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Review

Reduction in Ground Times in Passenger Air Transport: A First Approach to Evaluate Mechanisms and Challenges

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Abstract: Rising air travel demand, airport capacity issues, and schedule disruptions form part of the challenges that aviation stakeholders have to face in the upcoming decades. Minimizing ground times is one of their recent objectives as extended ground times induce operational, economic, and environmental risks. The flow of ground operations has a high impact on the overall air transportation system. Therefore, the impact and risks of extended ground times in passenger air transport were thoroughly compared, weighed, and compared based on pre-selected individual literature sources. Several studies deliver solution approaches to reduce ground times. The turnaround especially is a key element of any flight operation and impacts the competitive advantage of airlines and airports. Next to infrastructural changes, technological advancements, and operational performance improvements, the cooperation of stakeholders is a measure to shorten ground times. Special focus lies on the improvement of boarding procedures. They are essential for passenger air transport and reducing ground times.

Keywords: air traffic; passenger air transport; airport; ground times; boarding

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1. Introduction

The aviation industry is confronted with many different future challenges. Foremost, the challenge of traffic growth that affects the economy, environment, and safety of aircraft operations. Eurocontrol expects the number of European flights to at least rise by 1,9% per annum until 2040 [1]. Furthermore, the ongoing competition in the aviation sector increases the pressure on the performance management of airlines, airports, air navigation service providers (ANSP), and ground handling (GH) service providers. Aircraft only generate revenue when they are in the air transporting passengers or cargo. As time remains a precious resource, the fast provision of ground operations is of high importance for the entire air transport system. Ground times (GTs) of aircraft include the taxi time and the turnaround time (TAT) of aircraft (see Section 2) and have a great impact on profitability. They affect the on-time performance and can contribute to delay formation which are significant cost drivers for all aviation stakeholders [2,3]. Reducing GTs comes with advantages in all operational areas. However, the time needed to complete the aircraft turnaround depends on mutual factors such as the airport capacity, the situational awareness, and planning of stakeholders or their communication. The aviation industry is a system of systems which is the reason for the complexity of flight operations [4]. Hence, the interplay of the different components can lead to many difficulties when dealing with GT management. This requires full-time attention, because the more dependencies there are, the more risks arise.

Consequently, the following questions are of high interest: What are actual challenges for GTs in passenger air transport and what are suitable measures to mitigate risks? Many studies have been conducted that concentrate on different individual measures to reduce GTs by looking at process improvements or infrastructural changes. This comprehensive review takes into account most recent individual sources and does not focus on just one area but on giving an overview of selected measures with a brief deeper insight into the boarding process. The objectives of this review are to provide an overview of the stakeholders for GTs in passenger air transport, provide a holistic view of actual risks of extended GTs, and to describe suitable measures for stakeholders that should be taken to minimize them. The authors want to compile the broad factors of influence, such as business handling, technical, navigation services (ATM—Air Traffic Management), etc., from many individual sources instead of focusing on one specific aspect. Note, the authors are well aware that there are many more publications concerning the reduction in ground times that are of equal importance. Here, individual references were pre-selected with regard to as many measures as mentioned in literature but without redundancy and similar findings.

The review is structured as follows. First, the term ground times (GTs) is defined in detail. Section 3 introduces main stakeholders and looks at operational constraints as well as at economic and non-economic risks arising from extended GTs. Thereby, it clarifies the impact of reduced GTs on the entire air traffic system. Subsequently, Section 4 briefly touches upon the most important challenges and measures to reduce risks. This section addresses system-wide options and options for individual stakeholders and takes a closer look at measures to reduce boarding times. The subsequent Chapter gives a compact overview of all measures stated. Finally, Section 6 concludes and proposes future research topics.

2. Ground Times in Passenger Air Transport

The GT of an aircraft covers essential business activities important for travel distribution. Therefore, ground operations contribute to the overall travel experience of passengers and form a part of the travel value chain [5].

The GT divides itself into two core parts including the TAT and the taxi time of aircraft, exclusive of downtime when an aircraft is out of commission. Hereby, the taxi time consists of the taxi-in and the taxi-out process. Thus, the GT encompasses different activities within these three phases. Whereas the taxi-in process considers the routing between the landing runway and parking position of an aircraft, the taxi-out process defines the actual movement between the off-block time and take-off of an aircraft [2].

The turnaround is the term used for major ground processes that are necessary to prepare the aircraft for the next departure. It covers all GH activities that must take place while the aircraft is at its gate or apron position. Most of the processes occur simultaneously (e.g., embarkation and loading), but still, e.g., the boarding cannot start before fuelling or cleaning is finished. The completion of those GH processes demands the use of ground support equipment (GSE) such as vehicles or special systems [3]. Figure 1 provides an overview of the different GT phases and the core turnaround activities. It depicts the GT as an integral part of a single flight operation. Thereby, it concentrates on the air-to-air process of the flight, which sets the focus on efficient ground operations [6].

The time required for the turnaround process can vary drastically since it depends on mutual factors: the number of passengers, the aircraft type, the amount of baggage and cargo to be loaded, and the business model of the aircraft operator [7]. The turnaround is the connection between the airport and the aircraft. Each turnaround process is unique as there are different conditions for each airport [8]. Further, it can be carried out and controlled by GH companies, airport operators, or the airlines themselves.

