduction in the waiting time at the end of the runway to take-off and in the holding trajectories for landing, which results in poor cost effectiveness due to excess fuel-burn and wastage of time. Thus, there is an economical and social motivation to focus extra research efforts in order to solve the congestion problems in the TMA. In fact, the pressing need to improve airport efficiency has also been confirmed by an analysis of Eurocontrol data, in which three-quarters of the delays longer than 15 minutes (with respect to the planned times) generated in airports are due to poor activity coordination.

There are several recent technological advances, such as new aircraft with greater fuel efficiency, huge air freighters, an expanding general aviation fleet, together with better navigation and surveillance technology (ADS-B, satellite navigation, GPS, etc.) that are paving the way to a competitive air transport system. Nevertheless, delays are still generated and propagated in most airports. Improving air transport KPIs requires not only addressing the technical aspects, but also the tactical and operational procedures that condition both operational effectiveness and economic practicality.

Solutions to this problem vary according to the planning horizon. Long-term considerations involve building new airports and additional runways. Medium-term approaches focus on ways to disperse traffic to less-busy airports through regulations, incentives, etc. Finally, short-term solutions aim to minimise the unavoidable delay costs under the current capacity and demand. This chapter will focus on the airport dynamics that belong to the latter category.

12.1.1 The Current System

Some of the early strategies developed to handle the above problems started by improving airport infrastructures, e.g. building additional runways, taxiways, or terminals [1] and increasing handling resources. Stand-alone solutions, like additional radar, or control tower extensions, were also established; however, most airport managers realised after a short while that oversizing infrastructure and updating technology were not synonymous with airport efficiency. Instead, airport taxes increased, delay propagation at the operational level remained, and the passenger service quality factor (SQF) did not improve proportionally to the increase in airport taxes.

Despite the fact that new functionality was introduced through different technological changes, such as replacing old aircraft with new ones, thus expanding new capabilities of efficient aircraft operating possibilities, the rate of introduction of new tactical and operational ground airport alternatives has hardly changed.

It should be noted that congestion problems become more serious when air traffic increases. Airport resources are often exhausted, working at their limit, while at the same time some resources are idle or oversaturated during certain time frames. Air transport market competition and a lack of partnerships between handling operators, together with unpredictable arrival/departure aircraft times, make a deeper knowledge about airport dynamics necessary in order to improve its ability to respond efficiently to any time deviation with respect to the proposed scheduling.

Airport operational activities should be understood as a highly coordinated evolutionary process which requires planned periodic changes rather than reactive changes in configuration, with a procedural collaboration between the different airport operators (see Sect. 12.2). Nowadays, ground-based ATM capability in some areas is years behind airside capability; many of the landside operational procedures are based on the extension of past and current operating practices. To define new operational procedures at fundamental levels, the roles and operating methods of all members that interact in an airport's operational activities must be identified and the propagation of the consequences of their decisions should be properly understood in order to be able to deal with a safe and economically viable system that provides benefits and allows for sustained growth.

In order to handle adequately airport decision support tools and adapted operational procedures for the operators, a deep knowledge of the interactions, as well as the quantity and quality of the different relationships between the operations performed by the different airport operators, is essential to properly address the on-ground problems. Airport operators must have the means (systems and procedures) to coordinate the different operational actions in order to hand over efficiently the control of each aircraft.

Simulation models can contribute immensely to a better understanding of all interactions and of the different consequences of any decision made by an airport operator, and can help design the improvements and procedures that can be most easily integrated into a continuously evolving transitional process involving systems with a wide range of capabilities.

12.2 Main Airport Subsystems

A high-level description of the main phase sequence through which an aeroplane must flow from its arrival to the TMA until its departure will be introduced in order to provide a better understanding of the airport decision variables and their impact on overall airport performance. This section includes background information on an airport's operational environment. It describes the main partners and their services with the aim of facilitating the understanding of the main interaction that should be modelled to improve overall airport efficiency.

Airport decision-making is primarily carried out by four main operators: airlines, ground handling segment, airport operations and air traffic controllers (ATCs). Airline operators and handling agents can sometimes be grouped as one entity, since handling agents are considered to be the representative of the aircraft operator and act on their behalf. In fact, at an airline's home base, all the activities are normally performed by the aircraft operator's own staff. At other airports, some of the activities are delegated (outsourced) to the handling agent.

Decisions are made with the objective of optimising airport capacity (use of available capacity through the maximisation of resource use, throughput, etc.). These are based on information (e.g. arrival and departure time estimates) that changes over time or has poor timeliness/accuracy. Such data is received from various sources (airlines, handlers, local ATCs, etc.) and constrained by several variables: the operating airline's schedule, aircraft type, destination country, passenger information, terminal and pier capacity, etc. Unfortunately, each operator runs its own information distribution system, collecting data from dedicated sources within its own domain, without cross-fertilisation of information between the different operators.

12.2.1 Airport Operators

Airport operations are responsible for the management and allocation of airport resources, such as the planning of stands and gates, check-in desks, baggage reclaim belts, apron management and security management. In certain airports, aircraft operators and/or ground handlers self-manage their allocated resources (stands, check-in desks, etc).

Despite the fact that a first estimate for stand and gate allocation for a specific aircraft can be computed when the flight takes off from the originating airport, gate assignment decisions are often made at the very last moment when the aircraft is landing, due to the lack of an accurate landing estimate (landing sequence is established 10–15 minutes before landing when the flight passes into the approach area), unexpected delays in taxi-in time, or limited knowledge about the pushback of the preceding aircraft at the gate.

