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Executive Summary

This document describes the Time-Efficient (TE) airport concept. The TE airport concept is one of the three airport concepts that are developed within the Airport 2050+ project. The project proposes these three airport concepts focussed on mobility, economics, and sustainability in order to cope with the expected bottlenecks that would exist at airports in 2050 and beyond when operations remain unchanged. Following the Concept Development Methodology [4], a structured overview has been derived of the goals, needs, bottlenecks and possible solutions of a 2050 TE airport concept.

Based on the foregoing study ‘Vision 2050’ [1] a long list of goals, requirements and constraints with respect to time-efficient air travel in 2050 has been obtained. From this analysis, a value structure has been set-up, describing what operational goals a TE airport should fulfil in order to add value to the airport concept. In addition to the earlier defined project-wide goals of cost reduction, revenue increase and decrease of environmental impact, the core TE goals are: minimise throughput time for aircraft, minimise throughput time for passengers (and luggage), and have seamless intermodal connectivity.

Following the analysis of goals, the Concept Development Methodology [2] has been applied to the current airport airside, landside, and intermodal processes (including interfaces between them) to determine key bottlenecks, meaning those bottlenecks that are believed to persist in 2050 if the TE solutions presented here are not implemented. The bottlenecks that were derived include, but are not limited to:

- **Airside**: Taxi times (inaccuracy, long duration); inaccurate departure times; airport network capacity; turnaround time; unavailability of turnaround means; de-icing of aircraft; nontransparent information sharing; spatial and environmental limitations.
- **Landside**: Waiting and processing time for travellers; long security control procedures; nontransparent information; way finding problems; long walking distances; slow baggage handling; unpredictable boarding/disembarking times.
- **Intermodal**: Long distance between modes, transfer times, high risk of delays in door-to-airport travel (resulting in buffers), baggage handling between modes, updated information availability and guidance.

With these bottlenecks in mind, solutions for a TE airport concept have been developed. A selection of solutions is proposed for the TE concept to minimise the drawbacks of these bottlenecks and offer a time improvement of the airport processes. The scope of these solutions is limited to the passenger, baggage, and aircraft processes occurring within the boundaries of the airport, including the areas where intermodality occurs. Furthermore, in order to create a time-efficient door-to-door journey for the passenger, the transport from origin and destination to the airport is also partly included in the scope. The airport processes that are expected to exist in 2050 are defined as the invariant processes,

which cover airside, landside, and intermodal processes. The solutions proposed affect all invariant processes of the airport and include the optimization of turnaround services, the extensive use of mobile devices for the identification and guidance of passengers, the optimization of boarding and loading times, the increase of automation, and the improvement of connections with other modes of transportation. An overview of the followed Concept Development Methodology can be found in the table at the end of this summary, which includes: the expected bottlenecks per process at the reference airport, which value drivers are affected, what aspects could be changed to cope with these bottlenecks, and the names of the proposed solutions in the TE airport concept.

The proposed solutions are validated through two cycles. A first validation cycle, which aims at retrieving information from the industry on the practicality of the proposed solutions, provided a first assessment of the concept's solutions. The results of this cycle are described in this document, and showed that several of the proposed solutions are expected to be beneficial for achieving time-efficiency. Furthermore it was shown that some of the solutions of the other two concepts are also expected to be beneficial for achieving time-efficiency. A second validation cycle performs a process simulation in order to evaluate the performance of the TE airport concept. This cycle will be performed in the next months and its results will therefore not be included in this document.

The TE airport concept should not be considered in isolation from the other two concepts elaborated in the Airport 2050+ project. Only together with the Ultra-Green (UG) and Cost-Effective (CE) airport concepts can the TE concept offer the benefits that will enable the ensemble of large, medium and small airports in Europe to become the seamlessly integrated nodes in an encompassing European Transport Network of passenger and cargo operations.

Processes & areas affected	**Key challenges**	**Attributes affected**	**Aspects that can be changed**	**Resulting solutions [#[1]]**
Airside				
ATM, taxi	Inaccurate taxi times; long taxi times due to distant located runways (result of spatial constraints at airports); late decision making; inaccurate actual take-off times due to this; unavailability of correct aircraft sequences; arrival and departure delays; airport network capacity; lack of accurate weather predictions	Avg. taxi times Avg. delay	Increase accuracy and predictability in taxi procedure; optimise taxi planning for an optimal airport network capacity; alleviation of spatial constraints provided by new technologies that may lead to better movement area layouts	Electric taxiing using A-SMGCS [TE1] High speed rail system [TE2] Electric guided taxi system [TE15] *Also:* Intermodal SWIM [CE] Intelligent ICT [CE]

[1] Identification number of the concept idea (see Chapter 5). Some ideas referred to are elaborated in one of the two other concepts, i.e. Cost-Effective (CE) and Ultra-Green (UG) airport concept, as the ideas are in the first place applicable to the key bottlenecks of those concepts.

Processes & areas affected	Key challenges	Attributes affected	Aspects that can be changed	Resulting solutions [#1]
Turnaround	Unavailability of turnaround means; long connecting/fitting time of turnaround means, thereby increasing turnaround time and delays	Avg. turnaround time Avg. delay	Reduce the need of means; standardise, make aircraft stand independent of apron vehicles; automate apron vehicles	Underground pier [TE4] Underground automatic container loading [TE5] Automation of turnaround processes [TE13] *Also:* Automated apron services [UG]
Turnaround	Unpredictability of passenger boarding/disembarking time; lengthy passenger/baggage boarding/loading process; delays due to no-shows of passengers	Avg. turnaround time Avg. delay	Increase availability of information; allow seamless flow of passenger through airport; optimise and standardise boarding process; develop systems for quicker baggage loading and unloading in the case of a no-show; enable real-time information provision; reduction of uncertainty in passenger arrival time to boarding gates	Mobile device passengers boarding [TE8] Displaceable seats for passengers boarding [TE14] Underground container loading [TE5] Fast baggage sorting/ containerising [TE9]
Turnaround	Unavailability of sufficient aircraft stands with direct access to passenger bridge and loading devices	Avg. turnaround time (aircraft) Avg. throughput time curb-gate (passengers)	Create more aircraft stands by more efficient use of space available and enabling aircraft stands to be arranged more closely to each other	Underground pier [TE4] Circular terminal [TE11] High-pier concept [TE12]
Turnaround	Baggage unloading and loading becomes critical in terms of time; the use of apron vehicles may lead to delays; time required to perform each turnaround activity apart from baggage loading/unloading	Avg. turnaround time Avg. delay	Allow for a quick unloading and loading process by pre-processing baggage and cargo in dedicated containers; eliminating apron vehicles and replace by a solution that enables fast unloading and loading of containers; similar solution needed for catering, waste disposal, etc.	Underground automatic container loading [TE5] Automation of turnaround processes [TE13] Fast baggage sorting/ containerising [TE9]
Turnaround, taxi	Unreliability in docking process, due to e.g. bad visibility	Avg. turnaround time (more time needed for docking of the aircraft)	Add automatic detection/guidance for placing apron service vehicles; add automatic detection/guidance for placing aircraft in the apron	Underground pier [TE4] Automation of turnaround processes [TE13] Underground automatic container loading [TE5] Electric taxiing to and from runway using A-SMGCS[TE1] High speed rail system for aircraft taxiing [TE2] Electric guided taxi system[TE15]
Turnaround, taxi	De-icing of aircraft will increase due to increased traffic volumes thereby forming a bottleneck in the turnaround and taxi process	Avg. turnaround time Avg. taxi time	Remove the need for de-icing or increase the throughput of de-icing facilities at the airport and avoid queuing of aircraft	Automated anti- and de-icing of aircraft [TE3] *Also:* Taxi solutions above

Processes & areas affected	Key challenges	Attributes affected	Aspects that can be changed	Resulting solutions [#1]
Landside				
Check-in, security, boarding, transfer	Waiting and processing times will increase for passengers due to increased security measures at the airport; an even more detailed security screening will persist in 2050+; development of technologies/procedures that enable a balanced solution regarding time required vs. safety ensured in security checks; improve public's perception on security checks	Avg. throughput time curb-gate Avg. waiting time Avg. process time	Automation of several functional requirements of the security process, thereby eliminating queuing for the passenger and striving for a straight-through processing of passengers	Walk through security check corridor [TE6] *Also:* THz screening [CE]
Passenger movement through terminal	Information provision and way finding; long walking distances; separation of passenger due to safety and customs regulations; limited integration of information	Avg. throughput time curb-gate	Increase availability of information; allow seamless flow of passenger through airport; eliminate need for way finding; reduce walking distances	Automated People Movers (APMs) [TE7] *Also:* Intelligent ICT [CE] THz screening [CE]
Baggage sorting	Baggage sorting not fast enough; thereby requiring critical time for the passenger's baggage to be processed before loading and after unloading	Avg. throughput time curb-gate (result)	Increase throughput of the baggage sorting system; minimise distance between aircraft and drop-off/pick-up point; minimise distance between aircraft for connecting flights	Fast baggage sorting/ containerising [TE9] Underground pier [TE4] Circular terminal [TE11] High-pier concept [TE12]
Transfer passenger/baggage between connecting flights	Uncertainty of schedule/connecting time; long distances between aircraft; similar problems with way finding (passengers) and baggage sorting process will yield longer connecting time	Avg. throughput time curb-gate Connecting time/door-to-door time	Provide solutions for bottlenecks of passenger and baggage flow (as above)	*Similar as above*
Intermodality				
Transfer between modes	Long distances/long transfer times No updated information Guidance and navigation to terminal	Connecting time/door-to-door time	Shorten distance between modes; provide fast transport between modes	High-pier concept [TE12] APMs [TE7] Electric car for door-to-door transport [TE10] Integrated guiding system [TE16]
Baggage transfer	Baggage handling between modes	Connecting time/door-to-door time	Shorten distance between modes; provide fast and baggage convenient transport between modes; move baggage drop-off points to airport intermodal area	Fast baggage sorting/ containerising [TE9] Automation of turnaround processes [TE13] *Also:* Automated apron services [UG]

Processes & areas affected	**Key challenges**	**Attributes affected**	**Aspects that can be changed**	**Resulting solutions [#1]**
Home-to-airport journey	Large distance between home and airport; speed capabilities of transportation; unreliability of travel time; capacity constraints	None [total door-to-door journey time]	Improve transportation modes (speed); increase reliability of transportation by using dedicated infrastructure for airport transport; better information provision; passenger tailored travel advice; implementation of reliable early baggage drop-off points	Electric car for door-to-door transport [TE10] Integrated guiding system [TE16]
Infrastructure				
Turnaround, Taxi	Spatial restrictions limit airside capacity; spatial and environment restrictions limits runway use or building	Avg. turnaround time Avg. taxi time Avg. delay	Create apron with densely located aircraft stands (e.g. circular); move piers underground; distant located runways can be connected with the main terminal using an (external) high speed taxi system; remote terminals near the runway reduces the need for taxiing	Underground pier [TE4] Circular terminal [TE11] High speed rail system [TE2] Electric guided taxi system [TE15]
Passenger movement	Limitations to enable seamless intermodality; highly related with intermodality issues	Avg. throughput time curb-gate	Shorten distance between modes; provide fast transport between modes and eliminate risks for delays	APMs [TE7] High-pier concept [TE12]

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1 Introduction

1.1 Purpose of the document

The 2050+ Airport project develops three airport concepts for the future of 2050 and beyond. These three airport concepts are the Time-Efficient (TE), Ultra-Green (UG) airport concept, and Cost-Effective (CE) airport concepts. The Concept Development Methodology of WP2 provides the guidance to the development of each of these concepts.

The purpose of this document is to report on the development process and the final outcomes of the TE airport concept. It outlines why the concept is developed, the requirements, the goals it intends to achieve, and how existing and expected bottlenecks and challenges in current airport operations are proposed to be adapted to achieve time-efficient operations for the year 2050 and beyond.

1.2 Intended Audience

The intended audience is the European Commission, Directorate General (DG) Research, which commissioned the contract, and which will assess project results. Further, the 2050+ Airport consortium partners have used a draft of this document to perform the first validation cycle in WP3, followed by detailed research into this operational concept. As such, this document can be considered as a 'living document' throughout the project. Finally airports and other ATM actors (as our main stakeholders), receive an operational concept that is expected to give guidance and to support them in further planning and decision making of future airport development.

1.3 Document structure

Chapter 2 discusses shortly the Concept Development Methodology, the methodology that has been used for development of the airport concepts [4]. Then, based on the Vision 2050 [1] and other relevant documentation that approaches the future airport related developments, Chapter 3 describes a more specific vision from a time-efficiency point-of-view, dealing with Key Focus Areas (KFAs), stakeholder interests, boundary conditions, and (operational and user) requirements. From this initial analysis, a value and objective structure is derived, focussing the TE concept development on key value-adding aspects. Chapter 4 describes a baseline airport, based on a high level decomposition of current generic airport processes and infrastructure. This reference allows the identification of today's most common critical elements, challenges and bottlenecks to the TE concept and where to improve operations. Chapter 5 describes the proposed advanced operational concept of the TE airport for 2050, including the several solutions which drive this concept. In Chapter 6 an appraisal of the impact of these changing operational conditions is conducted. Using the previously identified value framework, the expected benefits of the TE concept's solutions are quantified in an industry experts involved workshop to distil the most promising ideas and combination of ideas. Finally, Chapter 7 offers conclusions and recommendations with respect to the TE airport concept and its development.

1.4 Background and context

The 2050+ Airport project is commissioned by the European Commission, DG Research, in order to study the perspective of far-future development of airports in Europe. The project explores new airport concepts with novel solutions, to support the development of airports and to cope with the bottlenecks that are expected to exist in them in 2050 and beyond when operations remain unchanged.

The project develops three different airport concepts. These three concepts address time-efficiency, cost effectiveness, and sustainability, with each airport concept strongly focusing on its own objectives. This means, amongst others, reduce the turnaround time of aircraft, reduce the throughput time for passenger from door to door, decrease airport's cost, increase airport revenues, minimise the airport's environmental impact, and strive for sustainability. Even if these aims are over-ambitious target values, they represent where the present concept of airports' deployment is most weak. The three concepts show what the future airport could look like and which level of performance can be expected. They describe the interface between aircraft and ground, passenger/baggage related processes, new airport operations management principles and how the application of new principles of airport layout can better integrate future intermodal connections.

More precisely, the project's main activities comprise:

- **Building a methodology for airport concept development (WP2)**: A uniform methodology is established to develop the three different airport concepts. The methodology is based on value theory [4, 7]. It assesses the different stakeholder relations and interests, and provides a high-level set of objectives and attributes to set the focus of each concept. This makes it possible to rate the concepts' designs and make trade-offs between different proposed solutions.

- **Delivery of three concepts, one of which is the TE airport (WP4)**: Several ideas will be captured mainly through workshops and brainstorming sessions. This in turn will create an initial version of the concepts in accordance with the methodology, which will be further refined by validation activities. The concepts will be updated and the process will continue following a spiral life cycle until they are considered sufficiently mature (i.e. European Operational Concept Validation Methodology (E-OCVM) late V0, close to V1 [6, 10]).

- **Partial validation of these concepts (WP3, [6])**: Validation activities will increase the maturity level of the concepts and enable performance assessments to be done. During the first cycle, the validation activities include gathering needs, generate ideas, identify potential areas of improvement, and make an initial assessment of the most promising ideas according to the experts and to the methodology developed in the project. Based on this validation a first selection of most promising solutions can be made. During a second cycle any issues detected during validation will be used for further concept refinement and specification. This task ensures the coherence of the maturity level achieved by each concept. This report describes the current status of the TE concept and serves as input for the second validation cycle.

1.5 Why develop an airport concept for 2050 Europe?

The world is changing and towards 2050 a strong increase of air traffic demand is expected due to increase of population and consumption worldwide, as well as a strongly growing economy in the emerging markets. Also, the air traffic demand in Europe is expected to grow, but this has to happen under constraining conditions of accommodating growing traffic in limited space available around the airports and tight time provisions on for example taxiing, emplacement, and turnaround time.

The growth in travelling demand takes place because the wish of European people to travel will increase, but the expected increase takes place only when the European Transport industry is able to meet its targets by enhanced mobility and improved service provision for door-to-door travelling. The Flightpath 2050 report [3] sets the objective to allow 90% of European travellers to be able to complete their intra-European door-to-door journey within four hours. Europe will meet this objective only if the European Transport Network improves significantly [14], which means that:

- The connectivity through the critical nodes of the network has to improve.
- The network of nodes has to expand to offer full coverage.
- A seamless service provision has to offer the door-to-door connectivity and to meet the requirements for user-friendly, seamless connectivity and undisturbed and undelayed service provision.

The airports are the nodes of this European Transport Network and, even if parts of the network are present and are functioning well, the network is far from being a complete and harmonized network, and does not comply with the four hours door-to-door objective. In order to achieve this objective, improvements should be made to the processes of the airport as well as their integration with the other means of transportation (intermodality). This is why an advanced airport concept should be developed, reflecting the current need to improve the performance of the airports as critical nodes of the future European Transport Network.

In a competitive world, constrained by limitations, the airports of Europe have to expand and enhance their operations, strengthening their role in the network:

- Airports have to improve seamless connectivity between airports and door-to-door connectivity by providing enhanced connectivity services for their customers in their catchment area. This justifies the development of a TE airport concept for 2050, improving seamless operations and removing delays and other hurdles in travelling whenever possible.

- Airports have to reduce their costs providing seamless connectivity services in a competitive world. This justifies the development of a Cost-Effective (CE) airport concept for 2050, reducing costs and improving efficiency whenever possible.
- Air Transport has to reduce its impact on the environment by reducing environmental pollution and by reducing any possible waste in consumption of resources. This justifies an Ultra-Green (UG) airport concept for 2050, reducing the load on the environment as much as possible. This relates to all operations at and around the airport, comprising transport services as well as all other activities to build, maintain and operate the airport.

European airports will all have to expand and modernise their operations to seamlessly function as a node in the travel chain bounded by the four-hour door-to-door services throughout Europe. Further, the focus is on civil commercial air transport operations. Very specific and dedicated service provision such as airships and/or cargo drones operating from dedicated airfields, and/or dedicated cargo rail transport lines are considered less relevant.

The three airport concepts are complementary. WP5 will offer the airports new views and new ways to initiate implementation plans for future enhanced operations.

None of the three concepts aim to offer a radical new way to operate an airport. The basic concept of aircraft turnaround operations and seamless connectivity to other means of transport operations is left unchanged. Consequently, all three airport concepts are constructed by analysing a baseline reference model for airport operations, whilst identifying those opportunities where the concept can be significantly improved by changing parts of its mode of operations, but each time with its specific focus on TE, CE, or UG improvements. Airports may ultimately adopt some specific solutions from each concept, benefiting from what suits their purpose and their vision of improving their competitive position within the European Transport Network.

Definition of the Time-Efficient airport concept:

The "Time-Efficient airport" is the airport that has been designed and is operated and managed in such a way that the mobility value is maximized for both passenger and aircraft, through efficient and effective air transport operations. Based on new forthcoming technology it aims to make sure that the passenger's and the aircraft's throughput time through the airport is minimized and that seamless intermodality is guaranteed. To do this the airport applies intelligent, collaborative, dynamic, and automated systems capable of reacting to the daily needs of its stakeholders.

2 Summary of the Concept Development Methodology

This chapter summarises the Concept Development Methodology, which is used to develop the Time-Efficient (TE) airport concept [4] so that it reaches the objective of proposing solutions to address the 'time-efficiency' bottlenecks that predictably will exist in 2050. The methodology, as developed during WP2, essentially consists of four steps that should be followed: (1) describing the background of the concept, (2) analysis of a reference airport and bottleneck analysis, (3) solution generation, and (4) initial value assessment that will compare the outcomes of operations regarding time efficiency, both for passengers and aircraft, between nowadays' procedures and 2050 ones. This chapter will describe these four steps in the subsequent sections and forms the base for the rest of the document.

2.1 Background of the concept: vision and objectives

The goal of the first step is to create a clear background on the development of the concept, how it is interpreted (definitions), what is in/out of scope and which requirements are derived. In this step the Vision 2050 [1] is re-examined to find which parts of it are key for the concept in terms of future forecasts, boundary conditions and pre-set performance goals.

Furthermore the Value Operations Methodology (VOM) [4] is applied, by setting down the value structure that will be used in the concept development. Working from the high-level value structure presented in the VOM framework, more detailed objectives and associated attributes are added to the value lever that is of primary focus (in this case time-efficiency). In this step also low-level weights can be assigned to all attributes. This part of the VOM has been applied in an early stage of the project, so a clear focus existed beforehand on what the concept intends to achieve (based on the expected TE needs of 2050), and which attributes are needed to measure this. Such focus will help direct the effort in the context analysis and solution finding phase.

2.2 Reference airport

When the concept's background, goals, and objectives are clear, an analysis of the current airport operational context is conducted. To make the final concept as widely applicable as possible, a generic, medium-sized airport is chosen and described in terms of processes, infrastructure, and/or services as the baseline situation (or 'reference').