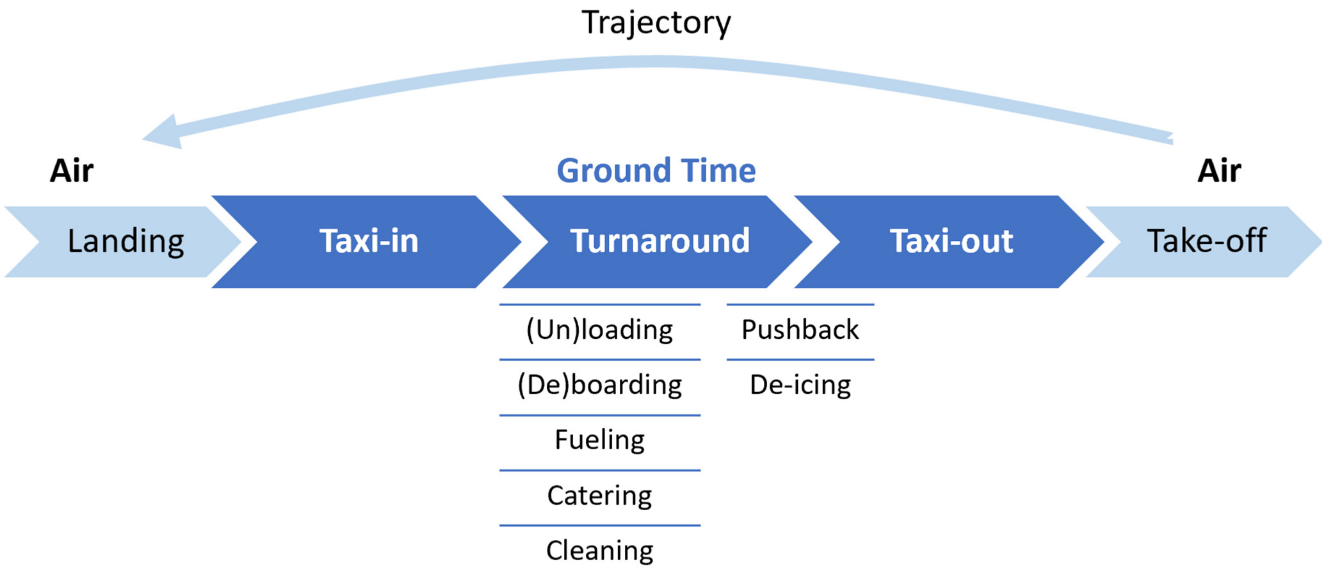

Figure 1. Ground time as part of one flight operation.

3. Risks of Extended Ground Times

The urgency for minimized GT is given as GTs directly influence the time of departure, which is a key element within the air transport network. Each additional unplanned or unnecessary minute affects the system and induces risks to various stakeholders that are closely related to each other (partnership [9]). In terms of aviation, a stakeholder is either involved in or impacted by aircraft or airport operations having its characteristics, structures, responsibilities, and objectives [10]. This multi-stakeholder system takes in passengers and airport neighbours. However, stakeholders for GTs only addresses those parties that are actively engaged in the management of the aviation system. Therefore, airlines, airports, GH companies, and ANSPs are the main stakeholders:

- *Legal authorities:* Policies of legal authorities that mainly provide guidelines and regulations aim at a safe and secure execution of air transport operations. However, in terms of reduced GTs, their influence is negligible.
- *ANSPs:* ANSPs are responsible for air traffic control (ATC) and particularly envision safety in the aviation sector, ensuring efficient management of air traffic by keeping sufficient separation between aircraft in the air and on the ground at any time [11]. GH companies are mainly responsible for the provision of turnaround activities including ramp handling and fuelling; their central interest is the fast and reliable provision of GH services [12].
- *Airports:* The business spectrum of airports is much larger. Airports are multifunctional entities that provide the basic infrastructure for the provision of commercial passenger flights. This includes the terminal buildings, runways, taxiways, and the apron. These essential facilities allow aircraft to take off and land, service aircraft while they are on the ground, and handle passenger movement on land and airside. The airport operator often supports and provides traditional GH services [13]. Furthermore, during the last decades, airports developed into commercial enterprises including non-aeronautical business activities. Their goal is to be profitable by focusing on a rising passenger inflow [10].
- *Airlines:* Similar applies to airlines. Airlines aim at a high passenger demand, high aircraft utilization (max. number of flights per aircraft per day), and short gate utilization so that the number of flights that an aircraft can perform per day is at its maximum [3]. The core business of airlines is to secure the execution of published flight schedules to transport passengers from A to B [14]. Generally, a wide range of airline business models differs among others in revenue, labor, and connectivity

systems [15]. However, airlines are not differentiated by their underlying business model as their high-level interests in terms of GTs are the same.

Concerning stakeholders in equal measure, the following risks arouse from extended GTs which justify the demand for sustainable improvement of ground operational efficiency.

3.1. Operational Constraints: Capacity Issues, System Disruption, Delay Formation

Capacity issues: Since the airline deregulation act in 1978, air traffic started to grow continuously [16]. As of today, forecasts envisage an annual growth in air traffic demand by 5% [10]. To be able to handle the increasing traffic volumes, the provision of sufficient airport capacity is indispensable. The term capacity defines the capability of a facility to handle a maximum number of traffic units [17]. Nowadays, large hub airports such as Frankfurt or Amsterdam airport already operate at their capacity limits. Extended GTs and external events, such as adverse weather, can further reduce capacity [17]. Thus, new challenges arise from the severe congestion on the gate and taxiways. This increases the risk of delay formation induced by inefficient ground operations that lack resilience to the occurrence of unexpected events such as aircraft or passenger boarding malfunctions. Particularly, the execution of aircraft turnaround frequently causes significant delays [18]. Ground operations solely account for 32.6% of departure delays. Furthermore, delays from extended gate occupancy times can easily propagate throughout the air transport system [19]. It starts with the taxi operations that already face the difficulty of more aircraft movements due to the higher demand. If the taxiing starts behind the scheduled time, this further increases the coordination effort [20], and delay time accumulates.

System disruption: One characteristic of the air transport system is the definition of a system of systems. Figure 2 pictures the different complex systems that combine and shows the overall complexity of the aviation sector. Close ties between stakeholders result in interdependencies. Ground operations are an important and critical part of the transport system. Thus, an insufficient match of ground-based activities with upstream and downstream processes can unbalance the aviation network [4]. As the air transport system is widely connected, the delay of a single aircraft caused by extended GTs can induce network-wide disruptions. For instance, the workload of air traffic controllers increases with the complexity of traffic patterns. Irregularities caused by extended GTs, therefore, reduce tower controllers' ability to handle the expected number of traffic movements [14].