A last-minute gate assignment could avoid these drawbacks; however, lead time differences between aircraft movement and passenger movement in the terminal platform limits this possibility. It should be noted that airport operation planners only update the original gate assignment if there is a significant delay in the off-block time (in principle, more than 15 minutes). This gap can cause some aircraft to be directed to remote points while there are free contact points.

12.2.2 Air Traffic Controllers

The ATC tower is in charge of aircraft operating in the airport's manoeuvring area and within the airspace around the airport (holding trajectories). With regard to airport logistics, the ATC can be seen as the boundary conditions of the airside workload at the airport, by establishing the arrival and departure sequence based on the traffic at the holding points.

Other decisions made by the ATC are: issuing clearance for pushback and taxi, guiding aircraft from the parking position to the holding point for outbound flights and from the runway exit point to the apron entry point for inbound flights.

Any change with respect to the scheduled times is propagated as delays or resource idleness to the other airport operators.

12.2.3 Airlines and Ground Handling Segment

Ground handlers provide services to both aircraft and passengers. Some of the tasks associated with passenger services are:

- Lounges and VIP services
- Passenger assistance
- Check-in, gate and transit
- Ticketing

Some of the tasks to be coordinated in relation to aircraft services are:

- Baggage transportation
- Aircraft loading and unloading
- Ramp support
- Pushback
- De-icing
- Operation control
- Load planning
- Supervision
- Ground equipment maintenance

Figure 12.1 illustrates different ground handling operations that should be properly coordinated to avoid delay propagation to the other airport operators.

Aircraft operators (AOs) are responsible for complying with their assigned slot. Most AOs use conservative models to estimate the taxiing period in order to be sure that the aircraft will be ready for start-up in sufficient time, which leads to a situation where many aircraft are often waiting at the end of the runway, resulting in very poor KPIs in relation to efficiency, environment and cost effectiveness, due to excess fuel-burn and wastage of time.

The taxi period includes not only the time to taxi from the parking area to the end of the runway (a default value for each particular airport), but also the waiting time at the runway, which in turn depends on various data, such as the number of arriving flights and departing flights.

Fig. 12.1 Ground handling operations

12.3 Collaborative Decision Approach Benefits

Despite the fact that there is an unavoidable cost due to changes in weather conditions (e.g. visibility, wind) which can justify a drop by half or even more in airport capacity due to bad weather conditions, there is a considerable amount of delay generated at the airport and propagated through the operational activities (http://www.euro-cdm.org) resulting from poor coordination of the operations [2].

Nowadays, from a functional point of view, most airport activities are considered and tackled in an independent way by different departments. Under the present operational situation, any perturbation can be easily propagated through the airport, affecting passenger service quality factors and airline company costs. Some examples of problems that could be mitigated with better knowledge of airport dynamics are:

- Gates are allocated to flights based on their scheduled arrival times. Lack of exact arrival time information when flights are late can result in empty contact stands while other aircraft are parked at remote stands. This increases turnaround times because handling resources located at the contact stand must be moved to remote stands, or remain idle near the contact stand.
- Changes in the landing sequence made by ATCs may allow certain aircraft to arrive earlier to the parking area. If handling or ground crew are not ready to handle the aircraft, the disembarking operation will be delayed, thus decreasing SQF because passengers will be forced to wait, and increasing airline costs because terminal occupancy will be higher.
- Handling resources (e.g. pushback trucks) are not always in place under the right aircraft because the staff is unaware of the departure sequence or pushback sequence.

A single delay in a certain operation can be easily propagated through all the airport subsystems. It is easy to notice that in order to avoid idleness in handling resources, handling operations should be scheduled to saturate workers and resources while providing a timely service. In this context, a delay in the start of the pushback operation will cause a delay in the freedom of the truck, which will force a delay in attending to the next pushback operation.

The design and proper application of new operational procedures that could take in consideration the state of the airport at any moment will provide better SQF to passengers and can propagate benefits to the different airport operators [1].

Some benefits provided to ground handling operators are:

- Improved pushback productivity thanks to better use of staff and reduced inactive time due to inefficiencies (e.g. less time wasted by ground vehicles)
- Reduction of (indirect) operating costs as a result of a reduction in delays
- Knowledge of the precise status of arriving aircraft well in advance that will optimise the handling of flights

Some benefits provided to airline operators are:

- Pre-departure sequence can be optimised, better ground movement and more efficient take-off order, less idling on the ground.

- More capacity maintained during adverse conditions and the return to normal conditions can be faster. Both can result in major cost savings.
- Optimisation of gate utilisation and other ground resources. The effects of late incoming or departing flights and missed connections can be reduced.
- Greater predictability leads to greater use of staff resources since rosters can be organised to meet demand. As a result, crew management costs can be reduced.

Some benefits provided to the ATCs are:

- A collaborative pre-departure sequence enables ATCs to take user preferences into account.
- Accurate taxi times increase the accuracy of the calculations in which taxi times are used, improving predictability (benefit to all partners).
- Constant work load, preventing controllers from becoming fatigued due to work overload.

Some benefits provided to airport operations are:

- Reduced delays and hence greater predictability leads to a greater use of staff resources since rosters can be organised to meet demand. As a result, staff employment costs can be reduced.
- Better information related to the departure and arrival sequence can result in a significant improvement in the planning capability for further operations and also allows better quality information to be dispatched to relevant partners (e.g. passengers and handling agents).
- Having knowledge about the departure sequence should improve the allocation of stands and gates.