After this, the baseline airport is analysed in detail using the tools and method presented in the first part of the Context and Architecture Description (CAD) method [2]. This analysis will point out where the key bottlenecks or challenges currently exist in airport operations and is concept-specific, i.e. what aspects in current airports are already main challenges that need to be overcome to achieve time-efficiency levels as derived from the concept background?

Finally, taking the found bottlenecks as a starting point, these are translated to a 2050 situation. What will it mean if current bottlenecks are not solved? Also, are there problems to be expected from other airport areas that are currently not a challenge for the concept, but will become so if no changes are made from now to 2050? This step distils those challenges that absolutely should be solved by the concept in light of the 2050 goals, as derived from the first step of the methodology (background).

2.3 Solutions and advanced airport concept

The foregoing analyses will have created a clear argumentation of what the future airport concept intends to do, and what aspects of current airport operations need to be radically improved to achieve these goals. Using creative tools such as morphological analysis, brainstorm sessions, and any other means presented in the second part of the CAD [2], the innovative solution(s) (directions) to the 2050 challenges are now developed. This is the creative phase of concept development, guided by the findings of the previous two steps.

Solutions will be developed for specific airport areas (landside, airside, intermodal links – or a combination/integration of those if deemed worthwhile), together with an outline of their expected benefits to 2050 goals in terms of mobility, economics, and sustainability. It should be noted that some solutions can have impact on more than one process. Also, some solutions can be compatible. This leads to a TE concept of airport operations, consisting of a number of selected solutions for 2050 and their expected benefits.

2.4 Change-Impact and value assessment

Following the steps outlined in the Change-Impact (C-I) methodology [16], the changes constituted by the concept solutions are mapped to concrete operational processes/services/infrastructure. The information obtained from the context analysis provides the framework for this. The specific operational metrics attributes which are expected to be affected are also listed.

Then, using the quantification scheme outlined in the C-I method, the different impacts expected from these changes are estimated. This is initially done by the consortium partners (as shown in Chapter 5), whereas the validation workshop in WP3 will invite industry experts to use this method to assess the impact of the proposed solutions on the value attributes. The results of this expert's C-I analyses will be used as input for the VOM and value structures, with which the value contribution (i.e. the ΔV score) for each solution is calculated. This analysis provides a way of determining the most promising solutions within the concept, as will be presented in Chapter 6. Next to the C-I method a gaming session will provide another way of evaluating the several concept's ideas.

The results of the four steps of the Concept Development Methodology as discussed in this chapter will be elaborated in subsequent chapter. Chapter 3 will discuss the background of the TE airport concept, including the derivation of its objectives. Chapter 4 describes the reference airport and will derive the expected bottlenecks for 2050 and beyond. The solution generation process will be described in Chapter 5, after which the change-impact analysis and value assessment of the concept will be discussed in Chapter 6.

3 Background of the concept

The first step of the methodology followed by the 2050+ Airport project is to understand the concept to be described and then to formulate a Vision on the year 2050 and beyond. From the information gathered, the concept-specific objectives can be derived. The Vision 2050 was presented in general terms and taking into account what could affect the air transport system [1]. In this chapter, this vision is analysed and expanded from a Time-Efficient (TE) point-of-view.

3.1 Understanding of the TE concept

The objective of the TE airport concept is to maximise value for the passenger and aircraft through efficient and effective air transport operations. This means that the user (the passenger) need to move between origin and destination in an optimal way. For this purpose, the user and its aircraft need to come together and flow seamlessly through the processes of the air transport system, of which this airport is a pivotal part. Thus, the whole process must allow the passengers to depart from their point of origin, be transported to the airport, and board the aircraft without any disruption. The aircraft subsequently takes off and when it lands, the passenger can exit straightaway and continue on to be transported to his or her final destination. This way, the total journey time of a passenger (from door to door) is significantly shortened.

In order to ensure time efficient operations, it is important that the links with other modalities (like trains, buses, monorail, taxis, trucks, and cars) do not imply additional delays so that the passenger does not lose valuable time during the transfer from one modality to the aircraft. Therefore, intermodality plays an important role in the description of the processes.

In this concept, the aircraft is treated as an enabler to create this efficiency for the customer. Aircraft would be operated by airlines as today, although more flexibility regarding the schedule would be necessary. Processes that need to be performed before the take-off of the aircraft need to be as efficient as possible and not hinder the passenger flow. Processes like checking in, security checks, and boarding are evenly distributed over the arriving transport section of the journey. Aircraft are swiftly emptied, serviced, and boarded, so as to facilitate short turnaround times. All this ensures that the airport makes efficient use of all its resources, and it could be achieved through a dedicated layout of airside (runway systems/ platforms) and landside (terminal building) to allow for the efficient handling of passenger, baggage, and aircraft. The airport concept process should describe the interface between the aircraft and the ground and the new principles for the airport layout including intermodal connections.

The Vision 2050 document makes clear that in any case, efficient and intermodal connections will become a core factor in 2050 airport operations. As the future focus will shift more and more to viewing the airport as just one part of the entire logistical chain, it is deemed appropriate to analyse for each concept the door-to-door (or at least door-to-enroute) flow of both passengers and cargo to the airport, and what this could mean in terms of e.g. processes, technology, etc.

The process oriented view towards the airport focuses on the actual operational processes that are conducted, how these are interrelated and what the inputs, outputs and performance are. This view is most important for the TE concept as likely all potential improvements that can be made for 2050 will be due to how these processes are (re)designed and (re)arranged. In this sense, the infrastructure (mainly in terms of technological solutions) can be mainly seen as the enabler for this improved design of processes.

3.1.1 Conceptual definitions and the scope of operations

The TE concept of the 2050 Airport is centred on operational issues. Nevertheless, the solutions proposed also address actual operations, design, development, and infrastructure. The Concept Development Methodology [4] describes what is inside and what is outside the scope of airport concept development. This scoping relates the context of airport operations and concludes aspects to be within or rather outside the scope of the concept. However, even that is insufficient. For example, flight operations, in particular, departure and arrival procedures, are outside the scope by being related to Air Traffic Management (ATM) although they have a strong impact in the performance of the airport, as they can be an important source of delay. Thus, that part of aircraft design, which is related to platform operations is within the scope of airport concept development. New aircraft design solutions may have impact on airport design, airport operations and airport deployment, and those are an essential part of the concept as such.

Therefore, in the definition of the airport concept, it cannot be ignored that the TE airport concept assumes operations by aircraft types optimised towards time-efficient service provision. This definition of an extended scope of operations is necessary in order to be able to describe a credible and in itself consistent scope of operations of an airport concept. Not only the airport itself is assumed to optimise its operations towards one of the selected optimisation parameters, but also the world around it and its operations have to be aligned with the main theme of the airport concept.

3.1.2 Definition of an airport within the project

In the context of this project, the airport is understood as the geographical territory of the airport including:

1. A tract of levelled land where aircraft can take-off and land, usually equipped with hard-surfaced landing strips, a control tower, hangars, aircraft maintenance and refuelling facilities, and facilities to accommodate passengers and cargo.
2. The areas dedicated to facilitate all other movements required to use airport services, i.e. all facilities to reach the airport by means of public transport, i.e. by trains, underground, buses and shuttles, and all areas dedicated to facilitate private transport, to access the airport by car.

3. The areas for industrial activities, hotels and community activities, related to the success of the airport, but not belonging to deployment of the airport as such, but supporting it to be able to act as an intermodal node in the transport network.

Therefore, the boundary of this scope is thus essentially on the airport terrain limits, and at the beginning of TMA for flight operations, though the intermodal connections to and from the airport will also be included partly within the scope, due to its impact in the time-efficiency of passenger's overall journey.

3.1.3 Focus

The TE concept focuses on the future changes of the airport regarding the processes followed by the passenger, baggage, and aircraft within the airport infrastructure. This includes also the associated services and the apron, including the handling of the aircraft. As the terminal building should support the seamless intermodal access in order to change from one transportation mode to another (e.g. bus/train/car), these connections should not require extra cost or time from the passenger. The intermodal connections are also elaborated in the TE concept as part of the journey.

The concept does not detail any of the ATM procedures; it just gives an overview about the future possibilities on developments, which should influence the provided service structure in the forthcoming period. The TE concept does not include commercial aspects either. Finally, In the 2050+ Airport context the cargo operations are not detailed.

3.1.4 Classification of airports

According to the methodology framework, all the three concepts have to look at three possible airport layouts: the small, medium, and large size (hub) airports. It was decided to develop a detailed description for the medium size airport that can serve as the baseline for each concept because its shape is generic whilst all problems experienced at a congested airport are present.

In addition these sizes of airports are expected to grow in the future, whilst some large (hub) airports have already reached their limits in regard to capacity and might be strongly influenced by the interest of a particular airline. On the other hand, some large airports may have the potential to growth further to very large hubs. Conversely, small airports will also grow, but their limited size will likely not require radical new solutions; they will however benefit from certain new ideas applied to medium-sized airports. Also, the presence of wide variety of services that should be considered by the project is usually not fully configured at small airports, and their direction of development might be not clearly established yet. Certainly, further development is highly dependent on the presence of transfer passengers and the availability of scheduled international and long range flights.

Whilst the medium sized airports have all the variety of services to be considered, they clearly have the most potential of further development and are not influenced by interest of one major player.

Therefore we consider them as good subjects to analyse possibilities of further development in terms of cost effectiveness, time efficiency and minimisation of environmental impact. However, the TE airport concept specifically develops a detailed solution description for large-sized hub airports, as these airports will face the most challenges from a time-efficient perspective. As stated, large-sized airports may or may not grow in the future. While some of these airports still have the opportunity to grow, others might already have reached their limits. Medium-sized airports are expected to grow towards 2050+ and have the most potential for further development [14]. Some medium airports will grow towards current size large hubs. These airports also require solutions that will contribute to their time-efficiency. Small sized airports may also benefit from the time-efficient solution proposed in this documents, as both passengers as airlines may require time-efficient journey and handling respectively. Therefore, most of the solutions proposed can be easily downscaled in order to apply them to medium- and small-sized airports.

Table 1, derived from the methodology framework [4] shows the general characteristics that each size of airport is understood to have, in the context of this project.

Table 1: Airport layouts.

General characteristics	Large airport	Medium airport	Small airport
Type of airport	Large (hub)	Large regional / small hub	Regional
Operations type	Scheduled	Scheduled	Scheduled / charter
Connecting passengers	>50% transfer	Limited transfer, or only self-connecting	No transfer
Intermodal connections	Large number of connections	Large number of connections	Limited intermodal connections
Fleet mix	WB+NB, hardly any GA	Mainly NB, some GA	Regional with NB, fair share GA
A/c movements [x1000/yr]	> 150	75-150	10-75
Pox numbers [millions]	>15	10 – 15	< 10
Runways	2 or more	1-2	1
Catchment area (120 min.) [millions]	>10	5-10	<5
Example airport	Schiphol, Frankfurt, Barajas	Palma de Mallorca, Warsaw, Nice	Eindhoven, Targu-Mures, Kaunas

The specific features considered for the large hub sized airport, like its building, number of security gates, check-in desks and access to intermodal connections are further detailed in Chapter 4.

3.2 Global trends, key focus areas, and scope of operations

The vision document address the main aspects related to airport concept in the context of the year 2050 [1]. This document does not have as main goal to predict the future with full accuracy, nor cover all possible scenarios for year 2050. Instead of that, the vision document aims to consider several areas like Demography, Society, Politics, Economics, Environment, Mobility and Technology and how they must be taken into account for a 2050 airport.

The vision document aims several areas in the context of a future airport, like environment, costs and performance. In this sense, the main aspects of these areas are summarized in time-efficiency, cost-effectiveness, and sustainability. Also the document describes the interfaces between airport and aircraft, between passenger, the baggage and airport. The vision document introduces the idea of same stakeholders with similar desires. Some considerations affect the following Key Focus Areas (KFAs), as shown in Table 2, which includes only those KFAs and aspects that may affect the TE airport concept with respect to year 2011, in which the project started. For a complete overview the reader is referred to [1].

Table 2: Relevant Vision 2050 aspects for the TE airport.

Key Focus Area	Aspects affecting TE concept	Value considered
Demography	• Growing of world population. • Pollution and noise effects. • Needs of an older society.	• 9 billion (+28.6% from 2011) • 30% of population will be over 60 years (+5% compared to 2010)
Society	• Evolution of a global middle class. • The 2050 world will likely be based on connection. • Society of 2050 will also be quite environmentally aware. • 2050 society as a whole will have stronger influence and impact.	• 70% of population travelling by air transport [40] • Use of Information and Communications Technologies (ICT) • Leisure travel: 70-80% of air travel by 2050
Mobility	• Operations: • Door-to-door service • The entire transport chain will need to be robust. • The air transport system will need to be optimized as a whole. • The operational and control systems should be much more flexible • Safety and Security: • People will demand ever-increasing safety and security. • New conflicts can increase the threat of terrorism. • In the demand for smooth travel, people want to have the least amount of hassle from e.g. security measures • Security focus will remain high, but more realistic: focusing on efficiency, objective threats and invasive only if strictly needed. • Increases in automation will make it paramount to assure high levels of reliability and thus safety in all situations.	• Intermodality is more relevant in the overall transport network • Increase of security checks • Worldwide traffic growth 4-5% per year • Worldwide RPK growth 2.5-3.5% per year between 2000-2050 • Worldwide air travel passengers 16 billion per year (+ 540% from 2011) • Commercial EU flights • 25 million per year (+ 166% from 2011) • European air travel passengers • ± 3-4 billion [+300-430% from 2009] • Needed airport capacity increase • >70% from 2005-2050 • Door-to-door EU travel time • 90 % <4 hours • Schedule deviation • 99% within ±15 min • Airport operating hours • 24 hours operations of airports possible • Time spent by passengers in airport related processes • <15 min. (short-haul); <30 min. (long-haul)
Technology	• Current aero-engines optimized to maximum fuel efficiency. • Kerosene still used at a highly costly level, but complementation by biofuels is much more prevalent. • Increased use of non-oil technologies such as solar, hydrogen and perhaps even nuclear power for non-aeronautical power.	• SESAR has been successful. New technologies (A-SMGCS) are implemented at most large airports. Data communication (largely) replaced voice R/T. R/T existing only as backup • The ATM network is able to cope with the demand. This means that the system is able to process all traffic and offer it to

	• SESAR will be fully implemented. • Increased capability for safety/security-checks. • Increased use of automated machines. • Optimized aircraft designs.	the aerodromes. As such, research can focus on airport bottlenecks. • Complete integration of airport operations in the aircraft trajectory possible (e.g. SWIM) • 4D ATM with a large share of aircraft taking care of their own flight path and schedule

Regarding the stakeholders, the vision document proposes a classification of stakeholders not very different from the current one. Nevertheless, regarding the TE concept, the stakeholders considered would be the passengers, airports, and airlines. The stakeholders are limited to these three because they are more implicated in the TE concept, and the more affected in terms of time-efficiency. As an example the following examples are provided:

- The passenger wants to have precise and updated information of the time of processes that it should pass through (check-in, security, etc.). Also, these processes should be optimized so that the passenger spends the least time at the airport terminal, eliminating waiting times.
- The airline wants to minimize the turnaround times at the airport.
- The airport is responsible for managing the passenger flows through the terminal, from the aircraft to the other modes of transportation.

3.2.1 Expected impact of the TE concept with reference to the Vision 2050

The TE airport concept, applied to air transport operations, has the aim of ensure reduced waste of time in air transport operations focusing on the improved time-efficiency. The main activities are focused on addressing a range of innovative concepts and methodologies. The results of that will optimize passenger and flight related airport activities. Expected impact comprises the following elements:

- To enable the air transport system to accommodate to air movements.
- To save time in arrivals and departures.
- To reduce the time spent by passengers in airports.
- To save time in all weather conditions.
- To maintain safety.
- To connect air transport to the overall transport system.
- To introduce advanced concepts and techniques for time efficient freight operations.

Regarding airports, advanced concepts and techniques developed for time-efficiency will impact among others on passenger and luggage flow, in passenger boarding patterns, in planning of airports operations, and in fleet management. Therefore, the TE concept will focus on an in-depth analysis of all airport processes and their performance and interrelations.

3.2.2 The TE concept challenges

The TE airport concept involves several challenges. Some of them are related with technology, while others are related with operational aspects of the airport. All of them leads to time saving and quick processing. Some of the expected challenges are the following:

- Movement of passengers within and between airport terminals (walking distances)
- Local transport inside the airport (e.g. Automatic People Movers (APMs))
- Safety and security processes requirements
- Stakeholders have conflicting goals
- Already existing infrastructure limitations, terminal distribution
- Information sharing between stakeholders
- Peak demand management
- Intermodality
- Uncertainty of passenger arrival times
- Transfer delays
- Baggage processing times

3.2.3 Time efficient approaches

Mainly two different approaches may be introduced as potential with respect to the TE airport of 2050. The first one is a *process oriented* view focused on the actual operational processes. This trend is based on the interrelation of inputs and outputs of the systems and the performances of that. The second trend is the *infrastructure oriented* view that basically is oriented to technology solutions and how they are applied to the airport. The infrastructure can be seen as the enabler for the design of the airport processes. Both approaches may impact on TE concept in the sense of improving in processing and time saving with technology.

3.3 Boundary conditions and requirements

This section’s objective is to lay down the basic footprint of the architecture of the future transportation system defined by the European Commission (EC) and to devise the place and role of the Time-efficient airport in it. Firstly, in order to address the TE concept, boundary conditions and requirements will be established. This will be necessary to delimit the solutions that will be defined within the concept and to take into account the operational and user needs respectively. Next definitions clarify those terms:

- <u>Boundary Condition:</u> Establishes the restraints to specify and delimit the TE airport concept, taking into account the situational context in the 2050 (population, trends, economics, politics, etc.), the future airport in 2050 with the future management philosophy, procedures, systems, etc. assumed as an integrating part of the future airport concept, and of course, the management of the processes based on a TE mentality.

- Requirement: A statement of the stakeholders‘ needs and operational attributes of a concept needed for the effective and/or efficient provision of airport service for the time-efficiency

The boundary conditions and requirements will be elaborated in more detail in the next sections.

3.3.1 Boundary conditions

The boundary conditions will establish the restraints to specify and delimit the TE airport concept taking into account the situational context in the 2050 as a set of conditions the 2050+ airports are assumed to comply with. Two types of conditions can be distinguished:

- External boundary conditions associated to the situational context derived in the Vision [1] and represented by the outer square remarked as Vision 2050+ in Figure 1.
- Internal boundary conditions related to the airport operations environment (as nodes into the transportation network with its management principles, systems, procedures, etc.) and specifically those ones related to the TE airport processes, reflected in Figure 1 by means of the square divided into four blocks representing the areas considered.

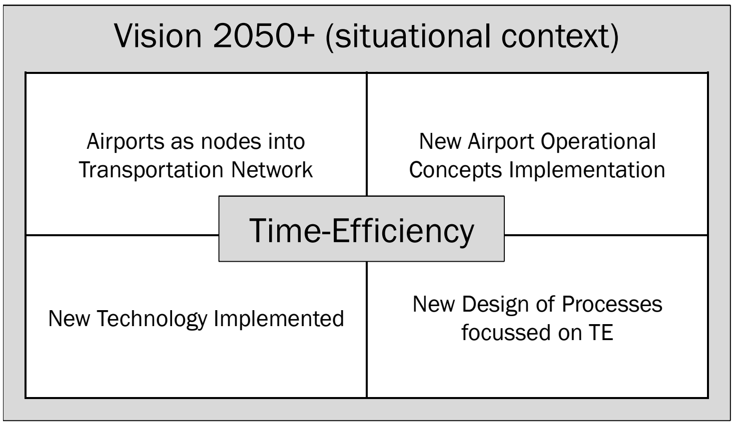

Figure 1: External and internal boundary conditions.

3.3.1.1 External boundary conditions

The Vision 2050 has stated all of the boundary conditions associated to the total 2050 situational context. Here, those boundary conditions will be filtered in order to relate them to the TE concept.

1) Increase airport capacity either by means of enhanced infrastructures/resources and/or efficient management of them due to increase of demand as a consequence of:
    a. Increase of world population to 9 billion people (+28.6% from 2011) will entail a worldwide travel passengers growth, estimated in 16 billion worldwide air travellers per year (+540% from 2011), according to the Vision 2050.
    b. The increase of passengers/baggage movements will imply a required growth in aircraft movements. According to EC Flightpath 2050 [3], the number of commercial flights per

year will be up to 25 million in 2050 (9,4 million in 2011). In other words, the civil aviation market will grow over 266% approximately.

2) Population concentration, i.e. more than 70% will live in cities in 2050, will entail an increase of the cities' size. Therefore the access to the airport must be improved trying to avoid the bottlenecks in the curb side. The ageing of the population, as discussed in the Vision [1], would be also an important condition to take into account for the concept solutions.
3) Travellers' selection of travel modes is possible from a wide range of transport combinations, focused on the door-to-door journey and fulfilling their desired travel time. The passenger will be flexible in his/her connections, and should achieve a door-to-door travel time not bigger than 4 hours for travel within in Europe (90% of European population [3]) if desired.