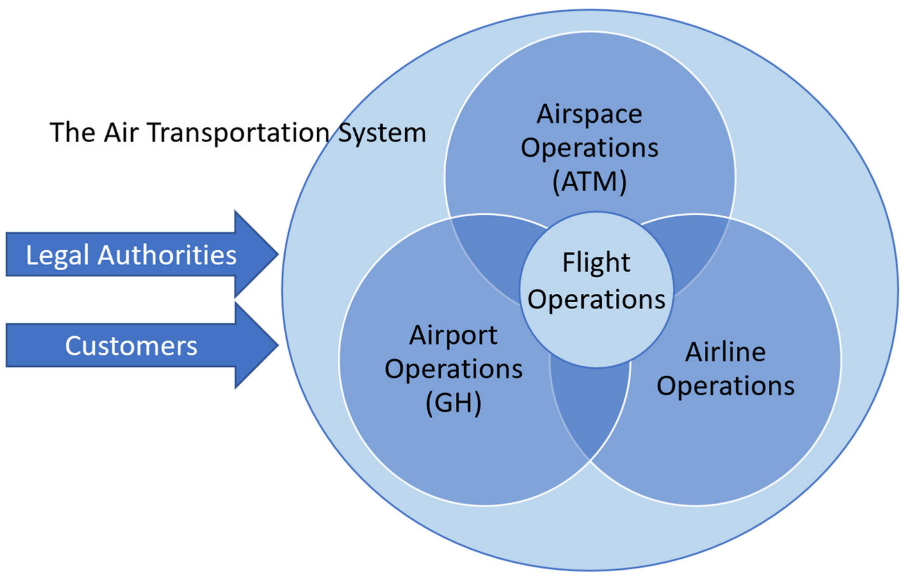

Figure 2. The air transportation system as a system of systems. Derived and adapted from Karish et al., 2019. p. 286 [4].

Delay formation: For the absorption of delays, there are two options. Either using buffer times or waiting until the aircraft goes off rotation [7]. Consequently, it is important to alleviate delays and therefore know about critical processes that are more likely to cause delays than others. Critical processes refer to all processes that have the power to influence the TAT [21]. For certain GH operations, there is a strict chronological order resulting from the limited movement possibilities around the aircraft. Usually, those operations form the critical path. Figure 3 depicts the sequence of typical GH activities for a single-aisle aircraft and indicates the critical path. It shows that the riskiest processes are those inside the cabin, including cleaning and boarding. These processes foremost address airlines' responsibility. However, fueling operations can still become the critical path as they must be terminated before the embarkation process starts [3]. The literature provides various evidence regarding delay formation during turnaround. The IATA found that untimely GH services and missing passengers are major causes of turnaround delays [22].

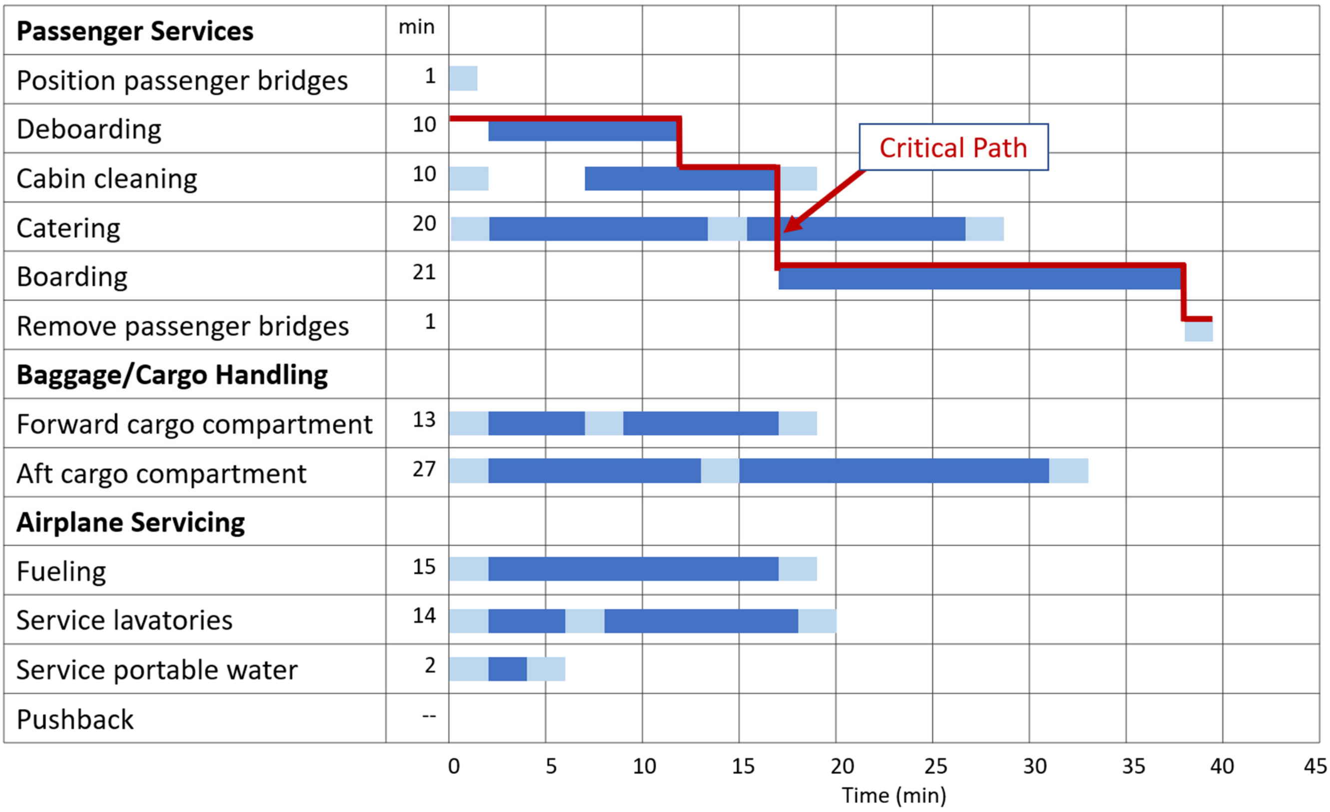

Figure 3. Turnaround Gantt-chart for a typical single aisle aircraft. Source: inspired and adapted from Fuchte 2014, p. 6 [23].

Operational constraints (capacity issues, system disruption, and delay formation) caused by long GTs have different origins. All in all, they increase the problem of capacity shortages and lead to delay formations that affect the system, especially during passenger operations.

3.2. Economic Impact of Extended Ground Times and Competitiveness

The logistic system of the aviation sector is very complex. Air transport operations have the power to influence local, national, and international economies. The scope of the industry grew with the introduction of lower air fares. Today, the Air Transport Action Group noted that air transport directly supports 11 million jobs, 6 million more than in 2012. Further, the number of employed people rises to almost 88 million when taking indirect and induced jobs into account [14,24]. However, extended GTs not only impact the general free economy, they also affect the success of aviation stakeholders. Specifically, in the segment of regional and short-to-medium haul flights, as they make the largest share of global air traffic [3].