12.4 A Discrete-Event System Approach

In this context, it is important to view the operations from the airport perspective. For the airport, the flight has three phases: an inbound phase, a ground phase and an outbound phase (see Fig. 12.2). A delayed inbound flight has an impact on the ground phase, but also on the outbound phase of the flight with the same airframe, on the crew and on the flights carrying connecting passengers.

To avoid delay propagation, a deep knowledge about all the events that take place and their interactions in each phase is important. Thus, by considering the ground phase, the turn-around, landing, take-off and taxiing operations can be formalised as a set of inter-related events which, properly coordinated, will satisfy the aircraft operative needs under certain SQF. With a proper model specification

Fig. 12.2 The three flight phases

considering its interactions with inbound and outbound phases, it will be possible to optimise operation efficiency through the proper management of airport resources (e.g. airport slots, stands and gates, check-in desks and baggage belts), considering the dynamics and costs of the passenger and aircraft operations.

In the particular case of turn-around operations, it is easy to understand the system dynamics from a discrete-event system approach, in which each operation has a certain number of pre-conditions, a duration time estimation, and a set of post-conditions (changes in the state of airport information). Figure 12.3 illustrates the different handling resources that should be properly coordinated to provide an efficient service to the aircraft.

To improve ground handling performance, a discrete-event simulation model that could provide resource planning and staff allocation closer to scheduled times would eliminate the need to plan additional time buffers for staff in order to cover delayed outbound flights. Some indirect consequences of improving ground handling efficiency would be higher productivity, and thus higher revenue or a reduction/elimination of operating costs, e.g. greater use of resources leads to a reduction in current operating costs (like those generated by resource allocation conflicts) and the elimination of future operating costs (less need to hire staff and buy equipment thanks to greater use of existing resources). Poor rescheduling when flights are delayed increases the volatility of the resources needed. As a result, the redundancy required is impacted, as is the cost of providing the service.

A coloured Petri net model describing the sequence of the turn-around operations was developed to tackle the ground handling operations from a logistics point of view. In this model, it is possible to apply different scheduling and planning policies in order to provide a proper answer considering the well-known ‘7 Rs rule’: ‘Ensure

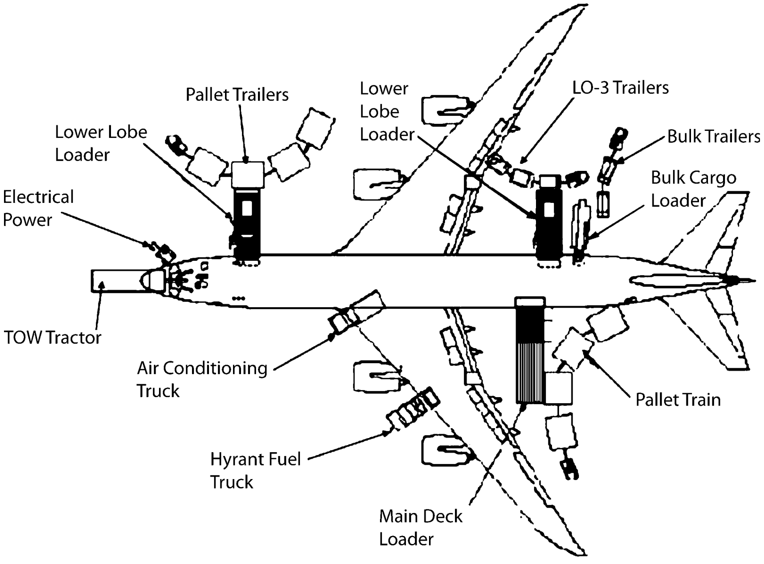


Fig. 12.3 Turn-around aircraft locations for ground handling

the availability of the Right product, in the Right quantity and Right condition, at the Right place, at the Right time, for the Right customer, at the Right cost'.

12.5 Palma de Mallorca Airport: Check-In Assignment Sensibility

Palma de Mallorca Airport (PMA; http://www.aena.es) is considered the third busiest Spanish airport [3] regarding the flow of passengers/year (23,228,879 passengers in 2007) and the number of aeronautical operations (197,384 movements in 2007).

The main infrastructure characteristics are:

- Two runways that can be operated independently: both can be configured for landing operations or take-off (06R has some restrictions due to environmental measures).
- 28 contact points and 42 gates for remote points distributed in four different terminals.
- 204 check-in points.
- A maximum airside capacity of 60 movements/hour: 32 arrivals/hour, 30 departures/hour.
- A maximum landside capacity of 6,000 pax/h (outbound passengers), and 6,300 pax/h (inbound passengers) (5,600 EU pax/h and 700 non-EU pax/h).

Figure 12.4 illustrates the runway and terminal configuration at PMA.

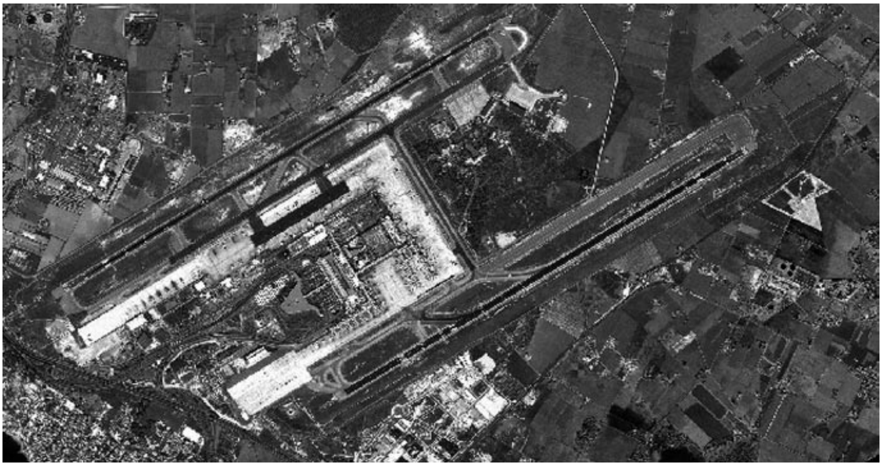


Fig. 12.4 Palma de Mallorca runway and terminal configuration

To improve the passenger and airline quality factors, PMA has recently designed a new functional area called the ‘Production Department’. This department works to ensure proper passenger, baggage and aircraft synchronisation during the boarding operation, considering the quality service and security levels defined by the airport and the present standards. The lower part of Fig. 12.5 shows the classical PMA model approach used to address the airport operational activities. The upper part of the same figure illustrates the functions of the new Production Department.