3.3.1.2 Internal boundary conditions

The following internal boundary conditions exist:

1) Airports are nodes in the whole European Transportation Network: A commonly envisioned trend in the transportation industry is to go from stand-alone, local and self-contained pieces of infrastructure which "can extract valued revenue from the airport users" (see [18]) to nodes in the future Single European Transport Area (SETA). This SETA is characterised by "a fully integrated transport network which links the different modes and allows for a profound shift in transport patterns for passengers and freight" [19]. As such the future development of airports will be intrinsically linked to the practical implementation of, among others, the European Commission's *Roadmap to a Single European Transport Area* [19] and ACARE's *Aeronautics and Air Transport: Beyond Vision 2020 (Towards 2050)* [20].

   Airports will be nodes in the whole transportation chain and will be impacted by other modes of transportation upstream and so on, will impact downstream. Therefore, airports and the other modes of transportation within the whole European Network will work under the same objective of complying with the travel time scheduled along the whole chain, and will be responsible of the information sharing between them, which it will be relevant to avoid or reduce the negative impacts on the network of the deviations on schedule encountered on the different modes.

   Regarding security of the airport processes, the project considers a change shift from current situation. As shown in the logical diagram of Figure 2, the security would be continuously applied over all processes, so that there are no longer security checkpoints creating bottlenecks. This positively affects the total travel time of a passenger through continuous examination of airport processes and time spent at changing modes of transportation.

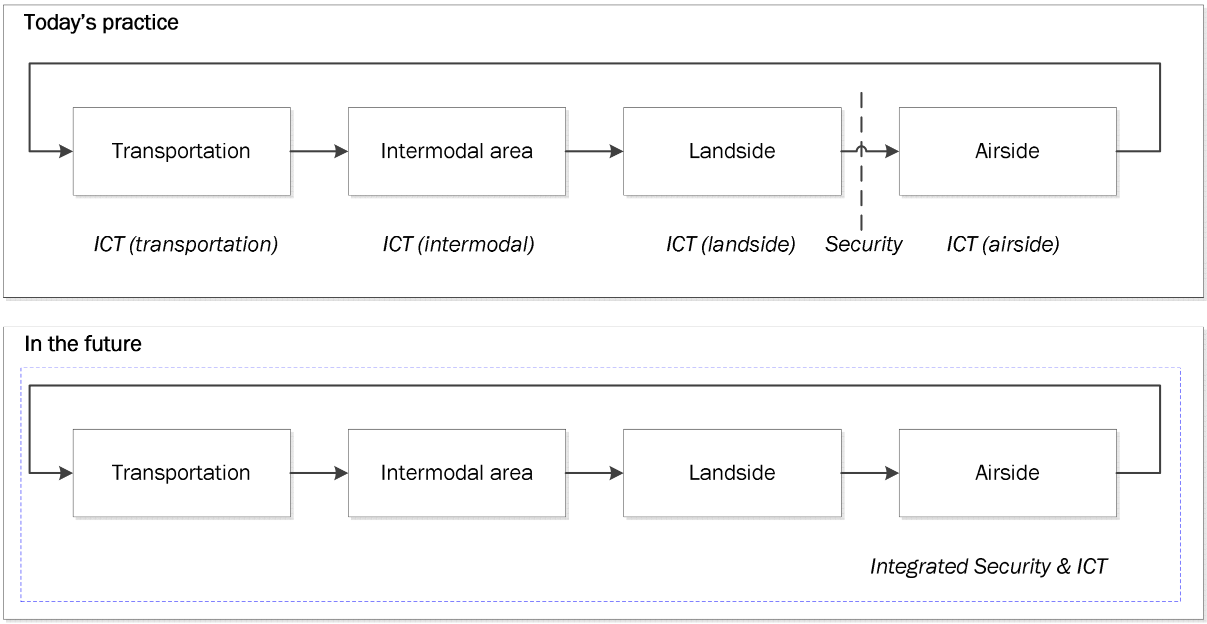

Figure 2: Rethinking of the TE airport concept in the Network.

2) New airport operational concepts are possible:
   New operational concepts, currently under definition or not implemented yet, are expected to be implemented or at least available in 2050, namely:
   - Airport Collaborative Decision Making (A-CDM).
   - Improved airport airside movements throughput: new modes of runway, taxiway, and apron management (enhanced sequencing systems, such as: Arrival Manager (AMAN), Departure Manager (DMAN), and Advanced Surface Movement Guidance and Control System (A-SMGCS)).
   - Combination of above systems including 4D ATM (which includes the whole trajectory followed by the aircraft, from off-blocks until in-block, i.e. the landside trajectory); resulting in optimal landside planning.
   - Improved airport movements capacity, at both strategic as well as tactical level (for example Dynamic Demand & Capacity Balancing (DCB), enhanced Ground Based Augmentation Systems (GBASs)).
   - Enhanced Satellite Based Navigation Systems (Galileo, European Geostationary Navigation Overlay Service (EGNOS); Satellite-Based Augmentation System (SBAS)).

3) Technologies available:
   Though it is impossible to foretell exactly what available technology will be in 2050, conceptually it can be summarized as follows:
   - Passenger centred culture shared across operators of transport services and transport planners.

- Capability for early information to travellers and cargo shippers about airport links and accessibility, providing real-time situational awareness (mapping, last minute changes advisor, intelligent tracking, etc.).
- Real-time airport process monitoring (security and information sharing).
- Door-to-door intermodal passenger travel.
- Door-to-door journey planning capability.
- Integrated electronic ticketing compatible with local fare management systems.
- Road-based fully automated transportation systems.
- High-speed guided transportation systems.
- Pipeline type goods transport systems.
- Transportation modes (approximate values for Europe [1]):
    - Road: ≤100km/h for urban areas and ≤200km/h for interurban connections
    - Rail: ≤200km/h for regional travel and ≤600km/h for longer travel
    - Plane: ≤600km/h for regional travel, ≤1050km/h for inter-European travel and ≤2500km/h for intercontinental travel
- Choice of transportation modes:
    - ≤300km will mostly be travelled by road or rail transportation modes
    - 300km – 600km will mostly be travelled by rail or air transportation modes
    - ≥600km will mostly be travelled by air transportation modes

4) Airport processes are <u>focused on time-efficient performance</u>.

3.3.2 Requirements

Requirements are a set of quantified parameters derived from the Vision [1]. Additionally, some requirements are derived based on discussions within the consortium and they state certain performance requirements that should be achieved by 2050.

- Capability of the airports to cope with the worldwide travel passengers and baggage increase, and to assume an increase in aircraft movements.
- Enhanced connections between cities and surrounding airports (maximise available public transport modes, new curb side designs, etc.).
- 90% for travellers within Europe are able to complete their journey in a maximum of 4 hour door-to-door travel time.
- 30 minutes travel time from the core transport network[2] [14].
- Airports network information sharing requirements:
    - Stakeholder information responsibility (accuracy, quality, privacy, etc.).

[2] The so-called core transportation network will have been built by 2030 to link major EU cities. So-called capillary connections will have been developed by 2050 to assure greater mobility.

- o Capability of real time information sharing (service quality, service safety level, systems needed, etc.).
- o All stakeholders (passengers, airlines, airport, ATM etc.) have access to extensive and (near) real-time information on scheduling and processes.
- o Interoperability between systems associated to different modes of transportation (codes, services in charge of data sharing, etc.).

- Capability of the airport to provide service to new aircraft designs.
- Technology implemented in the airport to monitor in real time the airport processes.
- 10 minute maximum turnaround time.
- Flights arrive within one minute of the planned arrival time regardless of weather conditions, requiring improved reliability and resulting in improved predictability.
- 10 minutes from arrival to the airport to boarding (passengers).
- Airside related time-efficiency should be independent of the weather conditions.
- Minimum buffer times considered by the airlines in their schedules.

Table 3 summarises and links the boundary conditions and requirements set in this section.

Table 3: Link between boundary conditions and requirements for the TE airport concept.

Aspect	Boundary condition		Related objectives or Requirements
External	Increase of Airport Capacity	• Increase of population (+28.6% from 2011) and incease of Passenger/Baggage/Cargo	• Airports capable to assume the increase on passenger/baggage/cargo demand and provide service with the level of quality required
		• Increase of Aircraft Movements: 25 million per year (+266% from 2011)	• Airports capable to assume the aircraft movements growth and provide service with the level of quality required
	Population Concentration	• Increase of the Cities size: >70% of population living in big cities	• Enhanced public transportation modes that conect cities and airports • New curbsides design
	Door-to-Door	• Wide range of travel modes selection and combinations	• Users Flexibility to select the different transportation modes and the different possible combinations • Maximum door-to-door 4 hours travel • 30 minutes for core transportation network • Minimum time spent in intermodal areas between different modes of transportation
Internal	Airports into the Network	• Airports and Network sharing relevant information (Schedules, Resources, combinations of differente trasportation modes ...)	• Stakeholders Information Responsibility (accuracy, quality, privacy, etc) • Capability of real time information Sharing (service quality, service safety level, systems needed, etc) • Interoperability between systems associated to different modes of transportation (codes, services in charge of data sharing, etc)
		• Current processes adapted to the idea of the whole transportation Network (Security, Check-in...)	• New methodologies of process application • New philosophies of infrastructures design taking into account new processes

	Airport operational Concepts	• A- CDM • Improved Airport Airside Movements Throughput • Improved Airport Movements Capacity Enhanced Satellite Based Navegation Systems	• New procedures associated to new concepts • New systems in service related to new concepts
	New Technology applied to transportation	• Passenger centred culture • Capability of information shared with travellers and cargo shippers • Real Time Airport Processes Monitoring • Door-to-Door capabilities • New Transportation modes (New radical aircraft designs)	• New systems that share information with users in real time: o Compatibility with user devices o Free access to relevant information o Flexibility to take the desired action (changes on the initial travel plan, baggage/cargo real time monitoring, etc) • New facilities design to provide service to new aircraft design
	Airport Processes focused on TE Performance		• New processes focused on TE performance • TE performance independent of weather conditions • Minimum turnaround time according to aircraft. • Flights arrive within 1 minute of the planned arrival time regardless of weather conditions (improved Planning and Predictability) • 15 minutes (approximately) from arrival to the airport to boarding (passengers). • Minimize buffer times considered by the airlines in their schedules • Maximum delays assumed 90% in case of disruptive event • 10 minutes maximum time spent along intermodal areas between different modes of transportation • Minimum time from leaving the gate to take-off.

3.3.3 The Time-Efficient airport in the total travel chain

The *4 hour door-to-door travel time* is the government requirement for the TE airport concept. It is understood that a study of various travel scenarios within the European Union will benchmark time available for each item of the travel chain in Figure 3. Chapter 5 will elaborate further on how this 4 hour door-to-door travel time will be achieved.

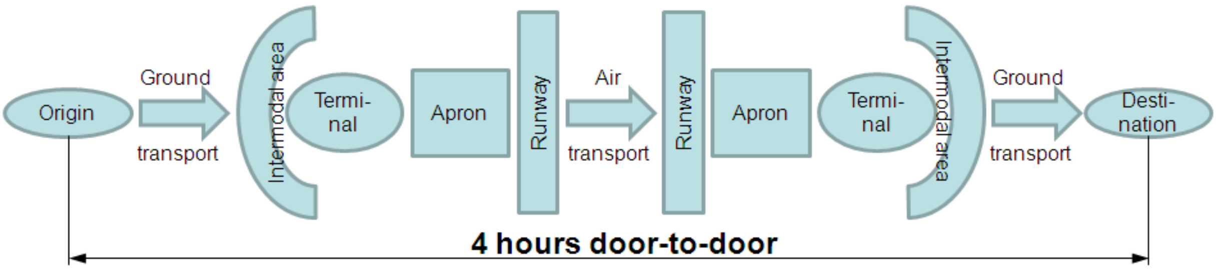

Figure 3: Door-to-door travel concept.

3.4 Detailed objective structure

Based on the understanding and focus of the TE concept, the initial structure of objectives (introduced in [4]) is now further detailed. The detailing focuses on the time-efficiency value lever (previously named 'mobility' in [4], to more accurately capture the value-goals as specific to this concept). The general objective structure is shown in Figure 4, where the objectives that were considered more relevant for the airport are shown.

From Figure 4 it can be seen that the value structure (given by the objectives) of the TE airport consists of the three parts: Time-Efficiency, Cost-Effectiveness and Ultra-green, which matches the three focus points of the project. In the TE concept, the focus is given to the TE objectives. The other two value levers are left as-is, and will be given low (but non-zero) weight in the valuation of the TE concept in specific. Weighting will be discussed in Chapter 6.

Three high-level objectives are defined for the TE concept:

- **Minimise throughput time of passengers:** This is one of the essential aspects of time-efficiency, namely to reduce waiting to an absolute minimum by speeding up the flow of and between passenger processes. This also affects the throughput of baggage, as passengers are required to drop them off and pick them up.
- **Minimise throughput time of aircraft:** Similarly, it is required that the throughput time of aircraft at an airport is minimised, i.e. minimising the required time between aircraft touchdown and take-off.
- **Ensure seamless intermodality:** As an integral part of the future European travel network, the airport should have the capability to enable time-efficient travel by all means. As such, connections to other modes of transport should be seamless (with minimal waiting time), which in turn should be achieved by maximising and making more flexible connections and travel speed.

The top-level objectives are further broken down into more specific low-level objectives, as shown in Figure 5. These are split between goals with respect passengers and airlines, as they are the key stakeholders that make use of the airport's services and for whom a time-efficient interaction is thus the main goal and contributor to their perceived value. As the low-level objectives follow naturally from the high-level ones, they are not elaborated further.

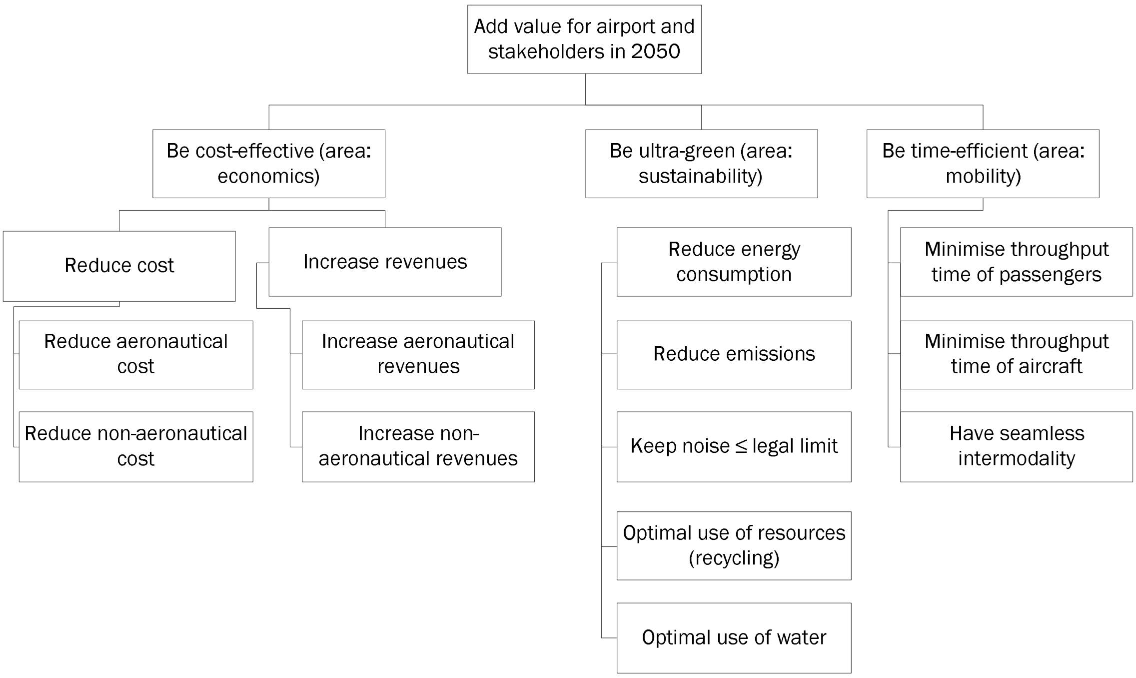

Figure 4: Airport 2050 high-level objectives.

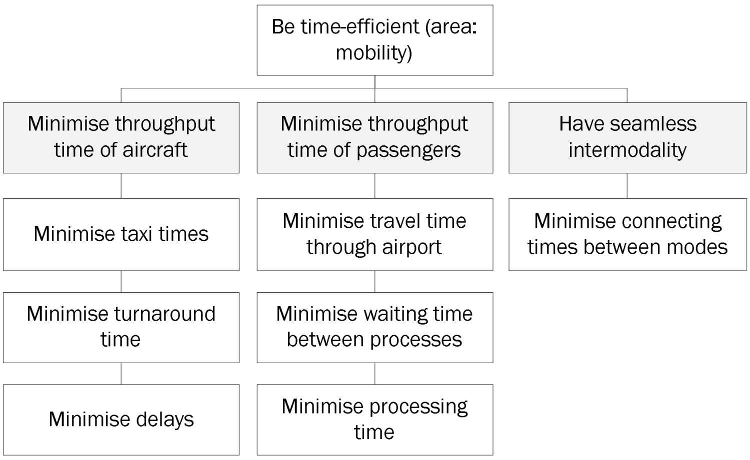

Figure 5: Low-level objectives for the TE airport concept.

Following the checklist provided in [4], the objectives are checked for their usability in Table 4.

Table 4: Checklist for fundamental objectives.

Objective property	Check
Essential	Yes
Controllable	Yes
Complete	Yes
Measurable	Yes
Operational	Yes, at least for a qualitative first estimation
Decomposable	Yes
Nonredundant	Mostly yes, only: the two objectives minimise waiting time between processes and minimise processing time may also affect mimise travel time through airport.
Concise	Yes
Understandable	Yes

3.5 Detailed attributes

For each of the resulting objectives, attributes are now defined in order to enable measuring how well they are fulfilled. These are shown in Table 5. Please note that the attributes related to the cost-effective and ultra-green objectives will elaborated in deliverables D4.3 [21] D4.2 and [22] respectively, but are given for completeness here.

Table 5: Detailed attributes selection.

Value lever: Be Time-efficient ("enable seamless mobility")				
High-level objective group	*Low level objective*	*Attribute*	*Description*	*Unit*
Minimise throughput time – airlines	Minimise taxi times	Avg. Taxi time	Time that the aircraft spends landing and taxiing until it reaches its parking position (including pushback).	[min.]
	Minimise turnaround time	Avg. Turnaround time	Time spent in all those activities needed for finishing the arriving flight (in-block), and preparing the departing flight	[min.]
	Minimise delays	Avg. delay level/ schedule punctuality	Time which is spent by the aircraft in the airport without carrying an specific process.	[min.]
Minimise throughput time – passengers	Minimise travel time through airport	Avg. Travel time from curb-gate	Time spent by the passenger from the arriving to the terminal to the boarding gate.	[min.]
	Minimise waiting time between processes	Avg. waiting time	Time that the passenger spends in queues while waiting for an specific process.	[min.]
	Minimise processing time	Avg. process time	Time spent by the passenger in the specific processes.	[min.]
Have seamless intermodality	Minimise connecting times between modes	Avg. ratio [connecting time/total door-to-door time]	Time spent by the passenger from changing between different modes of transport, including leaving the last mode of transport before entering the terminal.	[-]
Value lever: Be Cost-effective ("optimize economic performance")				
High-level objective group	*Low level objective*	*Attribute*	*Description*	*Unit*
Reduce cost	Reduce Aeronautical Cost	Aeronautical cost	All those costs related with the operation of the aircraft.	[€/WLU]
	Reduce Non-aeronautical cost	Non-aeronautical cost	All those costs not related directly with the operation of the aircraft.	[€/passengers]
Increase Revenues	Increase Non-aeronautical income	Non-aeronautical revenues	All those revenues related with the operation of the aircraft.	[€/WLU]
	Increase Non-aeronautical income	Non-aeronautical revenues	All those revenues not related directly with the operation of the aircraft.	[€/passengers]
Value lever: Be Ultra-green ("be sustainable")				
High-level objective group	*Low level objective*	*Attribute*	*Description*	*Unit*
Keep Noise within or below legal limit	N/A	Total annual noise	Level of noise accumulated over the year in the surrounding of the airport.	[L_{den}, EPNdB]
Reduce energy use	N/A	Energy consumed	Global energy consumed by the airport in operation.	[KWh/yr] or [GJ/yr]

Reduce emissions[3]	N/A	Airport emissions (NO_x, CO_2, heavy metals, particular matter, etc.)	Global airport emissions.	[kg/yr]
Optimal use of resources (recycling)	N/A	Volumes of waste (incidental/periodical)	Volume of waste made over the year.	[kg/yr]
Optimal use of water	N/A	Water consumption (consumed-recycled)	Water consumption in one year.	[m^3/yr]

The attributes are checked to fulfil the necessary properties in the Table 6.

Table 6: Checklist for proper attributes.