In today's highly competitive environment of the aviation industry, all stakeholders aim to differentiate from their competitors. Market pressure forces them to generate a competitive advantage. One method to do so is the implementation of quick and cost-efficient processes [2]. The Aviation Research and Innovation in Europe aims to reduce TATs by 40% until 2050 [25]. Accordingly, the TAT, taxi time, or on-time performance serve as a key performance indicator (KPI) and are core interests for the different stakeholders. KPIs must be aligned with the company's needs [26]. They are important for performance monitoring that aims to evaluate the competitiveness and profitability of an organization [27]. The time required for the ground processes defines the number of flights that an airport can operate per day. Extended GTs lower the overall throughput of airport stands [7]. Airports could miss out on revenue the higher the gate utilization per aircraft. They are two-sided platforms that generate revenue from non-aeronautical and aeronautical businesses. The higher the passenger flow, the larger the non-aeronautical revenues. Additionally, more flights per day increase the aeronautical revenue of airports as they can sell more occupancies of gate positions or slots to airlines. If both sides contribute, the airport can financially break even [28]. This can be achieved through faster ground operations that also lay the foundation for the negotiation of higher airport charges [23]. Every minute an aircraft stays longer on the ground directly affects the cost of operations. A delayed aircraft departure can cost between $30 and $250 per minute [29]. Additionally, the soaring airport charges and fuel prices make it increasingly difficult to cut back costs without minimizing the quality of the product [8]. This drives the necessity to reduce costs wherever and whenever possible. Parking charges are a significant cost position, and so are extended taxi times. Longer taxi times require a higher fuel burn which induces cost as well [30]. Even aircraft manufacturers are interested in short TATs as they magnify the market value of aircraft. Airlines are more willing to buy aircraft that promise short TATs. This shows that the turnaround serves as a competitive weapon as it defines the aircraft utilization. A high aircraft utilization reduces the average cost by spreading fixed costs and leads to profitable aircraft operations [27]. The same applies to GH service providers. The revenue potential increases with the number of services they can offer, e.g., ground transportation of passengers which is defined by the duration of operations [23]. In general, drivers for cost are personnel and equipment. Shorter GTs allow a respective shorter deployment and hence reduce cost [23]. Summarizing this, aircraft must return to the sky as fast as possible.

3.3. Social and Environmental Impact of Extended Ground Times

Delay propagation and avoidable costs are not the only risks of extended GTs. Social and environmental factors also constitute risks. The aviation industry is a service industry that is committed to deliver a safe and high-quality product to their customers. Extended GTs lack attractivity of the passenger product, harm the connectivity of flights, and enlarge transfer times of passengers. Waiting times inside the aircraft negatively affect passenger satisfaction and business reputation [19]. Furthermore, aviation GH operations drive climate change. The surface movements of aircraft contribute to overall airport emissions. Aircraft ground operations produce a large share of NO_x and CO_2 emissions [30]. After the start-up, pilots cannot turn off the engines. Thus, unnecessary idle times increase the local air pollution and the carbon footprint of airports. Every minute the aircraft engines of an A320 run without thrust provision emits up to 30 kg CO_2. For comparison, the climate-compatible annual CO_2 budget of one person is only 1.5 tonnes [31]. The International Civil Aviation Organization encourages aviation stakeholders to commit to the Paris Agreement 1.5 °C temperature goal. This is especially important to mitigate risks arising from climate change, such as hot temperatures that may threaten daily operations and lead to economic droughts [1]. Since propulsion technologies are not yet sophisticated enough to meet the European goals of reduced emissions for 2050, the reduction in waiting times of aircraft on the ground is even more important for environmental reasons [7].

4. Challenges for Ground Times and Respective Measures to Reduce Risks

There are multiple challenges for ground operations: airport capacity issues, long passenger process times, inefficient aircraft utilization, schedule disruptions, and cost pressure from competition. Stakeholders aim at time efficiency, better predictability, reduced operational irregularities, and robustness of ground operations. This allows a reduction in buffer times and delays and thereby mitigates risks of extended GTs [3]. Therefore, it is necessary to take into account challenges and measures for the entire system as well as for individual stakeholders. Especially improved passenger boarding processes are part of the critical path of the turnaround process.

4.1. System-Wide Challenges and Measures

The air transport system connects all stakeholders to a certain extent. Hence, the performance of each stakeholder influences the overall punctuality of air traffic operations [6].

According to IATA, standardized procedures are priority. If the staff is well trained, they enable time efficiency and a better process flow through repetition and assure compliance with safety guidelines. Furthermore, those staff-related processes come along with simplified prediction effort [22,27]. This is of special importance, because one major challenge for all stakeholders is the variability of GTs and the vulnerability to unexpected exogenous events. The completion of the turnaround process itself is of stochastic nature [3]. Therefore, it is difficult to estimate delay propagation. However, the ability to manage risks depends on the predictability of risk factors. Predictability means a reduction in uncertainties or at least the provision of time to react [14]. One possibility to do so is data analysis. Advanced simulation and modelling techniques rely on data collection of current, relevant, and refined data on the respective operational process. Researchers gladly use computer simulation tools. However, the amount of data currently available is scarce. This is due to a lack of data exchange and the commercial sensitivity of data of organizations such as aircraft operators or manufacturers. Gwynne et al. call for data to be published and broadly available to better understand and quantify forthcoming challenges [32].

Not only data release to the public, but also the exchange of data in the air traffic system, is relevant for good operational performance. Different studies highlight the importance of collaborative decision-making. Precise information about the current status of operations should be available to all parties as each stakeholder holds back different information. For stakeholders, it is vital to have a holistic view of the air transport system as a local focus can neglect transnational effects. Therefore, 32 European airports implemented Airport Collaborative Decision Making (ACDM) as a big technological change. ACDM is part of the Single European Sky initiative and promises smooth collaboration of stakeholders to best utilize the local and network resources and the available capacity. It focusses on the transparent sharing of reliable timely information in aircraft handling across airport partners (airlines, airport operators, GH companies, and ATC) and with the European network management. This facilitates the planning for each department and improves the air traffic flow and capacity management [7,26,33]. ACDM requires appropriate processes and technical architectures that come at high costs. However, once the necessary facilities are in place, ACDM contributes to a general reduction in turnaround times and a 7% reduction in taxi times [20].

Schultz et al. propose to enhance ACDM through data-driven approaches [20]. This implies the implementation of Automatic Dependent Surveillance-Broadcast (ADS-B) receivers at the airside of the airport, which receive data from arriving and departing aircraft. Those receivers facilitate the communication between the ACDM partners and contribute to an advanced monitoring system. The goal is to use this broadcast data for integrated airport management, creating improved situational awareness. Data analysis should help to better predict future system states. Users can directly respond to congestion. ADS-B comes with two big advantages. First, the installation, data acquisition, processing, and storage require only a small monetary investment. Second, a worldwide implementation would eliminate the problem of restrictive operational data access. It might be the starting point for data-driven and therefore improved operations.