As can be seen in Fig. 12.5, the new Department seeks to coordinate the planning of the Airside Operations, Terminal Operations, Security & Safety and Infrastructure and Information Technology Systems Departments, in order to:

- Monitor and supervise the state of the airport at any moment.
- Coordinate the best actions to be implemented in each department.

12.5.1 Delay Propagation in the Passenger Flow Area

The check-in processes at PMA are grouped into two primary areas at the main entrance building (at floor level). They are distributed in six parallel blocks with 32 counters in each (see Fig. 12.6).

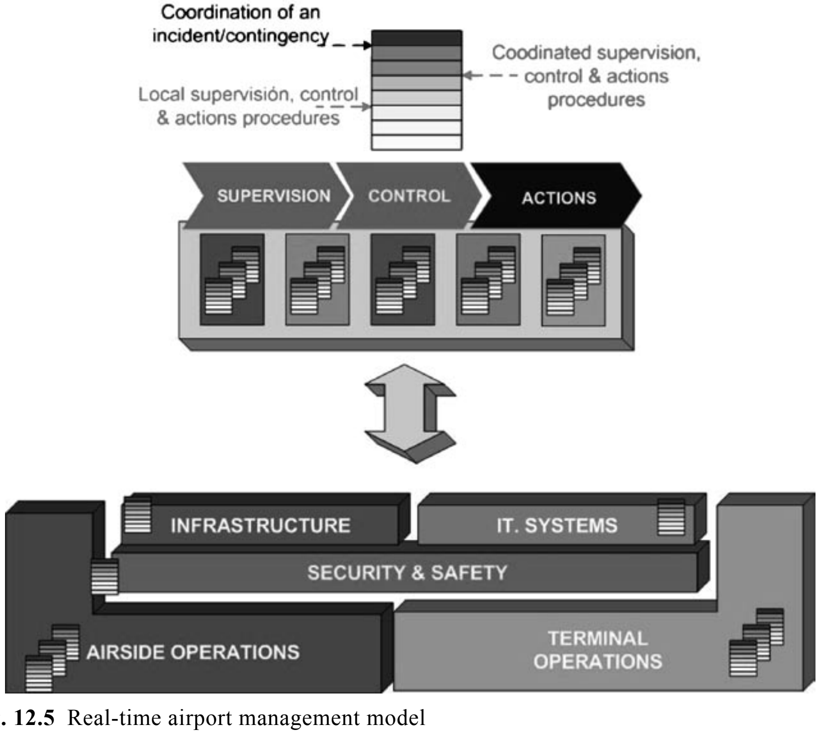


Fig. 12.5 Real-time airport management model

The check-in assignment is highly flexible, so the operational assignment can change daily according to traffic demand, traffic typology (i.e. regional, charter or conventional airlines, individual or block operations) and commercial aspects.

Before passengers can access the terminal area, once they have checked-in, they must pass through the security filters, which are placed at both sides on the second floor (see Fig. 12.7). Security is a very sensitive process which requires intensive human and technical resources and can drastically influence the time required by passengers to move from the check-in area to the gate. It can also influence turn-around time. Thus, to avoid extra delays, it is important to rearrange the number of open security filters on each side in advance (planning policy) or to redirect the passenger traffic to the opposite security area in order to balance the queues (reactive policy).

Since passengers will choose the security area closest to their check-in area, the check-in assignment model should consider the workload estimations in each security area to improve security assignment planning. Figure 12.8 shows the estimated

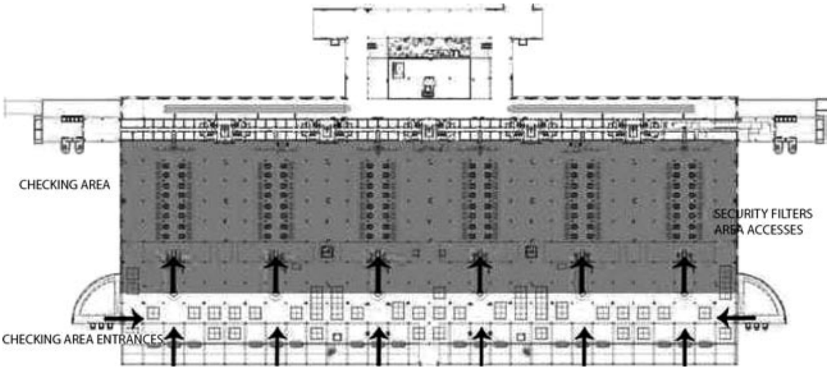


Fig. 12.6 Layout distribution of the check-in counters at Palma de Mallorca Airport