Attribute property	Check
Unambiguous	Yes
Comprehensive	Yes
Direct	Yes
Operational	Mostly yes; although it may be difficult to estimate performance levels in the preliminary design phase, which goes double for some of the constructed attributes. But in principle, most of the required data is physically measurable.
Understandable	Yes

3.6 Summary of scope, context, and objectives

The TE airport concept aims to make interaction with the airport in 2050 as efficient in time as possible. This enables the airport to act as a key node in the future European transport network, facilitating seamless travel between points, taking into account key boundary conditions with respect to traffic growth, perceptions of mobility and availability of technological solutions (both airport- and non-airport specific).

To this end, the TE concept will take mainly a process-oriented view, looking at the logical sequence of activities of passengers and baggage and their interaction with the transport chain, of which the airport is a key node, facilitated by other modes of transport.

Finally, the focus of the TE airport has been captured in a detailed objective and attribute structure. The initial structure of the Concept Development Methodology [4] has been revised and elaborated, especially with focus on the time-efficiency (or mobility) value lever. This has resulted in a structure of objectives and associated attributes that signify the key value-adding element of this concept, particularly for airlines and passengers as the main users of the airport. These objectives and attributes will direct the focus of the subsequent analyses, and at the end of the design phase be combined in a value function to assess the concept's performance.

[3] Including emissions for airside vehicles.

4 Reference for the Time-Efficient airport concept

This chapter explains the reference airport that has been used for developing the Time-Efficient (TE) airport concept. Subsequent sections will define the specific characteristics of the reference airport and will analyse current processes on this reference airport. Analysing the reference airport from a process-oriented view is an essential step of the Concept Development Methodology (D2.1.2 [4]).

4.1 Baseline concept for present airport operations

Figure 6 gives a schematic representation of a generic large hub airport, and illustrates which operational/infrastructural elements are within the scope of the project. For the following Context Architecture Description (CAD) analyses, not all aspects will be considered; only those that are deemed relevant for the main time-efficient flows of passengers, baggage, and aircraft.

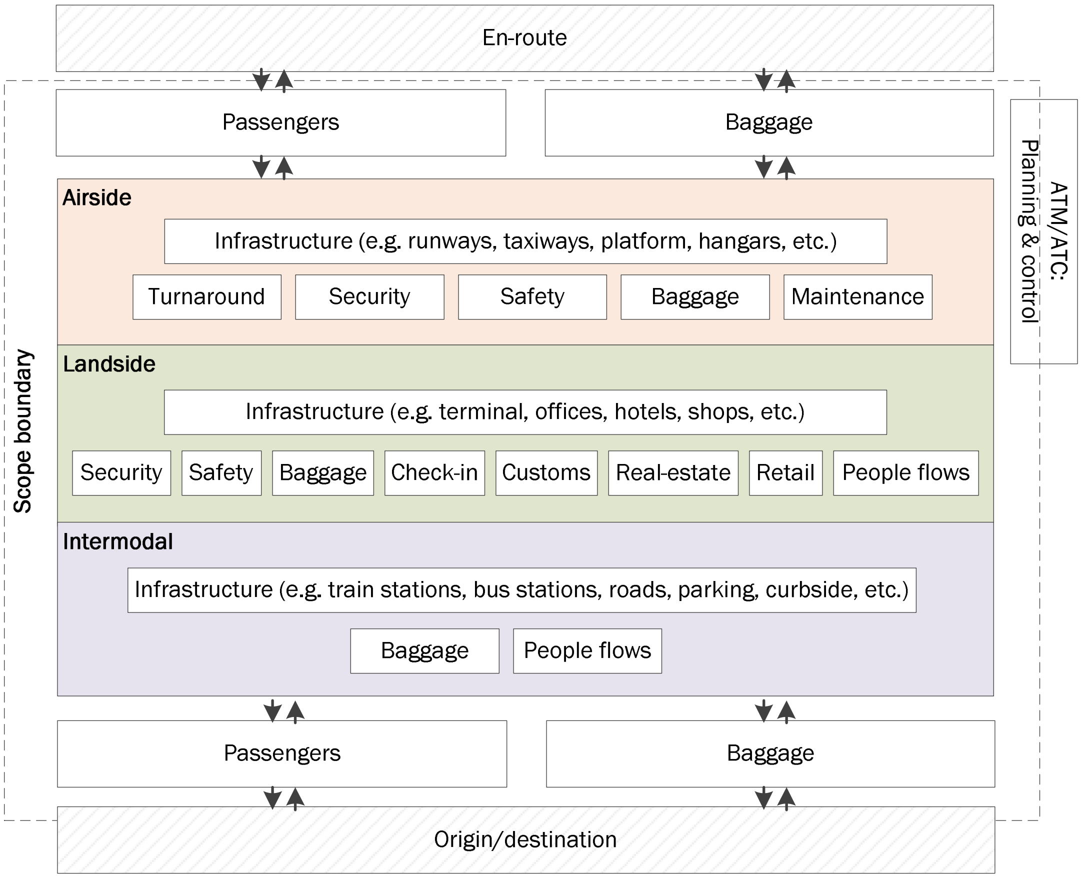

Figure 6: Areas/processes proposed by WP2 to present a high level airport decomposition.

4.2 Reference baseline airport and its basic characteristics

This describes the main elements of the nowadays (medium-sized) reference airport. For each element the basic characteristics are also given.

4.2.1 Runways and taxiways

The medium size airport bears 1 or 2 runways which are connected with the apron by several taxiways and rapid exit taxiways. In case of parallel runways they are able to operate parallel take-off and landing. For a further specification of airport sizes see section 3.1.4. The Instrument Landing System (ILS) at the runways is at least Category II. The length is around 3500 metres, the width is around 45 metres. The fire fighting capability is Level 5.

4.2.2 Terminals

The passenger terminal serves about 10-15 million passengers per year, consisting mainly of origin-destination passengers, with a limited amount of transfers. The terminal is capable to accommodate international and domestic flights (and Schengen and non-Schengen operations for European purposes). It should have jet bridges and remote stands as well. The minimum connecting time (MCT) should be around 45 minutes.

4.2.3 Air Traffic Management

It is a 'controlled airport' which operates 24 hours a day. It supports Air Traffic Management (ATM) communication needs (radio frequency, on-line) and supports Automatic Terminal Information Service (ATIS) creation and broadcasting. It has published standard departure and arrival procedures. Tower control (ATCT) is available and TMA-control is generally available. Generally, radar services are supported.

4.2.4 Intermodal connections

The intermodal ways of transportation identified for the baseline airport are: car, taxi, bus, metro, and mid-range train (or light train). The generic intermodal links layout for a medium-sized airport with the modes of transportation above described is schematically shown in Figure 7.

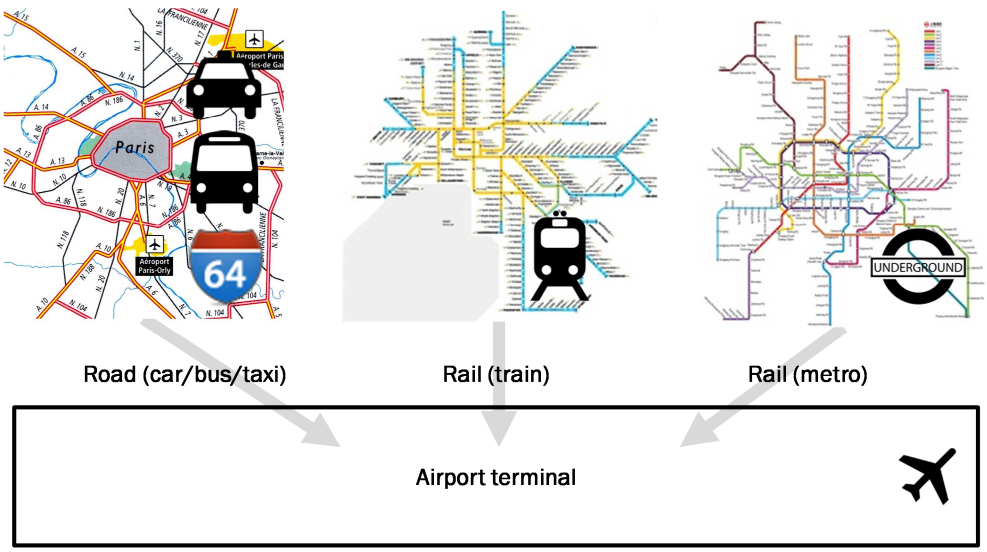

Figure 7: Schematic impression of the intricate intermodal airport connections.

Private transport connections are provided by motorway access and short- and long-term parking facilities.

4.2.5 Energy supply

The airport must have auxiliary and back up (internal) energy sources which are capable of providing sufficient energy to:

1. ATM facilities
2. Safety equipment
3. Security equipment
4. Terminal building (operations)
5. Apron and runway lighting
6. Aircraft at the apron

4.2.6 Invariant processes

Throughout the project a uniform process view has been developed for the reference airport, which is referred to as the invariant processes. The invariant processes are defined as the processes that currently exist on the reference airport, and are also expected to still exist in the 2050+ airport. Figure 8 gives a schematic overview of the invariant processes.

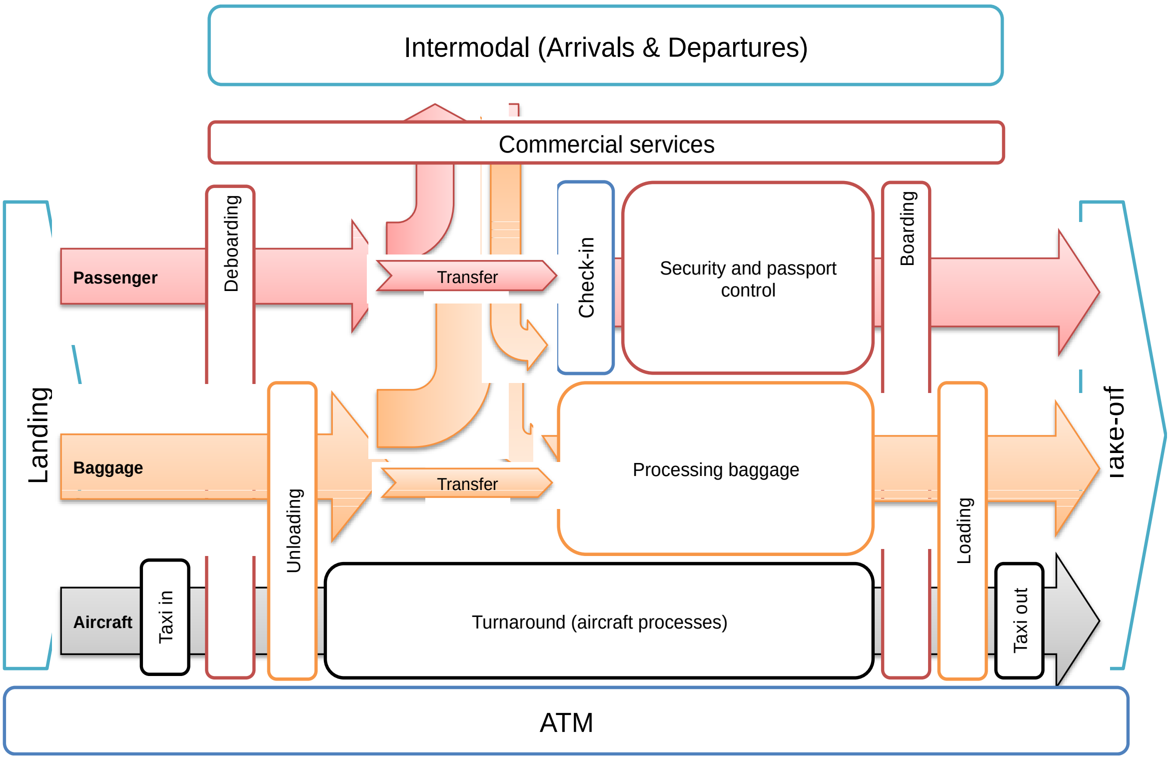

Figure 8: Invariant processes framework for which solutions are developed.

An analysis of the details per process can be found in the following sections.

4.2.7 Terminal characteristics

The average terminal is assumed to have at least the characteristics shown in **Error! Reference source not found.**.

Table 7. Terminal characteristics.

Feature	Amount
Terminal building Jet bridges Remote stands	1 ~15 ~25
Security gates	~14
Check-in desks (normal)	~30
Check-in desks (self-check-in)	~12
Intermodal connections	Access to rail and/or metro, public bus transport, motorway

4.3 Airside processes

In this section the segment affecting the airside processes is analysed: it covers from the approach (landing) of the aircraft and until the departure of the aircraft (take-off). This way, the airside segment will include the final approach, landing, taxi-way, gate arrival, turnaround, gate push-back, taxi-way and take-off. It includes all the processes between landing and take-off. It is important to take into account that what it is considered for the airport to be the airside segment, has been considered as the ground segment for those projects involving the business trajectory concept (according Single European Sky ATM Research (SESAR)). SESAR extends the trajectory management to include the airports, which will be fully integrated into the Air Traffic Management (ATM) network. This way, those processes related to the ATM will have to be coordinated with the whole trajectory as they will be a part of it. This will bring the application of the collaborative planning process, where all the stakeholders involved in the processes would perform those activities on schedule without bringing additional delays to the whole network. In the following section an analysis of the airside operations includes a description of the main milestones, stakeholders involved, and the main bottlenecks and processes.

Relatively to the efficiency of the airport, it is worth to mention at least the following concepts and technologies, currently available up to certain extend at the airside operation of most of the European medium and large size airports: Airport-Collaborative Decision Making (A-CDM), Advanced-Surface Movement Guidance and Control System (A-SMGCS), Arrival Manager (AMAN), Departure Manager (DMAN), Surface Manager (SMAN), and Flow Management for planning. All of this concepts and projects tackle problems related to the inefficiency of daily airport operations and the non-availability of reliable information.

A-CDM is as an important enabler that will improve efficiency and punctuality at the airport operations. The basic foundation of A-CDM is to have improved information sharing and data quality. This exchange of information should be mainly automatic to avoid the bottlenecks that cause oral

communications. It is important that the right airport partners get accurate data at the right time in the right place in order for them to make decisions while working together. This will lead to a better use of resources, partners being able to make preferences, improved punctuality and predictability.
In particular the approach followed by the A-CDM concept, as it pursues objectives of improving efficiency relevant to our project, is highly relevant for the time efficient concept.

The airside processes are analysed using milestones. Milestones are significant events that occur during the planning or progress of the aircraft operation. They concern mainly the airside operation, but at the same time link airside and landside, especially during the turnaround operation, where some critical events happening at the landside directly affects the airside operation. A total of 23 milestones have been identified for the airside processes, which are listed in Appendix A. The milestones have been grouped according of the phase of the airside operation in which they take place, which are the following four:

- Network process
- Arrival process
- Turnaround process
- Departure process

4.3.1 Network process at the outstation

These are meanly processes taken place at the ATM network level, outside the airport, but that can impact the operations taken place in the airport. Due to the ATM network effects, some processes and events taking place at the outstation departure airport will determine the arrival time or Estimated Landing Time (ELDT) of the aircraft to the destination airport and therefore will conditioned the efficiency of its operations.

These processes are related with the slot allocation by Central Flow Management Unit (CFMU) and with any change or deviation in the expected take of time and flight duration that may vary the landing time at the new airport.

Table 8: Network process overview.

Network processes			
Process	**Description**	**Agents**	**Bottlenecks**
Stand and gate allocation	The Stand allocation is related with the operational management of airports. When parking positions are needed from the time of arrival to the time of departure, the aircraft have to be allocated in parking positions (stands). The stands are located near the terminal, with a walkway connecting the plane parked in this location to a gate. There are often other parking positions of the terminal (on the apron), where planes can be parked for longer periods.	The Flight Dispatcher is the responsible of Apron/Stand and aircraft check finished between the in block and off-block times.	- Tactical constraints like works, staffing, rosters, equipment availability, etc. - Occupied stand due to delay - Physical constraints due to aircraft size and type. - Incompatibility of the aircraft size with the walkway. - Separation of national and international flights due to customs regulations. - In some cases, the stands are placed on the apron, so passengers must be transported by mobile lounges or buses, causing cost, inconvenience and often delay. - The ground handling agent assures that the stand is free of obstacles and other occupants and the handling equipment and staff are present.
Slot allocation	The slot allocation depends on the CFMU decision taking into account the ATM capacity and schedules. The airport's slot capacity available for allocation is determined twice yearly by the competent authorities, according to the two programming 'seasons' (winter and summer) in place in international aviation.	The EU country responsible for the coordination of a facilitated airport or the airport coordinator or schedules facilitator. The aircraft operators should negotiate with them in order to have their slots scheduled.	- Capacity shortfalls (scheduled works, known deficiencies). - Tactical constraints (works, staffing, rosters, equipment availability, etc.) can be mitigated. - Downstream effect of imposing ground delay on individual flights that cascades through the network. - Inaccuracy of ATOTs (Actual Take-Off Time), derived from EOBT+ Standard taxi time, is a mayor source for uncertainty in the overall traffic prediction.
CTOT allocation	The slot allocation and slot modification process relies to a large extent on an exchange of ATFM Messages between the AO, the CFMU and ATC Units.	- Aircraft Operator - Central Flow Management Unit - ATC units	The inaccuracy of ATOTs (Actual Take-Off Time), derived from EOBT+ Standard taxi time, is a mayor source for uncertainty in the overall traffic prediction and this lack of predictability leads to inefficient use of existing capacity.

4.3.2 Arrival process

The arrival processes are those processes that are necessary to manage, prioritize, and/or composing of arrival data:

- Estimated Landing Time (ELDT)
- Estimated In Block Time (EIBT)
- Flight status: Information indicating the progress of a flight, and also to illustrate the composition of the Flight Update Message (FUM) data.
- Estimated Taxi-In Time (EXIT)

Processes for updating this arrival planning information are defined in order to determine the best available ELDT, EIBT and flight status at all times. These processes form the basis for the design of information sharing and processing. Processes need to be harmonised for both standard flights (regular flights, charter flights, low costs, intercontinental, etc.) and non-standard flights (e.g. emergency, diversions from their nominal route).

Table 9: Arrival process overview.

Arrival processes			
Process	**Description**	**Agents**	**Bottlenecks**
Update of the ELDT	The process begins when the flight enters in the FIR of the destination airport.	- Approach controller	Uncertainty and ELDT non-accuracy at this stage significantly increase risks for bad and last minute decisions and internal disruptions.
Taxiing	Taxiways are the airport arteries, connecting runways to parking areas. Given the long developmental lead times, land and other infrastructure constraints and cost, taxiways are strategically designed to best facilitate the most commonly operated aircraft or runway operating modes and available 'real estate'. Consequently, taxiways and runway entry/exits cannot be optimal for all aircraft types or operating modes.	- Taxi controller - Runway controller	- Unstable sequence information to controllers and aircraft operators if the sequence is not fixed. - De-icing on the platform causes delays on taxi times. - Constraints such as layout complexity, construction works, weather conditions, de-icing, CFMU slot, and runway throughput will all be reflected in Target Start-up Approval Time (TSAT). - Default taxi times are used at most airports today to calculate In-Block times. Normally a single taxi time is attributed to each runway configuration. These values apply to all types of aircraft, all weather conditions and all parking stands.
In-Block	An accurate estimation and automated taxi time calculation for each flight of the In-Block time (derived from a variable taxi in time) prior to landing, enable ground handlers to make more efficient use of existing facilities and resources.	- Control Tower. - Airline - Ground Handlers	- Default taxi times can vary significantly due to aerodrome layout. The use of default times produces inaccuracies (difficult to adhere to Calculated Take-Off Time (CTOT)). - Inaccuracies of take-off times, unpredictability.

4.3.3 Turnaround process

The turnaround process includes all those activities needed for finishing the arriving flight, and preparing the departing flight. In the turnaround process, there are several milestones which allow the tracking of the progress. For example, the information about passenger and luggage related activities that take place on the landside can be used to plan the start and finish of passenger boarding and luggage loading.

The turnaround includes from the Actual Landing Time (ALDT) to the Actual Take-Off Time (ATOT) where the aircraft does not leave the business trajectory. So the turnaround should form an integrated part of the trajectory.

Table 10: Ground handling process overview.