Another example for data-driven improvement of operation is the A-SMGCS (Advanced Surface Movement Guidance & Control System) [34]. This system provides routing, guidance, and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL). At the same time, the required level of safety is maintained [34]. This system allows for improved exactness of movements and therefore to better estimate the time required.

Particularly, data that feed KPIs will play a great role in future performance monitoring and management. Performance based airport management (PBAM) is another method to operate efficiently. Goals and decisions of individual parties may contradict so that apparently optimal schedules do not function optimally and thus cause longer TATs. PBAM includes shared decision-making of stakeholders. It is executed in a cycle and first requires the definition of a long-term strategy and goals of the airport system. Therefore, the individual low-level stakeholder objectives must fit together. This is followed by a KPI definition and analysis so that in the last step, stakeholders can agree on compensation measures that have to be performed to meet the target values. Then, all steps are repeated from the beginning. This method allows for constant improvement and can help to identify bottlenecks [10]. Continuous improvement is a key factor to maintain a long-term profitable system and to cope with the envisaged growth. Feedback mechanisms create motivation for self-learning and lead to a more realistic target-time setting [26].

4.2. Operational and Technical Measures for Individual Stakeholders

Transparency and communication between stakeholders are paramount. Nonetheless, each stakeholder has its own area of operations offering room for improvement. The next two sections list sample operational and technical measures for the individual stakeholders.

4.2.1. Efficient Planning and Operations

Various challenges and measures arise in terms of efficient ground operational processes. As highlighted before, important objectives for all stakeholders are flexibility and predictability of TATs and taxi times. Thus, resilient procedures are of high importance to mitigate risks of long GTs. Flexibility means creating operational latitude in the case of disruptions to be able to still achieve the goals set. This is one key to success [14]. So, the right planning of ground support services is essential. Guimarans and Padrón emphasize considering the risk of perturbation as a result of the inherent variability of ground processes by taking stochastic parameters into account [35]. E.g., GH providers should not plan all their GSE and labour to be in use the whole day and airlines should plan for buffer times, even though this is unfavourable in terms of high utilization rates [23]. Another important point for all stakeholders is the sufficient provision of personnel, especially at peak times. This is a priority of the planning task as it has a major impact on the fluidity and speed of operations.

The business dynamics call for reliable quality of the service product at low cost. Shorter GTs should in no case compromise safety and quality. Therefore, process flow optimization (PFO) is crucial and favorable at any time. It implies an adjustment of the process that enables the change of specific parameters in conformance with procedural constraints. A preliminary analysis of the current operational level to identify system shortcomings is beneficial. There are the options of optimizing the equipment, improving the execution of control loops, or taking a look at operational procedures whether human behavior or technologies are the problems causing a bottleneck [36].

Here is a simple example of PFO for reduced GTs:

Identification of a Bottleneck

In general, aircraft ground damage including damage from GSE, other aircraft, or poorly connected cables can extend GTs.

Where Is the Origin of the Problem?

Ground damages often find their origin in human action.

What Can Be Done to Mitigate or Eliminate the Problem?

An appropriate measure to solve this problem is the proper training of personnel and employees. The IATA Airport Handling Manual suggests different training methods. It is essential to update the ground operations training to current rules and standards, especially in the interest of ramp safety for all involved parties [22].

For turnaround activities, parallelizing and shortening GH procedures are means to minimize the TAT. Further, refining process execution along the critical path is a possibility to increase robustness and efficiency. As mentioned above, fast cabin cleaning is essential. To assure cleaning does not become a critical activity, enough cleaners should be employed, however more workers induce higher costs for the airline [23]. Moreover, airport GH resources are scarce and they should be handled optimally. Szabo et al. found that the right placement of GSE can result in a significant reduction in GH times, so they propose a positioning for shorter delivery and GSE arrival times [37] These are only two exemplary measures that could be taken by GH service providers, and it is important to mention that the field of low-level options to reduce GTs reaches further. Still, stakeholders must observe the limits. Too short TAT could cause problems with aircraft brake cooling times or cockpit procedures [3].

Besides the options for GH procedures, there is also the taxi movement that defines the GT of aircraft. Ground routing is a fundamental aspect concerning safety requirements, conflict-free aircraft movements, and simultaneously short runway waiting times. The responsibility lies with ATC, which assigns passing times for specific taxiway intersections. Controllers must consider separation constraints, taxi speed, turning angles, runway occupancy, and origin and destination timing [30]. This is a complex task that requires good taxi time estimation to decrease traffic overload. Many studies are concentrating on this issue. Since taxi times depend on individual taxiway layouts, Lordan et al. found the development of suitable airport-specific forecasting models and predicting tools for surface movement time is an option to minimize taxi times [38]. Furthermore, Yu et al. point out that gate reassignment and taxi scheduling are closely connected and should be considered simultaneously to assure smooth surface movement, passenger satisfaction, and simplified ramp operations [18]. This is particularly important when bottlenecks tend to shift to the apron and taxiway areas. Guépet et al. state that the pushback is the current measurement to determine the departure time. This encourages to pushback as soon as possible, resulting in extended taxi times. They propose to measure departure punctuality with respect to take-off times, consequently reducing delay formation on the taxiways [30].

For airlines in particular, the use of an apron stand instead of a gate position speeds up the boarding time and additionally does not require a pushback, which reduces overall GT [23]. Further, airlines should assure appropriate flight scheduling and allocation of aircraft, crew, and ground resources. This affords the execution of operations research and consideration of KPIs. Especially in the field of GH, bad scheduling has direct or indirect effects on other airlines and stakeholders since they all share GH resources [4]. Still, if flight schedule disruptions occur, schedule recovery is an option that aims at keeping the system in balance. Therefore, the airline operation control centres develop flexible solutions for irregular operations management [19]. However, higher load factors and denser flight schedules challenge the ability of airlines to recover from disruptions [4].

Lastly, the growth in air traffic comes along with new challenges in the area of passenger handling at airports. More people with hearing impairment and reduced mobility chose to travel by air. However, barrier-free service systems for such passengers are not yet mature. This intensifies the need to invest in new suitable strategies and processes, making use of technologies not only to provide a good travel experience but also to prevent delays caused by unexpected difficulties and waiting times in this area [39,40].