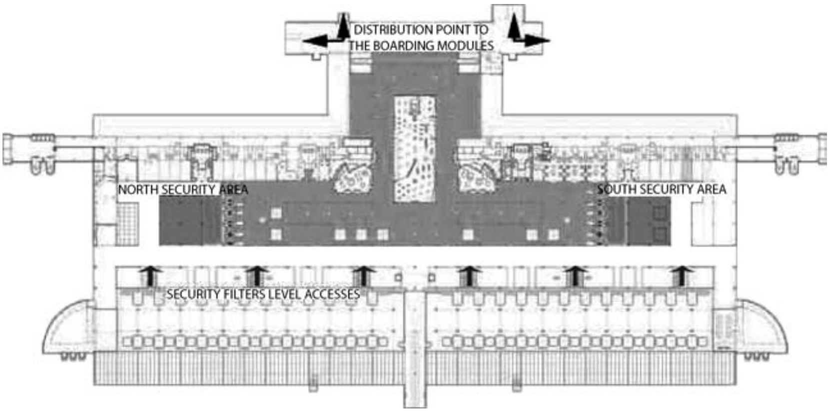
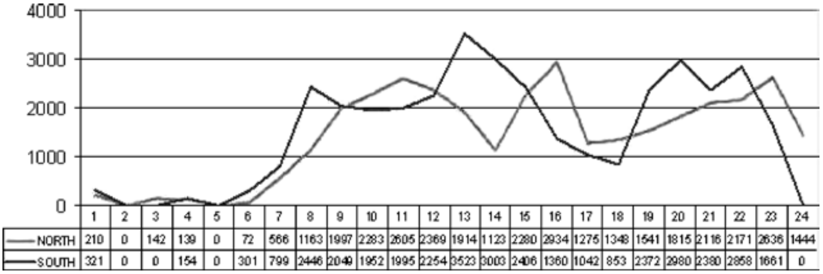


Fig. 12.7 Layout distribution of the security area at Palma de Mallorca Airport



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
NORTH	210	0	142	139	0	72	566	1163	1997	2283	2605	2369	1914	1123	2280	2934	1275	1348	1541	1815	2116	2171	2636	1444
SOUTH	321	0	0	154	0	301	799	2446	2049	1952	1995	2254	3523	3003	2406	1360	1042	853	2372	2980	2380	2858	1661	0

Fig. 12.8 Estimation of outbound passenger distribution at PMA

number of outbound passengers distributed according to a developed model in the north and south security areas to avoid long queues in one area while there is idleness in the other.

It is easy to note that in the event that the check-in process in the 1.00–2.00 p.m. interval is delayed due to a perturbation (Automatic Baggage Management System off, inexperienced personnel at the check-in counters, bus passenger arrival delayed due to city traffic jump, etc.), the security process will be overlapped with the workload estimated for the 3.00–4.00 p.m. timeframe at the opposite side (north security area). Something similar would happen if the check-in process during the 3.00–4.00 p.m. interval was advanced (earliness situation). The short time to react to security over-saturation will be propagated to stands, gates, boarding operations, handling requirements and, unfortunately, a departure delay.

The cause–effect analysis of a model considering the specification of the different events that interact through the different airport processes has contributed to the design and justification of new alternative procedures, such as:

- 'Last minute' check-in counters and security filters that can be used as a decision variable to avoid delay penalisations to certain turn-around processes (especially those with a shorter turn-around time).
- Selectively slowing down certain check-in processes to avoid an unbalanced security workload and to increase the time to redirect the flow of passengers.
- Specific check-in processes that can be performed at the terminal gate, thus uncoupling certain infrastructure and security operations.

12.5.2 Delay Propagation in the Passenger Transfer

Airlines try to concentrate arrivals and departures within a narrow timeframe due to commercial motivations, crew roster costs and resource minimisation. At PMA, the co-existence of the Air Berlin hub and the German and UK flight banks throughout the day generates emergent dynamics due to transfer connections when some flights arrive to PMA delayed. Figure 12.9 shows the three typical banks of Air Berlin on two different days. More than 20 aircraft arrive to PMA from different German

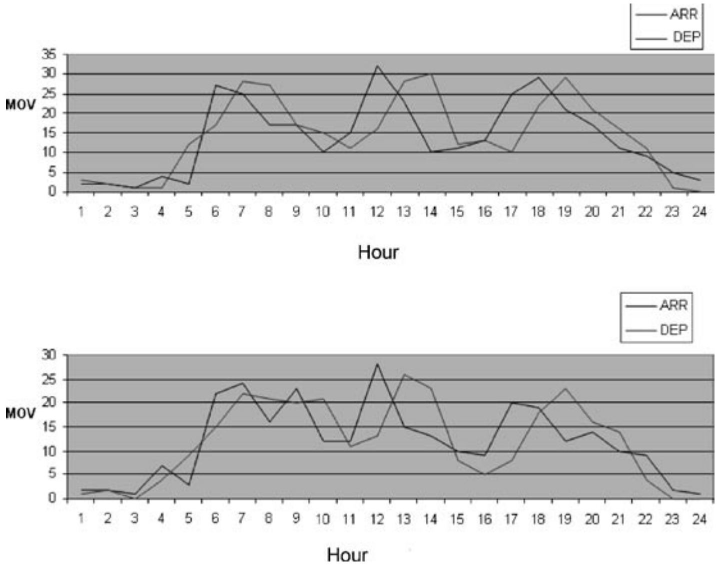


Fig. 12.9 Palma de Mallorca Airport: Air Berlin banks

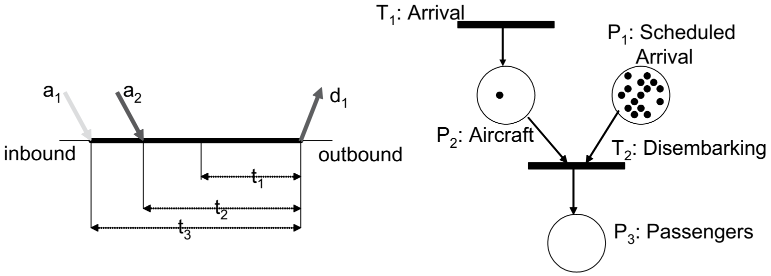


Fig. 12.10 Minimum connecting time and its PN model

origins within the timeframe of 1 hour, and they depart 90 minutes after their arrival to different Spanish airport destinations, mixing passengers from different aircraft (transfers).