Ground handling processes			
Process	**Description**	**Agents**	**Bottlenecks**
Docking (positioning of passengers bridge/stairs)	Docking is the arrival at the exact location for arranging the handling processes. As pilots are not able to see the location of their wheels, a flagger or automatic docking system is necessary to signal the crew how to move and where exactly to stop.	- Flagger - The equipment operator is responsible for the location of the stairs or bridge until the de-boarding starts.	- Inaccurate marshalling. - Unclear signalling. - Changes in gate allocation. - Ice on taxiways. - Stationed ground vehicle in the taxiway. - *Unknown Position*: Turnaround activities are easily affected by low visibility conditions. - Under extreme hot or cold temperatures aircraft cabin must remain conditioned during the turnaround.
De-boarding	De-boarding starts with bringing a bridge or stairs to the aircraft.	- Passenger - Crew	- Delay of passengers disembarking - *Sick Passenger*: Sick passenger on board can be considered as an emergency leading to the passenger to be disembarked. - In case passengers and crew disembark via stairs, additional airport personnel are necessary to guide them to the buildings or bus. The crew gets a special treatment as they will leave after the passengers and need more time for final checks.
Baggage and cargo/mail unloading	Baggage unloading can typically start almost immediately after the aircraft has come to a stop. A dedicated company will take out the baggage and bring this to the terminal building. Cargo, if not too voluminous, is unloaded at the aircraft's stand. More commonly, cargo from combi-aircraft is unloaded at the airport's cargo area, in which case the aircraft will be towed to that position with a tow vehicle.	- The cargo agents	- Collision between ground vehicles. - Mistreatment of baggage. - Delays in the unloading of cargo. - Reckless driving (high speed) - Crossing of forbidden areas - *Wet pavement*: The presence of liquid contaminants causes wet pavement. The inadequate state of the pavement or aquaplaning cause slips which can hinder operations related to aircraft.
Cleaning	Cleaning concerns the interior of the aircraft, including toilets and water wase, which is prepared for the following flight.	- The cleaning agent is the responsible for starting the crew cleaning till the end.	- The cleaning agent has to be out of the aircraft. He cannot start until the last passenger has left.
Catering	Catering delivers the necessary food to the aircraft. Depending on the destination of a flight, certain types of food are not allowed. Some airlines allow passengers to indicate special wishes (like vegetarian meals) beforehand. Several airlines do not serve food to every passenger; instead they provide food and drinks at a cost. In this case, fewer catering items will be required. Clean water should also be supplied.	- The catering agent is the one responsible for start to the end of the process of catering replenishment.	- Unavailability of resources. - Distance between aircraft and the Catering vehicle area. - The number of companies working in the handling process, as they all have to be coordinated to carry out all the processes involved in the turnaround process. Any deviation from the schedule or a wrong position of one vehicle during the process could cause a delay.

Security	All passengers and their luggage have to pass a security check. If this is performed at the gate, the process is included in the handling process. At some airports, the security check is performed at a central area. In this case, the security check is not included in the handling process.	- The security personnel make the specific passenger crossing security control/rejected at security control.	- Undocumented passengers. - Not clear identification - The queue waiting time at security control. The security personnel have to wait until the last passenger crosses the security control. - Specific passenger crossing passport control/rejected at passport control.
Fuelling	Fuelling is performed with pump vehicles, which take the kerosene from hydrant wells, which are located at the gates. Alternatively, tank vehicles bring the fuel to the aircraft.	- The fuel provider is the responsible for the refuelling.	- Fuel availability - Distance between the fuel take and the aircraft. - Unknown quantity of fuel to refuel.
Provision of electric supply	Start till the end of the electrical power supply.	- Ground personnel	- Availability of energy supply.
Passenger boarding	Passengers can board the way they disembark, either through an boarding bridge, through a short walk on the surface or through a bus connection.	- The passenger agent is responsible of: open of check-in, declaration and liability release form, check in time for each passenger. Then the close of the check-in and the start of boarding till the end of boarding. Counting of the passengers on board.	- Missing passenger - Special passenger procedure (unchecked baggage, Disabled passengers…) - Delays in the placement of the passengers. - Number of passengers on a flight: times on passenger boarding, baggage loading and placement. The higher the number of passenger is, the higher the possibility of delay is. - Aisle blockage.
Baggage and cargo loading	Like cargo unloading, if necessary, cargo loading is performed at the cargo area. Once the baggage is checked in and all its information, it should cross the Baggage crossing check points to finish at the corresponding baggage belt. Then the ground handling transports them from the terminal to the aircraft position. Then starts the baggage cargo loading activity.	- Ground handling.	- Lost or damaged baggage. - Location of the ground handling equipment far from where the aircraft is. - Bad information regarding the position of the aircraft to be served. - Malfunction of any resource implying the turnaround Time.
Aircraft check	The crew is responsible for the flight and will check the aircraft thoroughly before each flight. Aircraft checks concern inspections on the outside of the aircraft and proper functioning of the aircraft machinery and equipment (checks in the cockpit).	- Crew	- *Engine Failure*: Engine failure is a special incident not foreseen in the operation of the airports. - Delays due to inspection of the aircraft

Start-up request	On the taxiway and on the runway, it is ATC who determines throughput and sequence, and as a consequence the traffic flow balancing needs to be in control of ATC as well.	ATC Aircraft Operator	- All traffic related factors causing delays on TSAT, e.g. low visibility, snow, ice, and wind. - Deviations between aircraft readiness (Target Off-Block Time (TOBT)) and ATC start-up target (TSAT), despite the service oriented aim of a controller to equal TSAT to TOBT as much as possible. This difference has the effect that the aircraft needs to hold/wait at the stand before start-up is granted.
De-icing	De-icing is the process of removing the snow or ice from the aircraft surfaces prior to operation. It is also possible to apply chemicals over the surface so that the formation of ice is avoided for a period of time, allowing an easier removal of ice.	- De-icing personnel	- Ice can be accumulated on fuselage, tail, wings and engines. This causes that the airplane shape is distorted and the free movement of the control surfaces is not possible. - Delay caused because of the application of de-icing materials.
Start-up and Push-back	When all boarding processes have been completed, the aircraft can depart. Aircraft at gates need to be pushed-back using dedicated push-back vehicles. Aircraft at stands mostly require a pushback as well, depending on the configuration of the stand. At some stands, aircraft can directly start up their engines and start taxiing.	- Handler - Airline - ATC.	- Misunderstanding of information. - Unavailability of the push-back vehicle at the specified time.

Bottlenecks affecting all the processes of the turnaround:

- Non-compliance with the slot allocation requirements and as such in inefficient use of the available en route and airport network capacity.
- Inefficient or not transparent sharing of information
- No clear information
- Inaccuracy of sequencing
- Arrival delays: if the arrival aircraft has a delay, then the handling resources plan has to be adapted to the new scenario.
- Unavailability of means, i.e. unavailability of a boarding gate could cause delays while searching an available one.
- Iced Aircraft: Under cold weather ice is accumulated on fuselage, tail and a wing. The airplane shape is distorted and free movements of ailerons and flaps are difficult.
- Insufficient or unreliable information: most relevant information exists somewhere around the airport in various systems, but is not readily available to all partners.
- About the information systems, no single partner has the complete picture (the information systems of the various partners have been developed and built independently).

- Accurate information is provided too late for a partner to be ready: poor information on expected arrival time, together with the fact that the turnaround is not integrated into the overall planning process, leads to the late arrival of ground handling agents and equipment at the gate.
- Restricted information sharing: some partners are unwilling to share information because they consider some data “commercially sensitive” or the sharing of the information demands extra work from them.
- Standalone information systems: information system independently developed and built by various partners.
- Lack of continuous monitoring and update of the information.

4.3.4 Departure process

The flight plan presentation, CTOT allocation and updated take-off time estimate processes for the outstation airport will also take place for the aircraft departure from the airport.

Knowledge of realistic taxi times under changing conditions enables Air Traffic Control (ATC) to optimise the push back, taxi and take-off sequence and hence reduce queuing and taxiway congestion improves CTOT compliance. Table 11 Table 11: Departure processes overview.shows an overview of the departure processes and its bottlenecks.

Table 11: Departure processes overview.

Departure processes			
Process	**Description**	**Agents**	**Bottlenecks**
Taxi-out	Taxi Time is key factor to predictability of accurate take-off in block times especially at complex airports. At complex airports the layout of runways and parking stands can result in a large difference in taxi time.		- As this phase is highly dynamic, it is therefore difficult to predict. - Deviation between TOBT and TSAT is caused by the overall surface traffic situation, which can put additional constraints to the off-block sequence. Factors such as airport lay-out complexity, construction works, weather conditions, de-icing, CFMU slot, and runway throughput will all be reflected in TSAT, despite the progress of one aircraft.

4.3.5 Key current bottlenecks to time-efficiency goals

The above analysis gives a general picture of airport airside processes. Main drivers for delay are:

- Turnaround related delays (non-Air Traffic Flow and Capacity Management (ATFCM)): are primary delays caused by airlines (technical, boarding, etc.), airports (equipment, etc.) or other parties such as ground handlers involved in the turnaround process.
- Air Navigation Service Provider (ANSP)-related delays: are primary delays resulting from an imbalance between demand and available capacity. There is distinction between airport, en-route, and weather related ATFCM delays and ANS-related delays at the departure airport.

- Weather related delays (non-ATFCM): This group contains delays due to unfavourable weather conditions including delays due to snow removal or de-icing. Weather related delays handled by ANSP are not included here (see previous category).
- Reactionary delays are secondary delays caused by primary delays on earlier flight legs which cannot be absorbed during the turnaround phase at the airport.

All these delays affect directly the efficiency of the airport airside processes. The relative importance of the processes can be compared qualitatively with the following objectives taken from the detailed TE objective structure:

- Minimise Waiting Time between processes [WT]
- Minimise Processing Time [PT]
- Minimise Travel Time through airport [TT]
- Minimise Taxi Times [TA]
- Minimise Turnaround Time [TU]
- Minimise Delay [DE]

Table 12 shows the relevant objectives regarding time-efficiency compared with the different airside processes.

Table 12: Estimation of reference process' relation with TE objectives.

Process	WT	PT	TT	TA	TU	DE
Network process	/	/	M	/	/	H
Arrival process	/	/	/	/	M	H
Taxi-in	L	M	/	H	/	H
Turnaround process						
Position passenger bridge/stairs	L	/	/	/	M	M
Disembarking of passenger	H	H	H	/	H	M
Cabin services	M	M	L	/	H	M
Boarding of passengers	H	H	H	/	H	M
Remove passenger bridge/stairs	L	/	/	/	H	M
Cargo/Baggage handling	M	H	/	/	H	M
Aircraft services	M	M	/	/	H	M
Towing or pushback	L	L	/	H	M	M
Departure process	/	/	/	M	/	H
Taxi-out	M	M	/	H	/	H

* Relatedness is estimated by H(igh), M(edium), L(ow) or / (not relevant)

4.4 Landside processes

In this section the processes occurring at the airport landside are analysed, in order to determine the current operational bottlenecks that occur in this area. This information can then be extrapolated to 2050, taking into account on-going development and the expectations with respect to airport operations as outlined in the Vision 2050 [1]. This will then lead to the identification of key bottlenecks to time-efficiency.

The airport landside represents the link between the 'outside' of the airport (curbside and intermodal links) and the actual air transportation area (the airside). For the purpose of the project, the landside is defined as *The location connected to airside and curbside, where passengers and baggage are moved from/to the aircraft and intermodal links. This concerns e.g. the terminal buildings, baggage facilities, check-in desks, etc.*

More precisely, the process flow will be considered:

- Within the airport terminal.
- Concerning only passengers and their baggage. Cargo operations are outside of scope. Furthermore, processes pertaining to providing additional services (shopping, general security, cleaning, etc.) to passengers are not taken into account, as they are not directly influencing the time-efficiency of the main processes[4].
- For passengers: Starting with the entry from the curbside, until entering the airport airside behind the security check.
- For baggage: Starting with the entry from the curbside, until entering the airport airside after the going through the baggage system.
- As the reference airport is assumed to have one large/average terminal, processes of passenger handling/checking/security as well as baggage processing are assumed to be located in this one terminal (centralised system).

4.4.1 Passenger processes

Generally, it can be said that current terminal passenger processes constitute the following:

- For departures:
    - Arrival in the terminal[5]
    - Check-in at the airline counter
    - Optional: baggage check-in if more than carry-on baggage is present
    - For international and/or non-Schengen flights: passport control
    - Security check

[4] As understood by the TE airport concept, activities such as shopping remain completely optional for passengers. But as the passenger remains free in 'adding' more time on the airport as he/she sees fit, such processes are considered out of scope for the TE concept's solutions and thus also for the reference analysis.

[5] This is only taken as the starting point, i.e. 't0' of the landside phase. This point occurs at the exit of the intermodal processes. As it is only a starting point and not a real process on its own, this step is not further detailed here.

  - Transport between different counters and checks, either by foot or people mover
- For arrivals:
  - For international and/or non-Schengen flights: passport control
  - Optional: baggage reclaim if more than carry-on baggage is present
  - Optional: customs if there are items to declare
  - Transport between different counters and checks, either by foot or people mover
- For transfer passengers:
  - Not applicable as transfer passengers do no leave the airside. In case a transfer passenger leaves the airport (e.g. due to long free time), he is effectively treated as an arrival/departing passenger.
- General:
  - Provision of information and guidance (e.g. travel, schedule, signage, etc.)

Figure 9 indicates how these processes are generally seen to be related to each other. This division is based on [31, 32, 33].

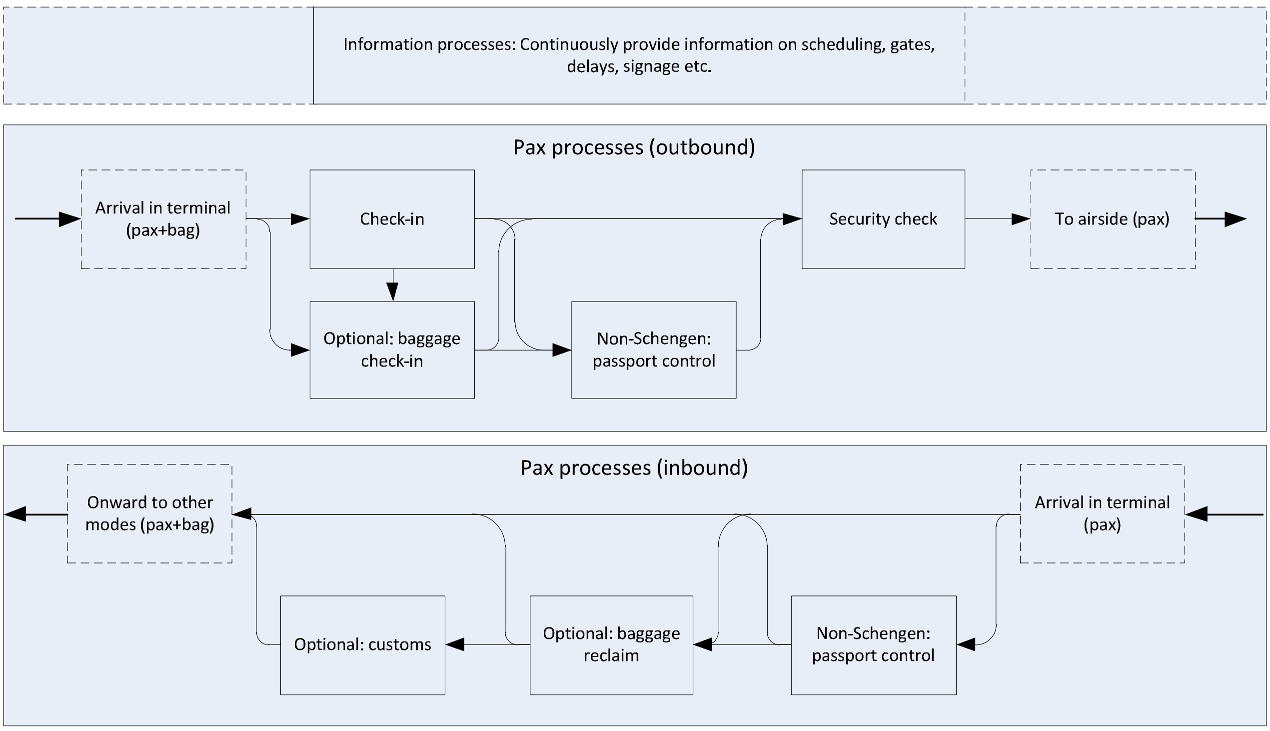

Figure 9: Generic (landside) passenger processes.

4.4.2 Baggage processes

Generally, it can be said that current landside baggage processes constitute the following:

- For departures
  - Check-in, weighing and labelling at the airline counter, or via drop-off points
  - Security scanning

    - Transport into the baggage system
    - Sorting/reconciliation and transport to correct pier
    - Optional: manual transport and sorting of odd-size baggage
- For arrivals
    - Transport to baggage system
    - Loading into the baggage system
    - Scanning, sorting, and transport to correct reclaim area
- For transfer passengers
    - Transport to baggage system
    - Loading into the baggage system
    - Scanning, sorting, and transport to correct departure pier

Figure 10 indicates how these processes are generally seen to be related to each other. This division is based on [31, 32].

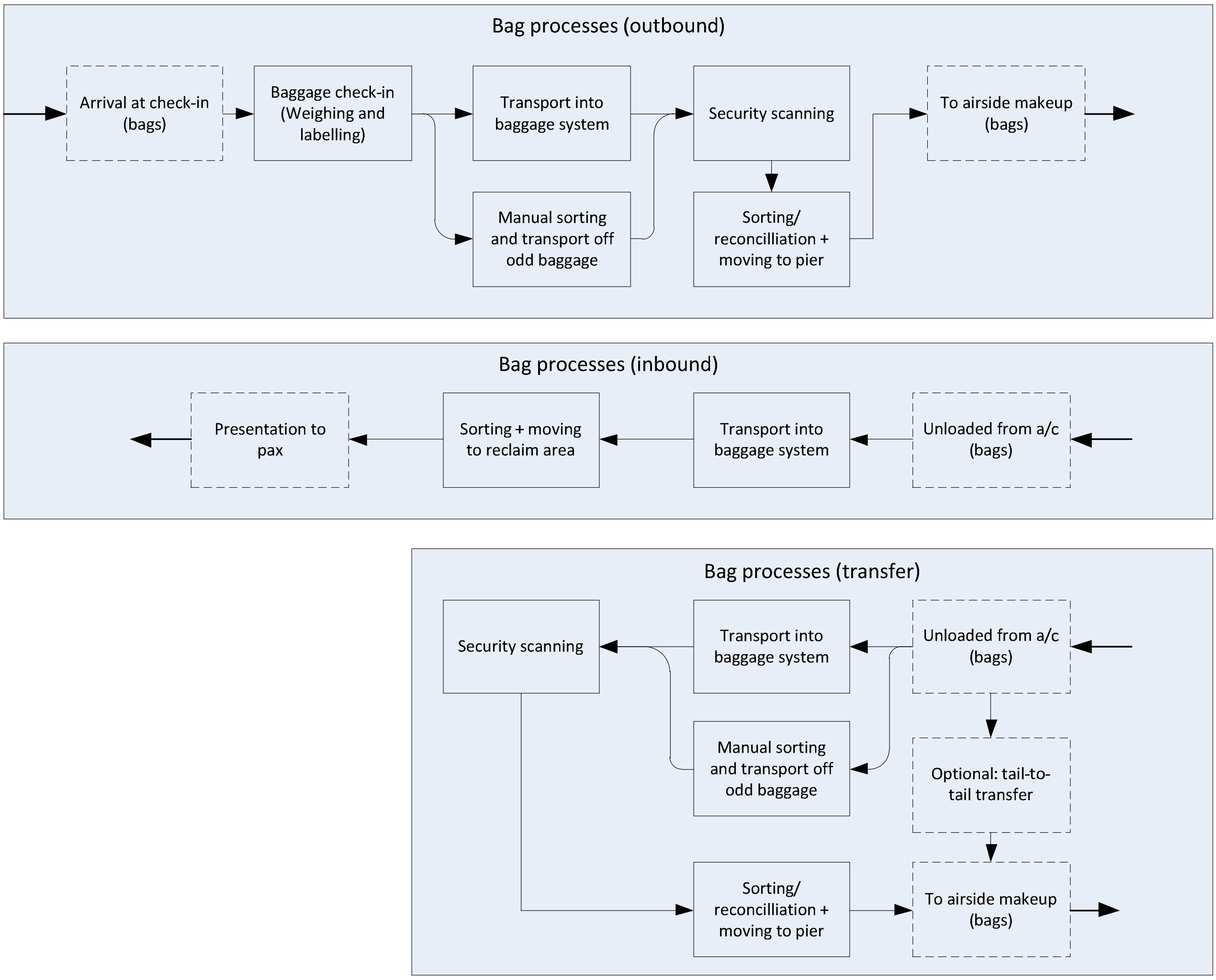

Figure 10: Generic (landside) baggage processes.

4.4.3 Key current bottlenecks to time-efficiency goals

The above analysis gives a general picture of airport landside processes. Although devised currently for the generic, medium-sized reference airport, it is true that most airports across the world execute more or less the same processes (with more or less complexity depending on the airport's size and layout).

Which of these processes are actual bottlenecks to time-efficiency depends largely on any airport's specific configuration, organisation and traffic numbers. However, enough relevant inferences can still be made. To do this, the different processes can be compared to the Time-efficiency objectives as set down in Section 3.4. In order to only derive landside-based bottlenecks and challenges, only the following objectives are taken into account here as they can easily be seen to be most relevant in this context:

- Minimise Travel Time through airport [TT]
- Minimise Waiting Time between processes [WT]
- Minimise Processing Time [PT]
- Minimise Connecting Time between modes [CT]

Table 13 compares the relevant landside processes to the main landside-applicable Time-efficiency objectives, in a way akin to the Change-Impact matrix, which will later be used to map out solutions' expected benefits. In the table, an estimate is given of the 'relatedness' that each main process step has with the relevant TE objectives.

Table 13: Estimation of reference process' relation with TE objectives.