4.2.2. Advanced Technologies and Infrastructure

Hereafter, this section gives a brief overview of technological and infrastructural difficulties and opportunities for reduced GTs. Note that each airport has its individual conditions including geography and weather that can be challenging and influence the applicability of measures. Figure 4 depicts a selection of concepts addressed.

Infrastructure changes are inauspicious for all stakeholders. In fact, they are not only costly and often not possible for special and regulatory reasons, but their implementation process disrupts operations. Yet, terminal layout, apron, taxiway, and runway configurations can only be changed in the long-term. However, they are a straightforward way for airports to reduce surface delays. One example are parallel taxiway systems for reduced surface conflicts [18,30]. Furthermore, the 2050+ Airport consortium proposes future technical measures for invariant processes at airports that might increase time efficiency, but also require infrastructure adjustments. Promising future concepts are the use of robot arms to support container loading [41], biometric boarder control [42], and electric engine taxiing, which shortens pushback times as aircraft can move backward on their own. Further, an underground supply system for electrical power or underground (de)loading devices could fasten the particular processes and minimize the number of required vehicles and GSE present at the apron. This reduces the surface traffic, which allows for a straight taxi-out [43,44].

The future of air traffic is characterized by ongoing digitalization. The most promising area for efficient ground processes are new technologies coming along with what is referred to as Industry 4.0 or Aviation 4.0. Smarter production processes shall be enabled by artificial intelligence, machine learning, data science, and the Internet of Things. Reduced GTs could result from the automation of GH at airports. Further, airlines and airport operators could implement a sensor network in aircraft and at the airport, which would allow for enhanced predictability [45]. In the upcoming years, next-generation aircraft types characterized by electric systems and advanced wing layouts will challenge airports. The better the suitability between aircraft and airport, the more efficient operations can be. The introduction of new aircraft types and configurations comes along with new GH characteristics. Recent studies concentrated on an autarkic turnaround that does not demand the use of GSE, as aircraft are furnished with appropriate tools and equipment. Those novel aircraft configurations require less airport resources and a lower number of GSE in place. This would allow airlines to operate more independently. Moreover, GSE positions are predefined by the respective aircraft interfaces. Even though there is a trend towards commonality, new aircraft design options for faster GH include a rearrangement in the form of clustering of those interfaces. This change will again require adaption in form of GSE positioning [3,7]. Since the TAT serves as an important KPI already, the development phase of new aircraft designs contains discussions about GH operations. Design choices should drive shorter TATs to improve economic performance. However, there are operations where the duration does not depend on the aircraft architecture—such as refuelling times, which depend on the fuel flow [27].

GH service providers could investigate more into the direction of deploying new and advanced GSE. Schmidt briefly touched upon the option of a multi-functional towing vehicle [3]. It should allow an embarkation process during taxiing. The concept already integrates the idea of autonomous driving and electric propulsion power. The vehicle combines multiple functions. It serves as a jet bridge, towing truck, and shuttle bus at the same time. Towing aircraft after arrival towards their parking position is also one of its envisioned functions. This enables a reduction in noise emissions and up to an 8% reduction in fuel consumption since pilots can shut down the engines right after landing [3].

Besides efficient GH operations, airports must ensure reduced delay in upstream passenger processes in the dynamic terminal environment. Therefore, more and more airports start to make use of digital solutions. At the forefront are Singapore Changi Airport, Munich

Airport, or Schiphol Airport. For example, the launch of dedicated apps that support the passenger journey allows for a smooth process from arrival at the airport to embarkation of the plane. It also enables better data gathering. Self-handling solutions (e.g., check-in) can speed up processes as well. Still, the digital transformation needs reconsideration of airport management and special education and training of personnel [46]. Contactless solutions are the next step. Khan and Efthymiou, for example, conducted a study on a biometric entry–exit program, specifically for the deployment of facial recognition [47]. Biometric solutions allow a quicker throughput of passengers, and hence they are beneficial for passengers, airlines, and airports. Even so, the main disadvantage of the envisaged cyber-physical system is that security risks from cyber-attacks can arise. This requires the establishment of countermeasures and security risk management. Yet, there is room for improvement in the application of those technologies [48].

4.3. Improved Boarding as Example for One Important Key Driver

The boarding and de-boarding procedures form part of the critical path for ground operations. They are often the last process to complete the turnaround and have direct impact on the success of the turnaround and profitability of airlines. Even if the boarding process can be outsourced to third-party service providers, it is often considered to be the responsibility of the airline operator. Reducing those times is beneficial.

According to Picchi Scardaoni et al., the passenger egress and ingress can account for up to 40% of the TAT [27]. They also emphasize that the difficulty lies within the estimation of those times. There is always a residual uncertainty because no one knows how passengers will behave. Moreover, an estimation error directly influences the overall TAT. Reliable prediction of (de)boarding times is necessary for efficient scheduling and the determination of the value of new aircraft designs. Different approaches to optimize passenger embarkation have been proposed in the literature, while only a few studies address the disembarkation process. This is due to passengers having an intrinsic motivation to get off the plane as quickly as possible, which complicates structuring the egress [3]. The first studies on the boarding problem were conducted in the late 1970s [7]. Several methods help to model the boarding phenomenon and compare the performance of boarding strategies. Two examples are a stochastic model [6] and linear programming [29].

The general problem of the passenger embarkation is the row and aisle interference, which shall be avoided. Passenger movement is limited because of the dense cabin layout to fit in as many passengers as possible. Row or seat interferences happen when a passenger cannot immediately take his/her seat because another passenger is blocking access (e.g., blocked middle seat) [27]. Aisle interference usually results from passengers storing their hand luggage or entering their seat row, preventing other passengers to move forward [6,49]. Both the selection of smooth and efficient boarding strategies or the implementation of cabin and aircraft layout advancements shorten the boarding process inside the cabin. The following table (Table 1) provides an overview of the research conducted in the field of aircraft boarding. It lists corresponding measures and links at least one relevant study to each of them for reference. The benefits assigned to the measures vary due to different underlying assumptions of the studies. The next paragraph briefly explains the most important methods summarized in the table.

Adapting the proper boarding strategy is a key issue. While the effort of applying special boarding methods is moderate, the accompanying cost reduction is significant [50]. The success of boarding strategies depends on mutual factors. Schultz lists studies that tried to simulate the boarding process by concentrating on passenger arrival punctuality, their interaction, their physique and properties, or on the negative effect of group constellations, such as families [6]. He also found that the number of passengers has a significant influence. One additional passenger extends the boarding time by on average 4.5 s for single-aisle aircraft.