The *minimum connecting time* is defined as the gap of time between the arrival of the last aircraft and the departure of the first aircraft. This is a critical factor that constrains turn-around time. Figure 12.10 illustrates the minimum connecting time concept, in which:

- a_1 is the planned arrival time of the last bank aircraft.
- a_2 is the arrival time of the last bank aircraft.
- d_1 is the departure time of the first bank aircraft.
- t_1 is the minimum connecting time.
- t_2 is known as the effective transfer time.
- t_3 is known as the scheduled transfer time.

On the right-hand side of Fig. 12.10, the conceptual model of the minimum connecting time has been represented in Petri net formalism. Transition T_1 represents the arrival of an aircraft to the in-block, while transition T_2 represents the disembarking process, which generates as many tokens to place on node P_3 as passengers that arrived in the aircraft. This information, together with the next connecting flight is carried in the aircraft token. A guard expression attached to transition T_2 compares the arrival time with the expected arrival time, to activate new procedures in case the minimum connecting time is not preserved.

Based on the final destination dispersion level of the passengers of each arrival flight and the distance between the gates assigned to each aircraft, different key performance indicator values of the available resources can be obtained. The fact that some of the passenger outbound flights have PMA as the source airport should also be examined. So, the check-in and security processes must also be considered in the dynamics of the transfer operation.

Sometimes, when the minimum connecting time is not preserved, all departing flights are delayed in a block, which from a discrete-event system point of view can be interpreted as a single event (an inbound delayed flight) that can freeze the firing of several events (departing flights). Coloured Petri net formalism makes it possible to represent, in an easy-to-understand way, this type of cause–effect relationship and evaluates new procedures to minimise delay propagation. Furthermore, most of the PMA departing flights in a first bank will come back to PMA during the course of the day (see Fig. 12.11). So, when departing flights are delayed waiting on the arrival of an aircraft, this delay will be propagated to other airports, and will affect PMA again with later delays.

12.6 Delay Propagation Simulation Model for Pushback Operations

Management of gate operations is a key activity at airports. Aircraft are assigned to terminal gates or ramp positions for the duration of a time period during which passengers and aircraft are processed. Amongst the three flight phases at the airport, the predictability at the second and third is not good enough: ground and outbound

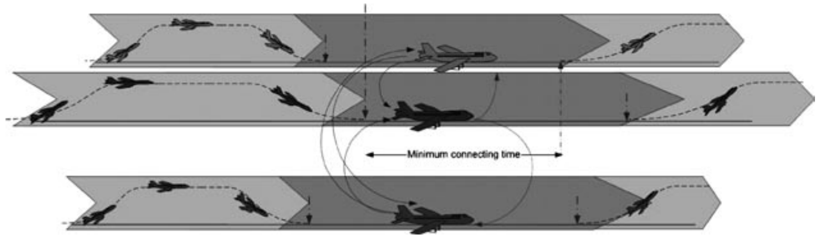


Fig. 12.11 Delay propagation throughout the day at PMA due to connecting flights

phases. Some statistics by Eurocontrol show that more than 22% of air transport delays are longer than 15 minutes (vs. schedule) and three-quarters of them are due to ground processes. As discussed before, delays at any of the flight airport phases have undesired consequences both upstream and downstream. Therefore improving the operation planning and management of these phases is important.

To illustrate the benefits of a simulation model that could consider the delays on the scheduled operations, the pushback operations will be considered. The example considers an airport where 30 departure operations have to be completed during a peak hour. The time elapsed between departure from the origin airport gate (pushback/out-block time: OBT) and wheels off (take-off time: TOT) is known as the taxi-out time. The model will represent the main operations of the out-block process. Usually, pushback trucks spend 15 minutes as an average with one aircraft while the actual process is only 5 minutes – so there is a good potential for improvement, maybe up to one-third of the time could be saved. A direct consequence of planning a more efficient operation is that fewer truck resources will be needed for a given number of operations. As an indirect consequence, aircraft delays caused by the lack of a pushback truck (which may be idling somewhere else and could not be repositioned) could be decreased and, therefore, an improvement of the SQF can be achieved as well.

The main purpose of the simulation model is to analyse different scenarios in which the performance of the system according to two different strategies can be compared: increasing the number of resources and introducing information to enable collaborative decision making. For simplicity reasons, a basic first-come first-served (FCFS) policy is adopted to assign trucks to pushback operations.