Process	TT	WT	PT	CT
Arrival at the terminal	/	/	/	/
Check-in passenger	/	H	M	M
Baggage check-in	/	H	M	M
Passport control	/	M	L	L
Security check	/	H	H	H
Transfer between desks/checks	H	/	/	H
Baggage weighing and labelling	/	/	M	L
Baggage security scanning	/	/	M	L
Transport into baggage system (dep)	/	/	L	L
Sorting/reconcile and transporting bags to pier	M	/	H	M
Sorting/reconcile, transport to pier (transfer)	M	/	H	H
Manual sorting of odd-size baggage	M	/	M	M
Transport into baggage system (arr)	/	H	H	H
Transport of bags to the reclaim area	M	M	M	M
Provision of information, guidance	L	/	/	L

* Relatedness is estimated by H(igh), M(edium), L(ow) or / (not relevant)

Looking at this broad analysis, and combining this with current knowledge of airport operations, a number of core bottleneck processes can be identified. These are described in Table 14 and Table 15.

Next to the perceived bottlenecks and affected goals, the underlined agent names indicate which actor is believed to have a key role in causing *and* alleviating these bottlenecks. When human actors (staff) are responsible, key causes of bottlenecks are often simply due to too little capacity/staffing. In such cases, also *personnel assignment, training and costing details* could be considered in achieving time-efficient operations, next to just process improvements.

Table 14: Passenger process overview

Passenger process			
Process	**Description**	**Agents**	**Bottlenecks**
Security check	This process is very lengthy and involves much hassle, especially when travelling to strict countries. In principle all TE objectives are affected highly	Security agent, passenger	• Waiting time: waiting in line • Processing time: being processed, which includes taking out carry-on baggage, walking through the scanners, being patted down etc. • Predictability of schedule: because it is unknown how long this will take, travellers have much uncertainty in their time planning, and as such often build in buffers • Flexibility of schedule: because the security check is mandatory and takes time, passengers have to build in buffers in their planning, which limits their 'free-travelling' flexibility • Connecting time: due to the time consumption, total time to connect to the actual flight is lengthened • Information/facilities: information w.r.t. security rules and carry-on allowances is often unclear to non-regular travellers. This creates hassle at the security station, delay and frustration.
Transfer between checks/desks	This process constitutes all walking times and distances, and is especially of influence on airports with large spread of facilities	Passenger	• Travel time through the airport: self-explanatory • Connecting time: although 'connecting time' is a term reserved mainly for transfer passengers (which are based airside), one can also see this as applying to departing passengers. The larger the distances in the airport, the longer time is needed to get from the 'door' of the airport to the final aircraft. • Information/facilities: during the transfer/walking process, passengers are searching where to go. The more information they have (mainly signage), the more 'in control' they will feel over their schedule and the more effective (time-efficient) they can travel through the airport. On the other hand, less freedom of walking can also contribute to being time-efficient.

Passenger and/or baggage check-in	These processes can be key bottlenecks, especially when desk capacity is insufficient. However, as more and more self-service options become available, these processes are not usually dominant	Passenger, check-in agent	• Waiting time: depending on capacity and airport size, this can be an issue especially in peak periods. • Processing time: This depends directly on the effectiveness of the staff and/or self-service functionality. • Predictability: due to uncertainty about how busy check-in is, passengers will need to build up buffers. • Flexibility: idem • Connecting time: idem • Information/facilities: Especially at larger airports it can be unclear where (and at which counter) one has to check-in. Also current self-service solutions can introduce frustration due to lack of information or defects.
Provision of information, guidance	This process is continuous, interacting with passengers at every step, and is only as good as the information it receives from other operational processes	Airline agents, ATM, gate scheduling, security agents	• Travel time: incorrect or confusing signage and gate info can really turn passengers around and lead to much time lost and frustration. • Predictability: incorrect or delayed information with respect to flight times, boarding gates etc. gives people less in control of their schedule. • Information availability: related strongly to the last point, the less detailed process/planning/direction information is available to passengers, the worse and less efficient they can move through the airport

Table 15: Baggage process overview.

Baggage process			
Process	**Description**	**Agents**	**Bottlenecks**
Transport into the baggage system (at arrival)	When passengers are deboarding, in principle they would like to have their bags waiting for them at the carrousel. However, due to crowding at either the apron or before entry to the baggage system, this takes more time, causing waiting time for the passengers	Baggage handlers, baggage system	Waiting time: self-explanatory Processing time: directly influenced by the baggage process Predictability: As the unloading/sorting can take very different amounts of time, passengers and airlines have uncertainty in their planning. Reliability: Current baggage systems may not be reliable enough to allow time-efficiency in the baggage process. Information/facilities: often passengers get little information on how the unloading process is proceeding, causing frustration. Connecting time: The speed of baggage delivery directly affects how quickly passengers can enter their next mode of transportation.
Sorting/reconciling and transporting bags to piers (inc. transfer)	Baggage handling systems are highly optimised and as such have a minimal processing time for any given bag	Baggage handlers, baggage system	Processing time: self-explanatory Flexibility of schedule: because bags need a certain minimum time to be sorted, flight (and thus passengers') schedules lose flexibility. Transfer time: especially for transfer-flight bags the processing speed is a limitation, and often a direct cause of lost baggage in any particular flight.

4.4.4 Translating to the future: core issues to be solved by the TE concept

In total there are thus 6 main processes deemed to pose a *current* challenge to TE goals:

1. The security check
2. Transfer/walking between desks and checks
3. The check-in process
4. Sorting and transporting of outbound baggage (including transfer)
5. Entering inbound baggage into the baggage system.
6. Information provision

However, it is likely that some of these will already be solved by natural developments in current research/applications. As such, these processes will require less focus for the TE concept. Specifically, two processes are considered in this regard:

- The check-in process: current e-check-in and self-service baggage drop-off points will develop over the coming years to become more standard. As such, this process will not be investigated in detail for radical solutions. However, the current technologies may be extrapolated with new functionality if applicable, to possibly offer improvements over the current situation.
- Transfer/walking between desks and checks: airports will remain large and possibly grow even larger in the future. As this occurs, current technologies already offer the best solutions to keep walking times acceptable (e.g. transport bands, escalators, mini-trains etc.). These will thus be used as applicable to the concept.

Effectively, thus four main landside bottlenecks are foreseen, for which new solutions need to be investigated in detail for the TE concept: *security*, *inbound baggage entry speed*, *outbound baggage sorting/transport speed* and *information provision*[6].

4.5 Intermodal transport services

One of the high level objectives for the transport network is that 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours. Thus, intermodality plays a major role in achieving such objective, which means that the intermodal processes performed at the TE airport concept have to be analysed in depth. Figure 11 shows the passenger's total journey from origin to the airport, including the origin-to-airport transportation and the area in which the passenger is changing from one mode to the airport. A first approach to the bottleneck analysis and the subsequent possible solutions analysis has shown that several solutions to bottlenecks have the potential to add value not only in the processes occurring in the airport intermodal area, but also in the journey from the passenger's origin point – which will be called 'home' from now on in this section – to the airport.

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[6] Although it can easily be argued that current mobile/IT technology will be well capable of solving this problem in the future, no real roadmaps or common architectures are yet devised to guide this implementation. As such this will also be investigated.

Therefore, with the objective of increasing the value delivered by the time-efficiency airport concept, a more holistic view of the door-to-door journey has been proposed for the intermodality section and its solution proposals. It should be noted that, as the development of the TE airport concept was initially bound to the airport terrain limits, the 'home-to-airport' part of the journey will not be elaborated in depth in the document. However, considering its value to the TE airport concept, this part of the journey cannot be completely neglected.

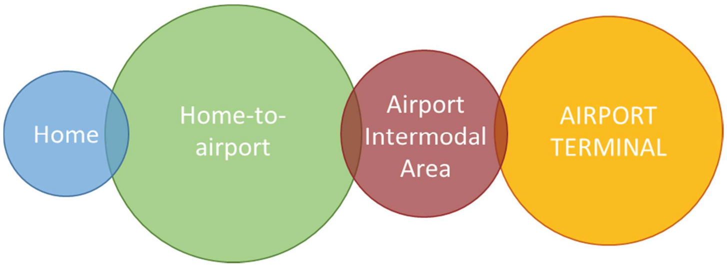

Figure 11: Passenger's journey to the airport.

Firstly, in this section, the processes taking place at the airport intermodal areas are analysed in order to determine the current operational bottlenecks that occur in this area, and secondly, but in a lesser extent, a process analysis on the home-to-airport journey is given. This will lead to the identification of key bottlenecks to time-efficiency that remain to be solved in the development of the TE airport concept.

4.5.1 Road access

Planning of airport roads is a specialised subject. At all airports there will be public (landside) roads open to all traffic, and non-public (airside) service roads restricted to authorised vehicles[7]. At large airports, it is preferable to separate service-related traffic long before arriving at the passenger terminal curbside area.

4.5.1.1 Public (landside) airport roads

The landside road system serves a number of categories of traffic, such as:

- Private cars: for passengers; airline and airport employees.
- Inter-terminal shuttles.
- Crew buses and staff vehicles (who can, of course, constitute a significant blockage at airside entry points because of the need to screen their baggage).
- Airport service vehicles.

It also needs to satisfy certain basic criteria:

- Basic planning requirements for landside roads.

[7] Part of this section is based on the IATA recommendations, presented in the *Airport Development Reference Manual 9th edition* [18].

- They should be designed to accommodate peak traffic volumes and have adequate expansion capacity (unless the airport takes the conscious decision not to cater for peak flows).
- All public roads should be clearly signposted. Clearly visible signs should be positioned on the roads and on the terminal curbside areas well in advance of desired destinations to allow drivers - to make any necessary changes without abrupt changes of lane and direction. Signs should be properly lighted for night use, and lettering and background colours should enhance clarity and visibility. Messages should be concise, quickly identifiable, and easily understood. Colour coding for multiple terminals, for specific airlines, or for major facilities like car parks, is recommended.
- Links between the external public road system and the non-public or service road system should be planned carefully in order to avoid either congestion or reductions in the potential for future expansion.
- Main through roads should bypass the road along the face of the terminal building.
- Roads running along the face of the terminal building should be wide enough to permit passing of stopped vehicles and should have a minimum of three lanes. These should be wide enough to allow space for loading and unloading bags.
- There should be no access to the apron, taxiways or runways from public roads.

4.5.1.2 Public transport and commericial landside vehicles

Taxis, buses, and coaches are commercial landside vehicles and should have access to the airport's intermodal area:

- **Taxis:** The requirement to provide a continual supply of taxis to the arrivals curbside loading area can be accommodated by creating a taxi pool staging area. This needs to be reasonably close to the terminal area, and provision for orderly staging and sequential dispatch of taxis to the curb is necessary. A means of alerting drivers to the need for taxis at the curb (and, in multi-terminal airports, which curb), is also needed.
- **Buses & coaches:** There are various types of buses and coaches, all of which have different needs to be catered for, namely:
    - **Charter and tour buses need dedicated curb space.** This is often provided at the end of the terminals or in a dedicated transportation centre. There is also a need for waiting and parking space, ideally with some form of communication for drivers meeting inbound passengers.
    - **Shuttles for hotels, car rentals, and car parks.** These also need dedicated curb space for loading and unloading, and facilities for waiting passengers (including phones for communications with hotels). In order to reduce on airport traffic, some airports have consolidated hotel shuttles into a number of fixed route services, each one serving a number of local hotels.
    - **Long distance buses and coaches.** These are usually accommodated at a dedicated transportation centre. This can be a valuable facility for local residents, who generally are

more likely to need a bus than a plane. A dedicated transportation centre needs a good walking route or a people mover to the terminals.

- **Local (public transport) buses.** These are particularly valuable for employees. A number of airports have provided a direct subsidy, start-up funding, or assistance with marketing for buses on core routes, especially those operating 24 hours a day. Some are demand-responsive, deviating from a fixed route if pre-booked - a useful answer to personal security concerns. Some airports have introduced free or discounted travel schemes for employees to reduce car traffic and to increase their pool of labour. The reputation of the airport depends in part on the quality of (often low paid) retail and cleaning staff, and increasing the ability of all shifts to get to work at an acceptable price is useful. A few large airports have negotiated free-tare zones around the airport to encourage employees to use the bus for travel between on-airport sites (for example to meetings) rather than to use a car.

4.5.2 Rail access

In the planning stage, a full analysis of the airport rail access system is required: the capacity of the system needs to be designed for the airport's capacity. Close coordination between airport planners, local planning authorities, and local transportation providers is necessary to ensure that proper and timely provision for the requirements, current and projected, is in the local or regional transportation plan and in the appropriate capital expenditure programmes.

Advance planning is highly important. Surface rail access development plans should be part of the airport master plans and development plans for the surrounding area. The forecast modal split between rail based access and road based access (private car, taxi, bus and other), can either be an input to or an output from these plans.

Figure 12 shows images of the four types of rail access. The characteristics of each type should be reviewed to decide which is best for the transfer processes in hand. Each type has evolved to meet local requirements. The four types of rail access are:

- **Metro and light rail:** Especially used at some European airports located near a larger city. This type is less good for air passengers- especially those travelling long haul, with much baggage. There may not be appropriate accommodation on the trains, and the airport needs to be alert for problems and to be ready to liaise if necessary with the transport provider.
- **Regional and national rail:** Public transport services connecting the airport to the near-by region as well as the rest of the country. Often high connectivity to the rest of the rail network for a large catchment area.
- **High-speed (dedicated):** This is often a premium rail service (compared to regional rail) and offers high-speed connection to the airport from more distant areas, both in the same country as

well as some international areas. Some high-speed trains have dedicated infrastructure, to be independent of other regional services and thus guarantee a reliable service.

(a) Airport Express Line, Beijing Subway

(b) Frankfurt (Main) Flughafen Fernbahnhof

(c) Light Rail SeaTac Airport

(d) AIRail Station

Figure 12: Types of rail access.

4.5.3 Intermodality and airport access

This section discusses the processes in the intermodal area of the airport, i.e. the area in which the airport and other modes of transport connect.

4.5.3.1 Principle of intermodal travel

Passengers and staff may travel by car to the airport, as it is both attractive and convenient. At the same time, other types of intermodal travel, which in this context means the principle of using one or more modes of transport to supplement the single mode of vehicular transport travel to and from the airport complex, are actively promoted by IATA. It is advantageous to the short and long term aspirations of airports to progress plans of intermodal travel, since it offers the airport complex the following advantages:

- Passenger and staff car parking facilities become far less onerous in size and complexity.
- Traffic congestion and therefore road infrastructure can be correspondingly downsized.

- The resulting volume of road traffic and the environment impacted upon is lessened.
- Car parking road space saved can be used for expansion plans by the airport operator.

4.5.3.2 Developing an intermodal strategy

The airport operator must work with the local community, as well as with local transport companies that support the operational airport, to ensure together that a network and tare structure is advantageous to staff and passengers. Typically in a large airport the passenger should have to travel long distances in a short time. That makes it necessary to equip the airports with an internal passenger transport network based on people movers and other mechanical facilities. It should connect the curbside and transfer stations with the boarding gates.

Three different intermodals models could be developed focused on the airport:
- A door-to-door approach: from the origin to the boarding gate in dedicated vehicles.
- A door-to-door approach in a multi-mode network ending in a transfer station at the airport intermodal network and people movers and other mechanical facilities to boarding gate.
- A multimode network up to the curbside to link with the airport intermodal network and people mover and other mechanical facilities to boarding gate.

According to ACARE conclusions the key attributes of well-developed intermodal airport strategies can include:
- Clear and competitive pricing.
- Total commuter and passenger travel solutions- the door-to-door approach.
- Optimization of all resources and facilities.
- A strategy that aligns with the master plan aspirations for the developing and expanding airport operation.
- Physical interfaces to ease transfer (differentiate passenger/freight): infrastructure needs to be in place to provide efficient and convenient transfer between modes.
- Information to customer, tracking and tracing, single ticketing/waybill for complete journey with alternative ways: provide alternative transport means in a visible and ease transfer between modes.
- Consistency of security checks.

4.5.3.3 Curbside design considerations for road modes

Private cars, taxis, and buses will need an interface with the airport's terminal entry. The curbside is the area in which mostly cars, taxis, and some buses connect to the airport's terminal. A major issue is curbside capacity and the potential for congestion, as well as the avoidance of queues and accidents. The following curbside facilities should be provided at the terminal complex:

- Departing passengers drop off:

  - Temporary stop, offload and go areas for cars and taxis.
  - Accommodating park and ride bus schemes.
- Arriving passengers pick up:
  - Temporary stop on, load and go areas for cars and taxis.
  - Accommodating park and ride bus schemes.

It is essential that signage is clear to all passengers and that simple routes to and from the areas dedicated to the above functions are adequately sized and positioned. Buses usually use fixed stopping points: there is a need to ensure that these are reasonably convenient for entering the terminals.

It is advantageous to accommodate taxi stand by parking remotely (off airport) and provide a dedicated holding area for taxis so that the terminal complex does not become congested with competing taxi traffic. Taxis can be controlled into the airport complex by on-demand flow management processes. This ensures the taxi areas are adequately supplied with taxis at the correct time and that all taxi companies with licences to operate at the private airport have equal opportunity to pick up fares. The major advantage of controlling taxi traffic flow is that less interference with other traffic exists and that emergency vehicles have unhindered access to the airport frontage at times of emergency, and that security can be monitored appropriately.

Finally, the following considerations should also be taken:

- At large airports, special lanes may be reserved for high-occupancy vehicles, and the curbside area should segregate buses and taxis (inner lanes) from private vehicles (outer lanes).
- Provision should be made for a future people mover system (note that such systems can be elevated above highways).
- Adequate facilities for two-wheeled vehicles (e.g. motorcycles) should be provided: secure parking spaces should be available near work areas and public transport stops. Safety can be improved by the provision of a segregated network for two wheeled or un-powered vehicles.

4.5.3.4 Airport intermodal area design considerations

The airport’s intermodal area contains the interface between rail and different forms of road access and the airport’s terminal. Further, the area should include parking spaces for passengers arriving by car and with the need to park their car for a certain duration.

Rail access

There are a number of characteristics which airport planners should consider for the implementation of train systems. The assessment should include at least the following characteristics:

1. The number of vehicles or carriages required to process the demand,
2. The speed and frequency of the train operations required to meet the demand,
3. Track and signal operating limitations,

4. Compatibility with other train operating and station systems,
5. Operational flexibility of the train operating systems,
6. Technology suitability.

Road access

For road access which does not continue to the curbside, several facilities are required:

- Parking areas for short- and long-term parking.
- Separate bus stations for the different forms of bus transportation: public transportation, coaches, charters, and hotel shuttles.

These facilities need to be adjusted for the required demand at the airport.

Airport station characteristics

The location of the station(s) to serve the airport is important, especially if there is more than one terminal. If there is more than one station, there is a need for good signage and communications; although a railway can then be used for inter-terminal transport. Stations for cargo, maintenance, sightseeing, or hotel areas are all possible, according to geography and demand. Here all future expansion plans need to be borne in mind to ensure that the station -a relatively fixed point- will not be rendered out of date (or at least to ensure that the railway can continue to serve the airport efficiently).

When planning the station, there is a need to consider the capacity of the access system. Provision for change of level needs to be appropriate for the numbers likely to be using them - the likely volumes of passengers and baggage from peak trains.

The following facilities should be available:

- Baggage trolleys. This can be an issue between the railway and airport. For understandable safety reasons, train companies prefer those where the brake is on unless released by a user. Many airports prefer those where the user is actually required to apply the brake when necessary.
- Accommodation for change of level can include rolling stairs, although here and on escalators trolley policy needs to be considered. Convenience and safety need to be balanced. Lifts/elevators are valuable especially for those with reduced mobility: they need to be designed to carry a stretcher if necessary. Ideally a choice should be provided some people are claustrophobic in lifts.
- Check-in, away from the platforms but on the natural route from the platforms to the terminals, is valuable. It will facilitate passenger circulation and relieve stress by disencumbering them of their bags as early as possible. It reduces the need for trolleys and for circulation space on the route to the terminals, and may even reduce the need for check-in space in the terminals.
- In-town check-in needs to be considered for the downtown terminal or at major interchanges. The facilities can range from self-service machines for those with just hand baggage via baggage drop systems, to full hold baggage check-in. Although these alternatives are popular among passengers, so far the economic case for them has been difficult to make. Everyone benefits, but matching the flow of costs and the flow of benefits can be difficult. Certainly baggage is a significant element in

choice of modal split: the presence or otherwise of bags is a key determinant of mode choice (another is the need to change vehicle, although the weight to be attached to this is a matter of debate and varies with the market).

4.5.4 Key current bottlenecks to time-efficiency goals

The preceding sections discussed the current design considerations (infrastructure view) and processes within intermodality. This process is schematically shown in Figure 13. All these process affect only one attribute from the TE airport concept's objective structure, being the connection time as part of the door-to-door journey, which has to be minimised to reach the concept's objective. It is important to note that the objective only has impact on the parts of the journey where passengers and luggage transfer from one mode of transport to another. Strictly seen, this does not encompass the travel time on other modes of transport than the aircraft. Shortening the time spent on other modes of transport (such as train from home to the airport's curbside) does however contribute to time-efficiency of the passenger. This section therefore also addresses most important bottlenecks in the home-to-airport journey. Since this part of the journey is slightly out of the scope of the project, this discussion will be limited though.