Table 1. Measures for improved boarding procedures.

Category	Measure	Benefit	Reference
Strategic Boarding	Boarding methods, passenger management	25%	Steffen/Hotchkiss 2012 [51]
	Seat assignment based on luggage	3%	Milne/Kelly 2014, p. 96 [52]
	Avoidance of hand luggage	12–34%	Schultz 2018, p. 10 [6]
	Boarding methods based on the use of apron busses	5–36%	Milne et al., 2019 [47]
Aircraft design	Aircraft type	-	Schultz et al., 2013 [21]
Aisle	Increased aisle width	5–7%	Fuchte 2014, p. 120 [23] Schmidt 2017, p. 35 [3]
	Increased aisle length	-	Schultz 2018, p. 373 [6]
	Twin aisles	40–50%	Fuchte 2014, pp. 94–98 [23]
Door	Second (rear) door	25–33%	Schultz 2018, p. 377 [6] Fuchte 2014, p. 118 [23]
	Quarter door	3–24%	Fuchte 2014, p. 119 [23]
	Door size	-	Fuchte 2014, pp. 100–120 [23]
Seat	Seat pitch	-	Gwynne et al., 2018 [32]
	Foldable seat pan	28%	Schmidt et al., 2016, pp. 6–9 [7]
	Side-slip seat	19–28%	Schultz 2017 [50] Schmidt et al., 2016, pp. 6–9 [7]
IT	Connected aircraft cabin	-	Schultz 2018, p. 12 [6]

Source: Benefits in part taken and included from Schmidt et al., 2016, p. 2 [7].

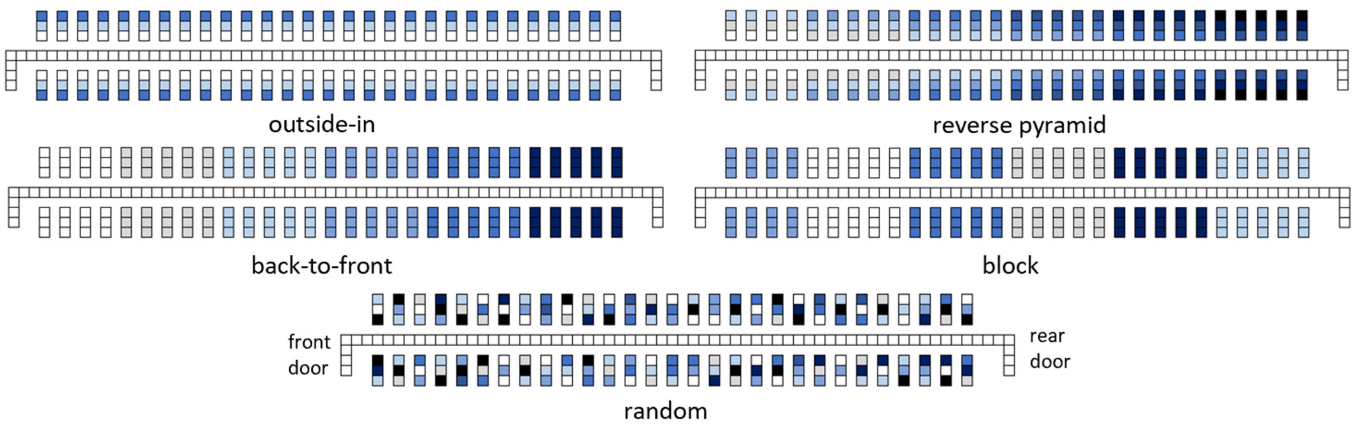

Figure 4. Grid model to represent different boarding strategies. Source: derived, adapted, modified, assembled and commented from Schultz 2017, p. 134 [53].

There are five well-acknowledged methods to control passenger movement. First, the *random* boarding method, which is used as the baseline scenario. Passengers access the aircraft without a special order on a first-come-first-serve basis. On contrary, the other methods predefine a sequence. The *outside-in* method lets the passengers with window seats enter the aircraft first, followed by the middle and aisle seats. For the *back-to-front* boarding, the aircraft is parted into blocks. The resulting passenger groups enter the aircraft following the sequence from back to front. The *block* boarding divides passengers into groups as well. However, it starts with the back group first, then the front rows, and lastly the centre rows. Finally, the *reverse-pyramid* boarding method is a hybrid approach combining traditional back-to-front and outside-in boarding. Within the boarding groups, seats are sorted from window to aisle. Another method that promises increased efficiency is the *Steffens method*. In this method, passengers with assigned seats two rows apart from each other board the aircraft together (e.g., 6A, 4A, 2A). Firstly, all window seats from back to front, continuing with the middle, and finishing with the aisle seats [21,50,51]. The currently preferred method to eliminate boarding interferences is the back-to-front method. However, Schultz highlights that block boarding might perform better [53]. It appears that there is general uncertainty about the actual efficiency of each method. Nevertheless, each of them definitely increases efficiency compared to random boarding. Figure 4 uses the grid model to demonstrate the basic boarding strategies.

However, executing those methods is limited to those flights that board their passengers via a jet bridge, accordingly only via the front door. If buses are used, it will almost be impossible to control the passengers according to the strategies since passengers board the aircraft in any sequence they like after leaving the bus. Building upon this problem, Milne et al. consider 13 different methods for improved boarding when using apron busses considering the seat assignment of passengers [50]. On the contrary, Fuchte states that the elimination of seat assignment from scratch could increase the motivation of passengers to access the aircraft as fast as possible [23].

Further studies take the quantity of baggage into account. In general, the time needed to complete the boarding decreases with a decreasing number of carry-on luggage items. Whenever a passenger needs to store his luggage, he/she blocks the aisle. The investigation of Schultz reveals that the boarding process would be significantly faster without hand luggage [6] because there would not be blocked or saturated overhead compartments that lead to counter flow movements of passengers. Besides eliminating hand luggage, there is the option to develop boarding strategies based on luggage characteristics. For example, assigning seats based on the number of luggage pieces allows for evenly distributed hand luggage, so the required time to find sufficient space in the overhead bins can be reduced [51]. Furthermore, it is effective when passengers with more items sit closer to the entry [6]. Note that, even if changing the strategy implies operational effort, the use of evolutionary algorithms can help to determine the appropriate boarding strategy [6].