On the basis of deterministic information about the set-up time and lead time of the pushback operation (5 min will be assumed in both cases), it is determined that five trucks are needed to perform 30 operations per hour. The graph on the left of Fig. 12.12 shows a feasible schedule for this case. Gate and resources availability and times of arrivals/departures (as given by an estimated time) can change during the course of the planning horizon due to operational contingencies (for example, congestion, lack of capacity, air traffic control). In a realistic scenario, such a theoretical schedule will never work. Queuing theory can be also used in order to take into account some of the stochastic aspects of the system. Still, such models can hardly capture all the events which can deteriorate the system perfor-

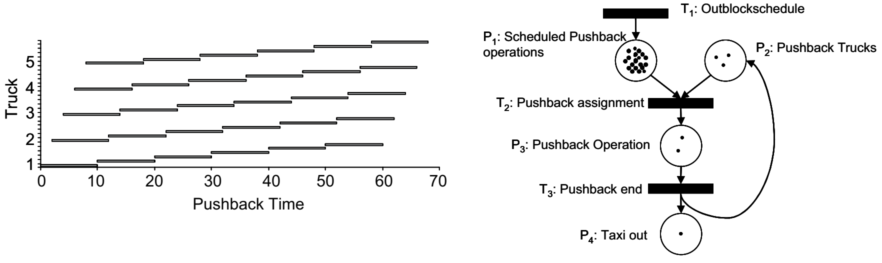


Fig. 12.12 Deterministic pushback scheduling and PN model of the pushback process

mance. A discrete-event simulation model can represent the stochastic behaviour and all the relevant events of the system, enabling an in-depth analysis of realistic scenarios.

On the right of Fig. 12.12 the conceptual model of the pushback process has been represented in Petri net formalism. Transition T_1 represents the schedule of an aircraft for the out-block. The place node P_1 represents all the aircraft scheduled for out-block (they are waiting for their pushback time and/or for the pushback truck become available). The place node P_2 represents the trucks which are ready for operation. The transition T_2 represents the assignment of an available truck to a scheduled aircraft whose out-block time has arrived. A guard expression attached to transition T_2 compares the current time with respect to the nearest expected out-block time in order to implement the FCFS assignment policy or to reschedule a new OBT if no truck is available. The place node P_3 represents the aircraft during pushback operation while the place node P_4 represents the aircraft at the taxi-out operation (this process is not modelled). Transition T_3 represents the end of the pushback operation and releases the pushback truck.

This model aims to illustrate the use of simulation as a means to analyse the system performance. It does not pretend to be an optimisation approach. The model has been implemented with the Arena simulation tool. In order to make the experimental results more comprehensive, only the OBT is modelled as a random variable.

No information about actual OBT (the instant when the aircraft becomes ready for the pushback operation) is considered in the first simulation scenario. Hence, the FCFS policy is applied over the estimated out-block time (EOBT). In this case, an

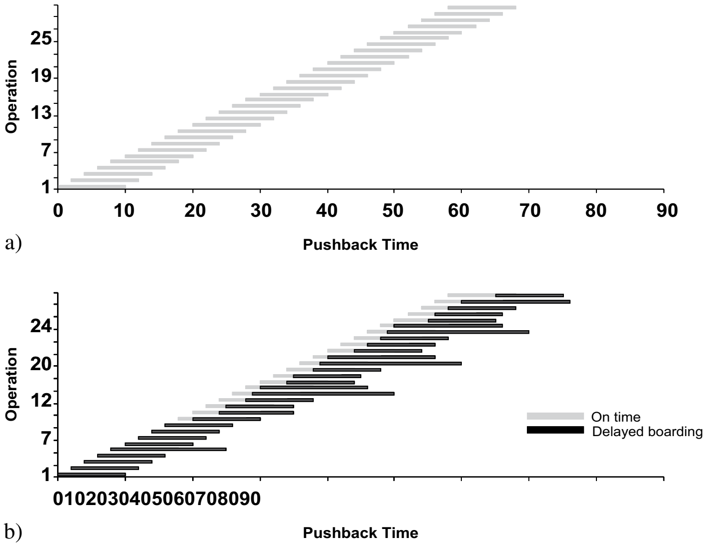


Fig. 12.13 Nominal operation (**a**) and delay propagation in the pushback operations (**b**)

available truck is assigned to the aircraft as soon as the EOBT is reached. If a delay (due to, for instance, the boarding process) appears then the assigned truck will be idle until OBT arrives, so its next assignments will be also delayed. The graph at the top of Fig. 12.13 shows the operation scheduling when no delay on EOBT appears. The graph at the bottom of Fig. 12.13 shows a more realistic scenario where OBT is moved ahead or delayed over EOBT. Five trucks are used in both cases. When a first delay occurs, it propagates over time showing an additive behaviour as new delay appears, since there is no available information about the possible earliness of some operations. Finally, 50% of flights show a delay greater than 1 minute in spite of only seven having a delay over the EOBT and eight being ready for out-block before their EOBT.

An obvious solution is to increase the number of resources. However, there are several limits: cost (evident), technical (constraints posed by the Airport Manager) and truck idleness (more trucks will not solve the problem of trucks assigned to a unready aircraft).

A second simulation model is set up in order to represent a scenario where the up-to-date information about the aircraft readiness for out-block is available, so CDM (collaborative decision making) is enabled. An FCFS policy is also applied but, in this case, using the actual OBT instead of the EOBT. Therefore, advantage of aircraft earliness can be gained. Both models are simulated with five to eight trucks in order to compare some illustrative indicators. The first significant measure is the flight idleness (elapsed time between aircraft's readiness and the initiation of out-block). As can be seen in Fig. 12.14, flight idleness is twofold without real-time information (RTI) and drops drastically when information sharing between airport operators is supported. The truck idleness (computed as the time elapsed between truck assignments and out-block initiation) is null with RTI, which is obvious since trucks are assigned as aircraft become ready. However, it increases without RTI as the number of trucks increase. It seems to indicate that the FCFS policy is not suitable when using EOBT. The graphs at the bottom show the absolute delay at each operation. It can be seen that better performance is achieved by using RTI. An also interesting figure, not included in the graphs, is the percentage of delayed aircraft. With five trucks, percentages are 50% (without RTI) and 27% with RTI. With six trucks, percentages drop to 10% and 7% respectively.