The core bottlenecks related to transfer intermodality (i.e. the transfer between modes) and the home-to-airport journey are identified and summarised in Table 16 and Table 17 respectively.

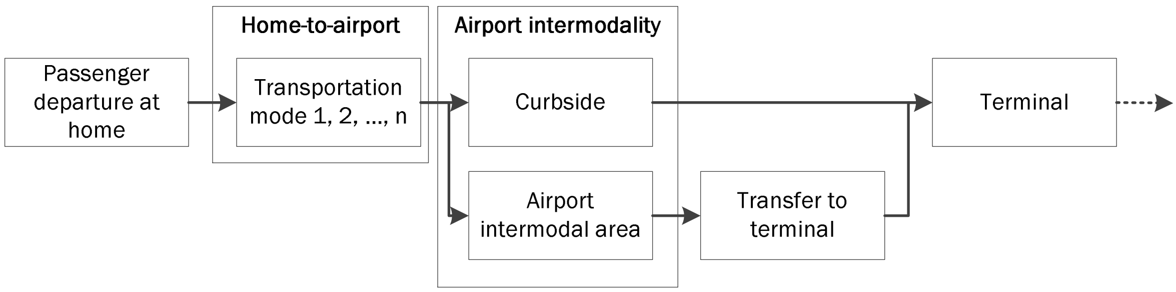

Figure 13: Process view of the current passengers' home-to-airport journey and intermodality.

Table 16: Intermodality process and bottlenecks overview.

Process	Description	Agents	Bottlenecks
Intermodal and curbside infrastructure	Physical transfer from one mode to the airport's terminal	Passenger	Long (walking) distances between modes Long transfer times Baggage handling between modes Facility readiness for people with reduced mobility (PRM) Number of parking slots Number of bus stops Escalators, elevators, people movers
Intermodal and curbside services	Situational awareness during transfer from one mode to the airport's terminal	Passenger	Signage Path finding Information update Schedules constraints for all types of transportation

Table 17: Home-to-airport transportation process and bottlenecks overview.

Process	Description	Agents	Bottlenecks
Travel from home-to-airport	Actual travelling to get from home to the airport	Passenger, other transport modes' operators	Large distance between home and airport Speed of the transportation High buffer times taken into account by passenger due to unreliability of transportation system Number of available modes of transportation Capacity constrains for road and railroad
Connecting between multiple modes	Physical transfer from one mode to another (both not being the aircraft/airport)	Passenger	Long transfer times Baggage handling between modes

4.5.5 Translating to the future: core issues to be solved by the TE concept

The *current* challenges to TE goals are thus identified in thus areas: transfer intermodality and the home-to-airport journey:

1. Transfer intermodality
    a) Long physical distances between modes
    b) Updated information availability
    c) Guidance and navigation on the way to the terminal building
    d) Baggage handling
    e) Long time spent on transfers
2. Home-to-airport journey
    a) Large distance between home and airport
    b) Speed capabilities of transportation
    c) Unreliability of travel time resulting to buffer times taken by the passenger
    d) Number of available modes of transportation
    e) Capacity constraints

However, again it is likely that some of these challenges and bottlenecks will be (partly) solved by natural developments. Information provision and way finding is an on-going research area, though the increase in passengers and the high expected level of service will continue to bring challenges to these areas. Current efforts are also done for providing seamless baggage transfer between different types of modes. However, such solutions are currently only tested on a small scale (pilot phase). Providing this service for all passengers still implies some major security and capacity related issues. Integrating different modes both in terms of location as well as scheduling still remains an important challenge.

As stated in the Vision 2050, more people will live in large cities, which may provide opportunities for better high-density connectivity to the airport. On the other side, capacity will be more constrained in 2050.Also in 2050, speed and reliability of different forms of ground transportation will still be a challenge.

As such, most of the given *current* bottlenecks (except information provision and guidance) are expected to also be *future* bottlenecks.

4.6 Infrastructure

A process based view on infrastructure itself is not useful in terms of time-efficiency, as most (airside and landside) processes are located within the infrastructure. Therefore, infrastructure provides a mean to perform such processes. From the analyses of these processes, improvements can be proposed for the infrastructure.

Infrastructure shall enable time-efficient processes. Relating this back to the objectives of the TE airport concept, this would mean that infrastructure should not be a bottleneck to minimise the throughput time of aircraft and passengers and to have seamless intermodality. Infrastructural changes can enable to comply with these objectives, as some characteristics have influence on the low-level attributes. For example, minimising the time from curbside to gate for the passenger is partly influenced by the distance between curbside and gate and therefore the size of the terminal. As another example, the airside infrastructure (both in form and distances) has influence on the average taxi time of aircraft.

The key bottleneck at the reference airport caused by infrastructure can therefore be summarised as: limiting the possibility to minimise the throughput time of passengers and aircraft and to have seamless intermodality. With this bottleneck in mind, changes to existing infrastructure may be proposed as part of the TE airport concept.

4.7 Summary of the reference airport context and key challenges

The previous sections described the reference airport, its processes, and its expected future bottlenecks. These bottlenecks provided a starting point for the generation of solutions to cope with them. The solution generation process can be summarised in a derivative of a morphological grid[8], as stated in the Concept Development Methodology [2]. This table, as shown in Table 18, lists the key bottlenecks that exist per area (airside, landside, intermodal, and infrastructure) and shows which objectives of the TE airport concept are affected by it. The next column summarises what can be done to overcome these bottlenecks. The resulting grid serves as an input for the concept's solutions presented Chapter 5, as these follow from the proposed aspects that can be changed.

[8] Note that the morphological charts was proposed in [2] as both a tool for solution finding as well as a way of relating solutions with bottlenecks and documenting this as such.

Table 18: Key bottlenecks, attributes affected, and the possible changes to cope with them.

Processes & areas affected	Key challenges	Attributes affected	Aspects that can be changed
Airside			
ATM, taxi	Inaccurate taxi times; long taxi times due to distant located runways (result of spatial constraints at airports); inaccurate actual take-off times due to this; unavailability of correct aircraft sequences; arrival and departure delays; airport network capacity	Avg. taxi times Avg. delay	Increase accuracy and predictability in taxi procedure; optimise taxi planning for an optimal airport network capacity; alleviation of spatial constraints provided by new technologies that may lead to better movement area layouts
Turnaround	Unavailability of turnaround means; long connecting/fitting time of turnaround means, thereby increasing turnaround time and delays	Avg. turnaround time Avg. delay	Reduce the need of means; standardise, make aircraft stand independent of apron vehicles; automate apron vehicles
Turnaround	Unpredictability of passenger boarding/disembarking time; lengthy passenger/baggage boarding/loading process; delays due to no-shows of passengers	Avg. turnaround time Avg. delay	Increase availability of information; allow seamless flow of passenger through airport; optimise and standardise boarding process; develop systems for quicker baggage loading and unloading in the case of a no-show; enable real-time information provision; reduction of uncertainty in passenger arrival time to boarding gates
Turnaround	Unavailability of sufficient aircraft stands with direct access to passenger bridge and loading devices	Avg. turnaround time (aircraft) Avg. throughput time curb-gate (passengers)	Create more aircraft stands by more efficient use of space available and enabling aircraft stands to be arranged more closely to each other
Turnaround	Baggage unloading and loading becomes critical in terms of time; the use of apron vehicles may lead to delays; time required to perform each turnaround activity apart from baggage loading/unloading	Avg. turnaround time Avg. delay	Allow for a quick unloading and loading process by pre-processing baggage and cargo in dedicated containers; eliminating apron vehicles and replace by a solution that enables fast unloading and loading of containers; similar solution needed for catering, waste disposal, etc.
Turnaround Taxi	Unreliability in docking process, due to e.g. bad visibility	Avg. turnaround time (more time needed for docking of the aircraft)	Add automatic detection/guidance for placing apron service vehicles; add automatic detection/guidance for placing aircraft in the apron
Turnaround, taxi	De-icing of aircraft will increase due to increased traffic volumes thereby forming a bottleneck in the turnaround and taxi process	Avg. turnaround time Avg. taxi time	Remove the need for de-icing or increase the throughput of de-icing facilities at the airport and avoid queuing of aircraft
Landside			
Check-in, security, boarding, transfer	Waiting and processing times will increase for passengers due to increased security measures at the airport; an even more detailed security screening will persist in 2050+; development of technologies/procedures that enable a balanced solution regarding time required vs. safety ensured in security checks; improve public's perception on security checks	Avg. throughput time curb-gate Avg. waiting time Avg. process time	Automation of several functional requirements of the security process, thereby eliminating queuing for the passenger and striving for a straight-through processing of passengers

Processes & areas affected	Key challenges	Attributes affected	Aspects that can be changed
Passenger movement through terminal	Information provision and way finding; long walking distances; separation of passenger due to safety and customs regulations; limited integration of information	Avg. throughput time curb-gate	Increase availability of information; allow seamless flow of passenger through airport; eliminate need for way finding; reduce walking distances
Baggage sorting	Baggage sorting not fast enough; thereby requiring critical time for the passenger's baggage to be processed before loading and after unloading	Avg. throughput time curb-gate (result)	Increase throughput of the baggage sorting system; minimise distance between aircraft and drop-off/pick-up point; minimise distance between aircraft for connecting flights
Transfer passenger/ baggage between connecting flights	Uncertainty of schedule/connecting time; long distances between aircraft; similar problems with way finding (passengers) and baggage sorting process will yield longer connecting time	Avg. throughput time curb-gate Connecting time/door-to-door time	Provide solutions for bottlenecks of passenger and baggage flow (as above)
Intermodality			
Transfer between modes	Long distances/long transfer times No updated information Guidance and navigation to terminal	Connecting time/door-to-door time	Shorten distance between modes; provide fast transport between modes
Baggage transfer	Baggage handling between modes	Connecting time/door-to-door time	Shorten distance between modes; provide fast and baggage convenient transport between modes; move baggage drop-off points to airport intermodal area
Home-to-airport journey	Large distance between home and airport; speed capabilities of transportation; unreliability of travel time; capacity constraints	None [total door-to-door journey time]	Improve transportation modes (speed); increase reliability of transportation by using dedicated infrastructure for airport transport; better information provision; passenger tailored travel advice; implementation of reliable early baggage drop-off points
Infrastructure			
Turnaround Taxi	Spatial restrictions limit airside capacity; spatial and environment restrictions limits runway use or building	Avg. turnaround time Avg. taxi time Avg. delay	Create apron with densely located aircraft stands (e.g. circular); move piers underground; distant located runways can be connected with the main terminal using an (external) high speed taxi system; remote terminals near the runway reduces the need for taxiing
Passenger movement	Limitations to enable seamless intermodality; highly related with intermodality issues	Avg. throughput time curb-gate	Shorten distance between modes; provide fast transport between modes and eliminate risks for delays

5 The advanced Time-Efficient airport concept

This chapter will describe in detail the advanced Time-Efficient (TE) airport concept. . The discussion starts with a short overview of the aim of the TE airport concept, after which the state-of-the-art operations in 2050 are described. The different processes considered are also discussed, after which the separate solutions are elaborated in the subsequent sections. These solutions are summarised afterwards in order to explain their contribution to the 2050+ airports.

5.1 Overview of the concept

This section discusses the underlying idea of time-efficient travelling in the TE airport concept. Figure 14 shows a timeline for what is possible within a four hour door-to-door trip today and in 2050, as stated in Vision 2050 [1], assuming travel time to and from (i.e. the catchment area) the airport is 30 minutes maximum. Even though the timing is very tight, with just small allowances for delay getting to and from the airport (15 and 10 minutes respectively) and just 10 minutes for boarding, it currently only allows a cruise flight time of about 50 minutes. Assuming a ground speed of 850-900 kilometres per hours, this results in a range of about 700 kilometres. The time spans needed for each step in the process are estimates based on experience and only illustrate an arbitrary European journey. The actual layout of the journey is of course dependent on the chosen modes of transport, departure and arrival airports, and other local circumstances. The time span between the passenger's leave at home and the planned take-off time is even optimistic, as passengers usually tend to arrive at the airport's curbside more than 1 hour before take-off time because of (1) the tendency to be on time for their flight, (2) this requirement may be set by the airline, and (3) to include a buffer for possible disruptions during transportation to the airport.

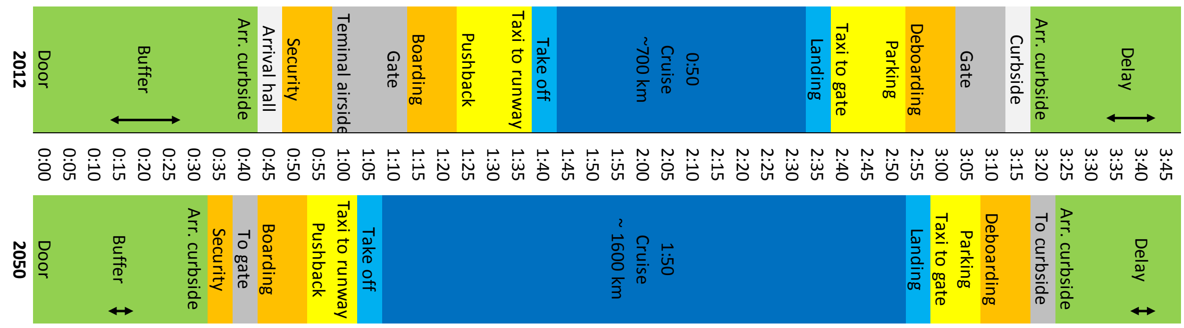

Figure 14: Current and future four hours door to door journey.

The flight range of about 700 kilometres is however barely enough for a flight within northwest Europe, as can be seen in Figure 15. With this scenario it will therefore be impossible to serve a four hour door-to-door travel for 90% of European travellers. This statement is strengthened by an analysis of the air travel distances within Europe, as was made in [25]. Figure 16 shows the cumulative distribution of the distances of direct European flights, in which it can be seen that 90% of European direct flights are approximately within the 1600 km range.

If a 4-hour door-to-door travel time for 90% of European travellers is required and the speed of ground and air travel does not significantly increase, a range of 1600 km is only possible in 2050 by increasing the time-efficiency, i.e. reducing the time needed before and after the flight. In order to accomplish this, the processing, waiting, and transfer times at the airport must be reduced significantly, next to the reduction in buffer time due to possible delays getting to and from the airport.

Figure 15: 700 vs. 1600 km range [Source: http://www.gcmap.com].

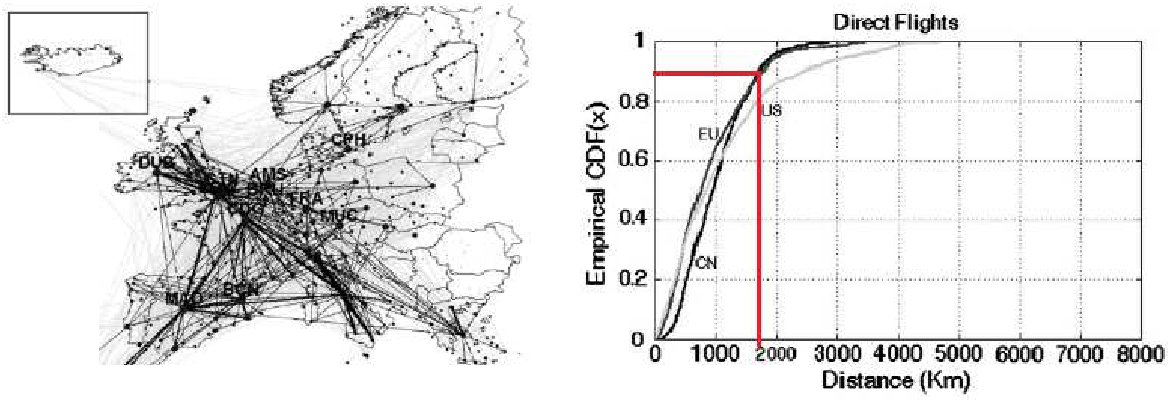

Figure 16: Network of direct flights in Europe (left) and cumulative distribution function of the distances of intra-European direct flights (right) Source: [25].

5.2 State-of-the-art airport operations in 2050

Before discussing the ideas proposed in the TE airport concept, a short summary will be given on the state-of-the-art operations expected in 2050. This text is based on the project's vision on 2050 (D2.1.1, [1]) and on the expected results of the Single European Sky Air Traffic Management (ATM) Research (SESAR). Furthermore the security and travel culture of 2050 will be discussed in this section.

5.2.1 Technology in 2050

The SESAR programme will be fully implemented and operational by 2025 and the European ATM Master Plan will have led to the application of time-, trajectory-, and performance-based operations by 2030 [34, 35]. The ATM system has evolved resulting in a 'European high-performance, integrated, network-centric, collaborative, and seamless air/ground ATM system'. More specifically, the following technological improvements are expected by 2050.

Integrated systems such as Arrival Manager (AMAN), Departure Manager (DMAN), and Surface Manager (SMAN) will be operational and will allow for a capacity-optimised planning of ground, departure, and arrival movements. Runway capacity has increased due to the use of time-based separations, optimal aircraft sequencing, and technology which enables the reduction of the minimum (wake turbulence) separation between aircraft. Dynamic Demand & Capacity Balancing (DCB) allows for dynamic planning of aircraft movements and will result in capacity benefits, especially in special circumstances such as reduced visibility. The implementation of the planning and guidance part of Advanced Surface Movement Guidance and Control System (A-SMGCS) makes sure that the surveillance, control, route planning, and guidance of airport ground movements is accurate and reliable – also in reduced visibility. The latter two developments will increase the airport's reliability in terms of capacity. Other technology will be implemented to have an optimal aircraft's en-route phase, ideally leading to a reduced flight time.

Current aircraft design is proven and is still used in all new aircraft designs and aircraft that are built at the time of writing. The newest aircraft will still fly in 2050 and it is therefore expected that the aircraft' design will not differ considerably by that time. Although the Blended Wing Body (BWB) design is gaining interest, none of the aircraft manufactures have shown plans to actually introduce an aircraft of such type. Furthermore, as stated in the Vision 2050, fossil fuel will still be used in aviation. As of today several flights have already been successfully performed using alternative bio-fuels and it is therefore expected that this use will increase towards 2050.

By 2050, an improved way of information sharing between different stakeholders will exist. Airport-Collaborative Decision Making (A-CDM) will be implemented and increases the airport's operations by increasing the predictability and reliability of the Target Take-Off Time (TTOT) through collaboration between the different partners in aircraft operations [37]. The System Wide Information Management (SWIM) will provide the means for this information sharing. Information & Communication Technology (ICT) will thus be used to a higher extend in 2050, not only by the airport but also by its customers, i.e. airlines and passengers. Passengers will be more informed through mobile information devices and will be able to have better control of the journey.

On the landside part, new active and passive security/screening technology is foreseen to enable for more optimal security processes compared to today. The airport's landside will have improved connections with the catchment area, especially to the larger cities in which the population will concentrate even more than today. Different modes will be integrated to a certain extent, most notably in terms of enhancing connectivity between different modes of transport.

5.2.2 Security culture

Airport security aims to reduce to the minimum the probability of an unauthorised access or interference with aircraft or systems on the ground. Moreover, the security within the airport is part of an integrated security strategy for all modes of transport which is based on the principles of: resilience and effectiveness; passenger experience; and fast, integrated and seamless processes. The security process should be consistent in order to avoid the disruptions between processes such as security and check–in, which nowadays force the passengers to arrive earlier to their flights.

The security in the airports of 2050 would be focused mainly on the user. The travel experience would be considerably improved through non-intrusive security processes which should preserve the user privacy and personal dignity. This is achieved with the implementation of dissuasion and detection systems with improved performance and extended scope. The majority of passengers will pass through airport security processes without disruption or delay. The assessment of risks is integrated into the security screening process for passengers and also cargo, based on a range of inputs such as intelligence information and behavioural recognition to ensure that resources are focused appropriately and effectively. All the airport and air transport data networks (i.e. navigation and air to ground communications) are secure and resilient to new threats like cyber-attacks ensuring the continuous and normal operation of the airport.

The security system is structured as a multi-layered set of processes (check-in, boarding, etc.) or segments:

- Security of inter-modal structures, ground services, etc.
- Security within air transport infrastructures (people and goods)
- Security while boarding
- Air space security: take-off, en-route, approach and landing subspaces

Each layer has its own probability of failure. To reduce the probability of a simultaneous failure, the number of layers has been increased and the security effectiveness of each one of them improved. The human factors are also considered, as the security procedures would ultimately be supervised by people. The different layers provide continuous feedback and support to each other and allow an easier supervision of them. There is also a deeper understanding of how to recognize and identify potential security situations and how to act appropriately in these circumstances.