Beyond those operational improvements, there is the possibility to modify the cabin layout focusing on the aisle, doors, and seats. Future technologies promise to support boarding efficiency. Connected aircraft cabins characterize themselves with implementation of sensors that detect the occupancy of seats. This promises to enable a more reliable prediction of boarding times [6]. In peak times, the infrastructure often restricts boarding time. Fuchte reveals that a twin aisle layout for short-range aircraft would allow for quicker (de)boarding [23]. It reduces aisle interferences as it divides passenger streams and therefore shortens the queue length. Further, the effect of double-sized doors is noticeable as passengers can enter the aircraft in parallel. However, it only makes a difference if the door size is the bottleneck, such as for twin aisle aircraft. An increasing number of boarding doors (dual door or quarter door in front of the wing root) splits the passengers into multiple streams so that aisle intersection becomes less severe and makes (de)boarding far more efficient than single door procedures [23]. Moreover, moveable cabin monuments would allow for adaptability to the requirements of the different flight phases [25]. Likewise, an alternative seat configuration could improve egress and ingress times. A wider seat pitch [54] reduces the time to stow and collect baggage underneath as well as the time to access and leave the seat. On the contrary, it reduces capacity [32]. Additionally, foldable seats [3] would also allow for more manoeuvring space when sowing luggage [25]. Further, Schultz analysed the effect of a side-slip seat architecture [53,55]. It is a promising approach that allows for a temporary extension of the aisle width so that passengers can seamlessly pass each other. Nevertheless, an implementation demands a boarding strategy adaption in terms of differentiating between the left and the right aisle side.

Overall, there are many options and novel concepts to shorten the boarding time. However, especially for the design options, there is uncertainty about the applicability [25].

5. Overview of Presented Measures

In the last century, tactical ATC changes were sufficient to deal with the demand that was within the capacity limits [14]. Nowadays, alternative solutions need to be implemented. As several possible measures to reduce GTs in passenger air transport and improve operational efficiency at airports were listed this section, Table 2 helps to quickly identify the options to mitigate risks. It provides an overview of the topics addressed within this brief first approach to recap measures. The table does not contain a weighting of the measures, as this is very difficult to determine, and responsibilities are with individual stakeholders.

Table 2. Overview of considered measures to reduce ground times in passenger air transport.

System-Wide Measures	
Operations	Data
- Standardized procedures - PBAM	- Data analysis and publication - Data exchange (ACDM) - Data collection (ADS-B)
Operational measures for individual stakeholders	
For all stakeholders	For particular stakeholders
- Right planning to stay flexible - Process flow optimization (PFO) - Parallelizing processes - Training of personnel - Sufficient personnel for peak times - Measure departure punctuality concerning take-off times instead of push back times	- GSE positioning (GH providers) - Airport-specific taxi forecast (airport) - Simultaneous consideration of gate reassignment and taxi scheduling (airport) - Apron stands instead of gate positions (airline) - Flight scheduling(airline) - Schedule recovery (airline) - Prepare for passengers with reduced mobility (airport, GH providers)
Technical measures for individual stakeholders	
Apron (airside)	Terminal (landside)
- Renew terminal building, taxiways, runways - Automation of GH (e.g., robot arms) - Autarkic turnaround (without GSE) - Electric taxiing - Underground systems - Cluster aircraft GH interfaces - Advanced equipment: Multi-purpose vehicle	- Mobile apps - Passenger self-handling - Biometric system
Boarding	
Operational method	Aircraft cabin layout
- Boarding strategies (random, outside-in, back-to-front, block, reverse pyramid) - Consider luggage, groups, seat assignment	- Seat and aisle configuration - Door usage - Connected aircraft cabin (sensors)

There are many possible approaches to quantify the respective effect of the methods in order to compare them to each other. It appears that the greatest potential can be found in the area of collaboration using new technologies and data analysis. The structuring and constant adaptation of the boarding methods to new circumstances turn out to be promising as well. Even though all other methods appear to be of minor influence, they should still be considered as they drive operational performance.

6. Conclusions

The reduction in GTs is of interest to various stakeholders. Operational constraints and economic, environmental, and social drawbacks that result from extended ground times represent clear risks for the aviation industry. This review points out actual challenges for GTs in passenger air transport and approaches suitable measures to mitigate risks. Namely, risks arise from capacity issues at airports due to increased travel demand. Further, operational irregularities, such as variance in weather or passenger behavior, make it difficult to predict future challenges. This often leads to the occurrence of delays that can easily propagate and negatively affect the entire air traffic system. Costs associated with such system disruptions are significant. Shorter GTs would not only reduce the likely hood of additional costs, but they would also allow for higher profit margins, for example through increased aircraft utilization. Consequently, the challenge is to support and implement efficient and timely ground operations and thereby mitigate risks, taking into account that different areas are contributing to the reduction in GTs. First, the whole system is challenged by the necessity of efficient collaboration. Stakeholders must exchange relevant data to be able to better predict future stages and plan accordingly. Suitable measures are the implementation of ACDM, ADS-B, A-SMGCS, or PBAM. Moreover, data analytics is a relevant topic. Further, process monitoring and optimization as well as improved planning and scheduling of turnaround and taxi operations and resources (GSE, personnel) are important fields to consider for minimized GTs. The introduction of new technologies is promising as well. The ongoing digitalization offers many opportunities for increased efficiency, including electric taxiing, autonomous operations, robotics, and advanced passenger handling at airport terminals.

Increased boarding rates lead to boarding activities forming a critical part of the turnaround process. There are four major challenges affecting the boarding time: passenger behaviour, amount of luggage, boarding sequence, and aircraft configuration. There are methods that show the potential to better predict the boarding process and to shorten it by on average 30%, such as the application of the appropriate boarding sequence with consideration of passenger and luggage characteristics, implementation of side-slip seats or foldable seat pans, a twin aisle cabin layout, or the utilization of multiple doors.

As a result, the field of GTs is complex and allows many different approaches to increase the performance of flight operations. The scope of this review aims at concluding and qualitatively describing risks and measures addressed by a selection of recent individual sources. Discussion of the individual mechanisms and a comprehensive review on the influence of aircraft maintenance or runway scheduling and slot allocation for the GT are of further interest to quantitatively approach the subject in future. Two other limitations are as follows: firstly, the pre-selection of references that may overlook or even strongly support important findings not mentioned in this first approach. Secondly, the weighting and partly the adaptability of the individual measures remain uncertain. However, the described interconnections of existing measures may serve as a starting point to develop more holistic concepts for GTs reduction.

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