Finally, Fig. 12.15 shows the usage ratio of a truck. Without RTI and five trucks, the ratio is over 100% which means that the 30 pushback cannot be dispatched within 1 hour. Furthermore, the usage ratio stays very high even when the number of trucks increases (usage includes idle time since the resource is not available meanwhile). That makes the system very sensitive to faults. Once again, with RTI the usage ratio is 83% or less, except for the case of five trucks where the demand equals the capacity.

An interesting non-trivial question emerges: what is the most important for the best performance, an oversized set of resources or a proper information system enabling collaborative decision between different airport operators?

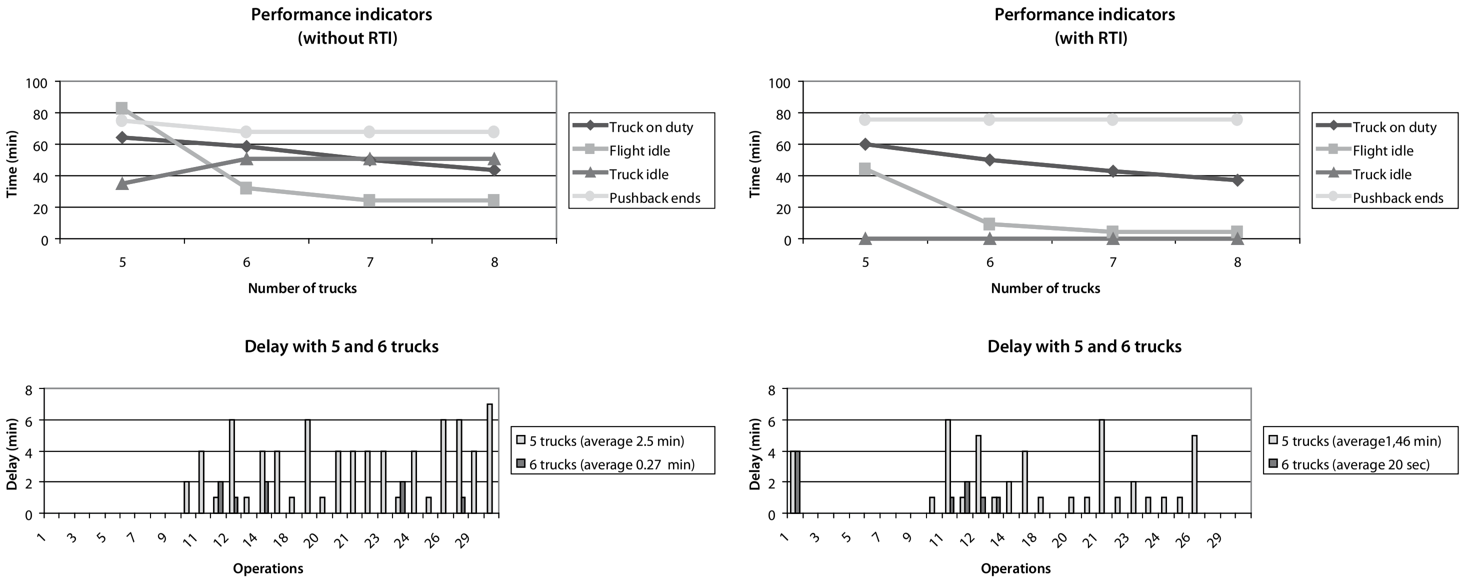


Fig. 12.14 Comparison of some performance indicators without and with real-time information

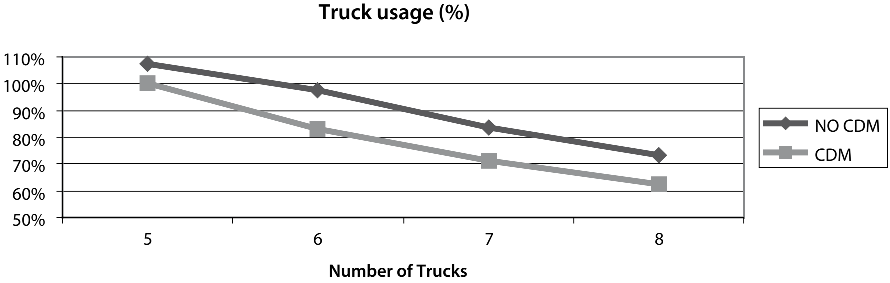


Fig. 12.15 Truck usage ratio

12.7 Conclusions

A discrete-event system view of certain cause–effect interactions in the main airport operations has been presented. Delay generation and propagation through different airport areas due to the poor coordination of interacting operations has been illustrated by means of real examples.

The use of planning and scheduling policies developed in the logistics area can considerably help in the understanding and improvement of the overall performance of airport operations, while providing benefits to all airport agents.

A simulation model to improve the productivity of pushback handling resources preserving service quality factors for airline companies has been developed to justify the advantages of using simulation technologies. These technologies can contribute to a deeper knowledge of airport dynamics and help design operational procedures which will mitigate perturbations.

12.8 Questions

1. What are the main consequences of the late arrival of an aircraft?
2. What are the main aspects that provoke uncertainty in pushback truck scheduling?
3. Why can't gate assignments be resolved at the last minute once the aircraft has landed?
4. What are the main aspects of airport flexibility that limit the use of classical optimisation techniques in order to deal with optimal scheduling policies?

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