The changing nature of the security threats (which is the main driver for change in security systems) has resulted in the implementation of variable performance capabilities instead of an increase in the number of security measures imposed. The different systems are well integrated and are more responsive for the needs of changing scenarios. For this purpose, new intelligent and highly automated systems would complement currently existing solutions. This makes the security systems to be responsive to the specific threat. For instance, using modelling and simulation it would be possible to predict behaviour in potential dangerous scenarios to support security managers through an intelligent decision making process.

The new communication and surveillance technologies allow a better access to information and the position of every element (passenger, baggage, vehicle, etc.) within the airport, improving the efficiency, affordability, and continuity of the different processes (like an integrated mobile security system; an Unmanned Aircraft System (UAS) based area surveillance system; CBRNE detection and support; an automated real time detection of unattended luggage and tracking of specific goods). The imaging and sensing technologies would be still in use in the airport, but the checkpoint concept would be changed for one based on new technologies of sensing, scanning and detection (like biometrics evaluation and testing, fast and trustworthy identification and check of the identification card).

5.2.3 Travel culture

Air transport remains the only viable direct way of connection between several regions Europe. Air transport is the principal way of conveniently satisfying the growing demand for diffused, flexible point-to-point connections. The number and quality of aviation market services has increased significantly mainly because of passengers demand to plan and predict their journeys in real time whilst at the same time staying connected to work, relatives and friends. Namely, the European air transport system is integrated in a complete logistical transport system and is part of a fully interconnected global transportation system that is based on a multilateral regime. Commercial air transport services are provided mainly by airlines organised as a few global alliances. This improves the mobility of all passengers, so that those coming from outside Europe experience the same processing time as the others.

In the year 2050, passengers and freight experience efficient and seamless travel services, based on a resilient air transport system which is effectively integrated with other means of transportation, allowing passengers and freight to travel seamlessly from door to door. The user is offered in real-time with different choices between customised products and services offering levels of facilities, quality of service, on-board comfort, journey time, optional rescheduling and price.

As today, the users of commercial aviation would be divided between tourist and business, the first interested in reaching their destination without disruptions and the latter willing to pay more for getting faster to their destinations. However, there would be two other concepts of aviation sharing the airspace with commercial aviation in 2050: the general aviation (GA) users, and those users of a new concept of flight, the sub-orbital spacecraft, which would develop its en-route phase above the atmosphere and would provide great benefits in terms of flight duration. The TE-concept has focused in solving the bottlenecks that mainly exist in airports due to commercial aviation operations, but this does not mean that some of the solutions can’t be used within the GA operations in small or medium airports.

A collaborative planning has been implemented so that all parties involved in flight management from departure gate to arrival gate can plan their activities based on the performance achievable by the system. Shared information platforms and new IT tools and services facilitate data exchange and decision making. They support optimised and interconnected services, providing real-time information to professionals and the travelling public and enhancing system resilience in the event of disruption and crisis.

The transport system is resilient against disruptive events and is capable of automatically and dynamically reconfiguring the journey, including transfer to other modes, to meet the needs of the traveller if disruption occurs. Finally, access to airports is facilitated by specialized vehicles. Traditional hub airports operate at high utilisation levels. Delays are mitigated by highly efficient operations.

5.3 Airport concept development following the invariant processes

Given the objectives and value attributes for the TE airport concept, several areas of improvements can be identified. In order to identify these, the current air travel process has to be discussed.

5.3.1 Invariant processes

In order to have a common framework for which solutions are developed between the different airport concepts, a set of processes is defined which are assumed to exist in the 2050+ scenario. The invariant processes are the minimum processes that are needed to achieve the loading and unloading of passengers and their luggage into and off the aircraft. Figure 8 in Chapter 4 shows an overview of these so-called invariant processes. This diagram shows the areas that can be improved in order to create a TE airport concept.

Four main areas can be identified. The intermodal area comprises the process of getting passengers from and to the airport. Airport services can be grouped in two categories: airside and landside. Airside services include landing, take-off, and aircraft turnaround. Landside services include the various passenger services and disembarking and boarding facilities. Air Traffic Management (ATM) is also included as one of the processes. In the future environment of operations, with the Performance Based Operations (PBO) concept implemented within the ATM, the trajectory of the aircraft would be en-route to en-route based. Therefore the trajectory developed within the airport would also be part of the aircraft trajectory. Changes to any of the discussed areas may also imply changes to the infrastructure of the airport.

5.3.2 Needs, solutions, and benefits

Recalling the three main objectives for the TE airport concept (i.e. minimise throughput time for aircraft, minimise throughput time for passengers, and seamless intermodality) already implies the needs for a time-efficient airport. First of all the throughput time for aircraft should be reduced. This can be achieved by minimising the turnaround time and eliminating congestions and delays. The turnaround time is defined as the process of or time needed for loading, unloading, and servicing an airplane [13], which implies that the turnaround time can be reduced by minimising time needed for servicing, loading, and unloading the aircraft. Solutions are also necessary to eliminate the chance of congestions and delays, which may increase the average turnaround time.

Secondly, in order to minimise throughput time for passengers, the time necessary for passenger processes related to air travel should be minimised. Both the process and waiting time of these processes therefore need to be minimised. This can be achieved by radically improving processes such as security and the airport's layout in terms of minimal physical distances. Furthermore by referring back to Figure 14, uncertainties in air travel for the passenger should be minimised to the highest extent, such that current buffer times can be reduced, thereby increasing the time available for flying.

As a last objective, different forms of transport should be integrated in order to deliver seamless intermodality. This should lead to a minimised time between different forms of transport, for example between the train, which brings the passenger to the airport, and the boarding of the aircraft. Next to this, the chance of delays should be minimised for these processes. Thereby buffers nowadays taken by the passenger can be reduced and the time available for flying can be increased.

By finding solutions for these three high-level objectives a TE airport concept can be developed for 2050+ European air travel.

5.3.3 Concept solutions and expected benefits

In summary, the TE concept follows a known structure of processes along lines (called the invariant processes), and which takes into account the flow of passengers and luggage through the airport from arriving by any means of transport to departure by any means of transport. In order to achieve the operations as described, innovative concept solutions need to be implemented. Solutions are described for four areas: (1) airside airport services, (2) landside airport services, (3) intermodal transport services, and (4) infrastructure. Each solution is elaborated and the expected contribution to the TE airport concept's objectives is given. Table 19 shows the solutions of the TE airport concept, which will be discussed in Sections 5.4-5.7. The solutions are presented in the following order: airside airport services, landside airport services, intermodal transport, and infrastructure.

In order to give the reader a better insight in the expected[9] benefits that the proposed solutions have for the TE airport concept, the solution descriptions are followed by an estimation of their impact on the low-level objectives of mobility. Recall from Section 3.5 that seven low-level objectives were

[9] The benefits presented in Chapter 5 are first estimations made by the consortium. Chapter 6 (validation of the ideas) will give the expected impact foreseen by different stakeholders.

established for mobility. The expected impact are visualised in a spider graph, indicating the effect of the solution on each low-level objective.

The expected impact per objective is given for each solution. This score is given on a linear scale, ranging from -2 to 2. Negative scores indicate a negative contribution to the given objective, while positive scores indicate a positive contribution to the objective. In summary, score -2 is the worst-case scenario, while score +2 represent the best contribution to the objective. Score 0 indicates no variation. A justification of the chosen scores can be found under the solution description. An example of the radar plot given per solution is shown in Figure 17, in which a positive score (0, +1, or +2) is shown in green, while a negative score (-1 or -2) is shown in red. Note that minimising process, waiting, connecting, and curb-gate times are related to the passenger throughput time. Minimising the taxi and turnaround time and the delay level are related to the aircraft throughput time. The same format will be used in Chapter 6 to display the results of the expert's value assessment.

Table 19: Overview of solutions in the TE airport concept presented in this chapter.

Identifier	Area	Description
TE1	Airside	Electric taxiing to and from runway using A-SMGCS
TE2	Airside	High speed rail system for aircraft taxiing
TE3	Airside	Automated de-icing and anti-icing systems
TE4	Airside	Underground pier
TE5	Airside	Underground automated container loading
TE6	Landside	Walk through security check corridor
TE7	Landside	Automated People Movers (APMs)
TE8	Landside	Using mobile devices to sequence passenger boarding
TE9	Landside	Fast baggage sorting and containerising system
TE10	Intermodal	Electric taxis for door-to-airport transport
TE11	Infrastructure	Circular terminal concept
TE12	Infrastructure	High pier concept
TE13	Airside	Automation of turnaround processes
TE14	Landside	Automatic displaceable seats for passenger boarding
TE15	Airside	Electric guided taxi system
TE16	Intermodal	Integrated guiding system

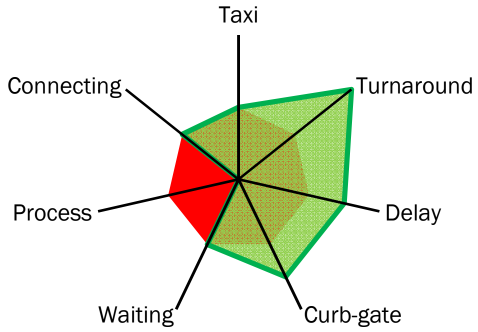

Figure 17: Example radar plot indicating how solutions contribute to the objectives.

5.4 Airside processes

This section elaborates all solutions that affect airside processes.

5.4.1 Electric taxiing to and from the runway using A-SMGCS

5.4.1.1 Concept description

Electric motors for taxiing can be attached to the aircraft's nose wheel and can be used during the taxi phase of the flight, thereby eliminating the need to use the aircraft's jet engines for taxiing and providing better speed control of the aircraft. In 2050 technologies like A-CDM and A-SMGCS are foreseen to be implemented, enabling an optimal taxi process using information sharing and, at the same time, using A-SMGCS to better cope with operations under bad weather conditions.

An electric motor can be attached to the aircraft's nose wheel to enable electric taxiing. Figure 18 shows an artwork of an existing idea. While several solutions have already been introduced (e.g. WheelTug [8]) at the time of writing, electric taxiing is far from implementation. Some existing solutions describe the attachment of an electric motor after touchdown. However, in order to achieve time-efficiency (by eliminating the need to have a separate electric motor that has to be attached to the aircraft on the airport), the authors propose an electric motor that is attached permanently. Another current developed solution is the TaxiBOT system [9], which replaces the pushback truck with a hybrid towing truck that still performs the pushback, but also enables the aircraft to taxi using the truck's power. The systems allows for a 'transparent' taxi process for the pilots, as they are in control of taxiing. The taxi speed that can be achieved is similar than conventional taxiing. Combining advanced versions of these solutions with advanced guidance and control systems is expected to result in a more optimal, time-efficient taxi process at the airport.

5.4.1.2 Implementation and expected benefits

One functional requirement (in terms of time-efficiency) when using this motor for taxiing is that the aircraft can reach equal of preferably higher taxi speeds as is currently achieved with jet engines, obtaining at the same time the required power to do so from an electric energy source installed on board. This energy source is expected to be an evolution of the current jet engines installed in the tail cone of the aircraft (i.e. the Auxiliary Power Units (APUs)) combined with an electric generator, or the outcome of recent research on fuel-cells, which are expected to be able to provide electric power to the aircraft when needed [26]. Fuel cells may in the long term even replace the APU.

Using an electric engine attached to the aircraft's nose gear may improve the current performance levels of the airport system in several ways:

- Minimisation of the average taxi in/out time, due to better and more efficient speed control of the aircraft compared with current full thrust and braking practices using jet engines.

- Improvement on pushback operations:
    - Elimination of the pushback done with trucks or towing vehicles, due to the aircraft's capability of taxiing autonomously, including pushback. Thus there would be a reduction in the time needed to perform such operation and also a reduction in the probability of interference between vehicles in the apron.
    - For the same reason, the number of vehicles which have to interact with the aircraft during its turnaround is reduced, easing the turnaround process and eliminating the possibility of not having available pushback trucks at pushback start.
- Better air transport system performance: Increase in the accuracy of the Calculated Take-Off Time (CTOT) due to the new simplified pushback operation, where the only agents involved are the pilot -using cameras and training while driving backwards-, the aircraft itself and the ground controller, so the dependency on and use of external pushback equipment (like towing vehicles) is no longer needed. A better predictability on this process will have a positive effect on the flow management, improving the current slot allocation made by the Central Flow Management Unit (CFMU) and the way peak demands on certain airports are satisfied and redistributed in time so that the efficiency of the air transport system is maximised, creating an optimal arrival pattern and taxi process for all the aircrafts.

Using an electric taxi engine can have several drawbacks:

- The APU has to be operative for longer periods of time and the power of this unit should be bigger, as it should feed all the current aircraft systems plus the electric engine attached to the aircraft's nose gear. Approximations on the power required to move an aircraft (size of B737) at current taxi speeds determine a needed power of 500 CV (367,5 kW) only to perform the aircraft towing by the electric engine. This power can be deduced from the friction coefficients between aircraft and ground [28] and basic equations. Another possibility is airport supplied power, however this dependency on airport infrastructure may have negative impact in terms of time-efficiency, as additional time will be required to place the aircraft in the taxi starting point.
- Engines must be turned on around 5 minutes before take-off (there should be a procedure oriented to solve the risk of engine start failure). Given this need, fuel cost savings and environmental benefits will be minimal on small airports having short taxiways between the terminal and runway.
- Extra space should be reserved in the cargo compartment to fit the electric engine and its complements inside the aircraft. This would diminish the available space on-board to carry payload. Furthermore this will lead to an increase in aircraft weight and the need for a more powerful APU.
- In this solution the pilot is still the last person in command of the aircraft during the taxi operation. This means that in low visibility conditions the declared capacity for taxiing will be probably lowered even using A-SMGCS, which will already improve operations in such conditions, but not

fully eliminate the weather-related issues, as pilot and controller are in this system still in charge of keeping safe distances between aircraft.

- Given the drawback mentioned right above, situational awareness is not completely solved. The main problem will still be the control of the pilot under low visibility conditions and the presence of other aircraft or vehicles. Also, in operation with other aircraft which do not have this system, it will be required to wait for them to clear the taxiway as nowadays.

The expected impact on the TE KPIs is positive on taxi time, turnaround time, and delay levels. This is summarised in Figure 19. Electric taxiing furthermore has a positive impact on the KPIs for the Cost-Effective (CE) and possibly also for the Ultra-Green (UG) concepts, most notably regarding energy use, emissions, and noise on the airport. The use of fuel cells for the electric engine can result up to a reduction of 19% in emissions [27]. However, any added weight to the aircraft may neutralise this positive impact. Consequently, the solution idea is also mentioned in those airport concepts. Furthermore, airlines would also benefit further from the implementation of this solution, as the maintenance of engine fans, compressors and turbines would be reduced due to lesser ingestion of debris and small particles during the taxi operation.

Figure 18: Example artwork of a safran-honeywell electric motor attached to the aircraft's nose wheel (Source: [17]. © www.aeronauticmedia.de).

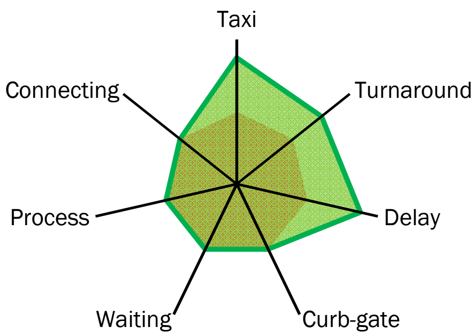

Figure 19: Expected impact of electric taxiing on the TE KPIs.

5.4.2 High speed rail system for aircraft taxiing

5.4.2.1 Concept description

Both now and in the future runways may be located more distant from the terminal due to spatial and environmental constraints existing in some European areas. To avoid long taxi times to and from these runways, the TE airport concept proposes an automated rail-based system for taxi operations. Aircraft can be placed on a moving, adaptable to several aircraft types platform ('train cart', although other solutions like contactless rails/magnetic levitation may also be worthwhile to consider), which will move the aircraft to and from the runway. Depending on local circumstances, this rail system (schematically shown in Figure 20) can either be implemented for a certain path in the taxiway system or can be expanded to cover the whole taxi path from gate to runway, as also shown in Section 5.4.7. The pilot would take control of the aircraft once the platform releases it automatically before take-off or, on the other side, would have to place the aircraft in a on the platform after landing.

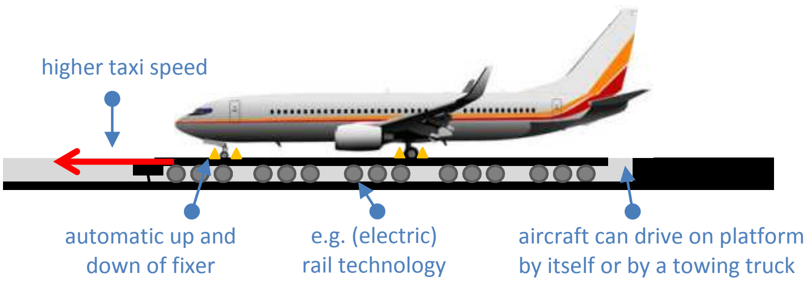

Figure 20: High speed rail system, moving platform for aircraft taxiing.

5.4.2.2 Implementation and expected benefits

This solution proposes moving the aircraft from their stands to the runway (and vice versa) using a track system similar to a train rail system. Aircrafts would do taxi operations placed on one or several moving platforms that would be assembled on these tracks. By implementing this system the restrictions imposed on the taxiing speed no longer depend on the performance of the aircraft's tires or pilot's skills, although some acceleration limits would still be needed, i.e. those associated to the comfort of the passengers during taxi operations or to the turning speeds.

This platform-railway track system would provide several benefits to both airport and airlines:

- Minimisation of the average taxi in/out time: Higher taxiing speed, which would lead to a reduction in the amount of time needed to perform taxi operations in airports; especially on those airports which have greater distances between terminals and runways.
- Improvement on pushback operations: the pushback operation can be eliminated as the aircraft is placed at the gate using this train system.

- All weather system. Taxi movement would not be affected by low visibility conditions or cross wind conditions. The aircraft's taxi speed using the rail system would not have to be decrease because of low visibility conditions, as the rail system is autonomous.
- Better air transport system performance:
  - Positioning the platforms in the track system using beacons similar to those used in current train transportation systems would be much easier than positioning aircrafts in the movement area of the airport using ground radars, as it is currently done. As the aircrafts would be attached to these platforms, this would lead to a better control of aircraft movements within the airport, especially under bad weather conditions. Altogether, these facts would generate a positive impact on CTOT (with the associated positive impact on CFMU performance) and slot allocation, improving this way the air transport network performance.
  - This solution can even result in lower delay levels, due to the unified stream of aircraft at the airport (given that the train system has sufficient capacity).

To develop a successful system like this, several requirements should be met. The system should first of all comply with safety, passenger comfort and separation standards. Furthermore the reliability should be ensured, both such that it can achieve the necessary capacity, also during severe weather conditions. The implementation of a rail taxi system would require full integration with ATC procedures and systems.

The high speed rail system furthermore has a positive impact on the KPIs UG concept, most notably regarding emissions and noise on the airport. For the airport the system however results in high investment and maintenance cost and more energy consumption. Furthermore controllers are needed for the system, adding possibly to staff cost, though this might be integrated with current ground control operations. Aeronautical costs may thus increase, resulting in a possibly negative impact for the CE airport concept. The expected impact is summarised in Figure 21.

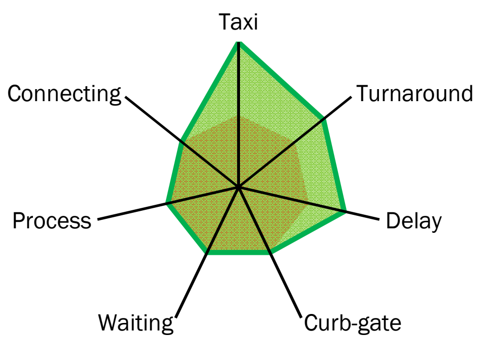

Figure 21: Expected impact of a high speed taxi train system on TE KPIs.

5.4.3 Automated de-icing systems

5.4.3.1 Concept description

De-icing aircraft can result in a considerable delay occurring after the turnaround process and take-off of the aircraft. Currently, de-icing is done using one or more de-icing vehicles at a dedicated platform. The TE airport concept proposes (1) to automate this process, and/or (2) to introduce anti-icing systems either on the aircraft or as a facility at the airport. Introducing anti-icing solutions mostly relate to the aircraft itself. On the airport, solutions like ‘protected turnarounds’ may minimise the generation of ice on the moving parts of the aircraft. As such solutions are already described in the UG airport concept, this section will focus on automatizing the de-icing process.

Today’s de-icing process requires an extra process step between the start of the taxi process and take-off. More specifically, the aircraft mostly first has to taxi to a dedicated de-icing platform, where de-icing liquid is sprinkled over the aircraft manually using preferably at least two de-icing vehicles (process will take about 20 minutes [36]). Both this detour in the taxi process as well as the process (and waiting) time for the de-icing process will impose delays on the departure times. As an illustration, Figure 22 shows the two de-icing platforms available at Amsterdam Airport Schiphol. The detour distance necessary and the waiting time depend on the aircraft’s gate, departure runway, and other local circumstances. However, Figure 22 gives an idea on the implied queuing and detours necessary in the case de-icing of aircraft is a necessity.

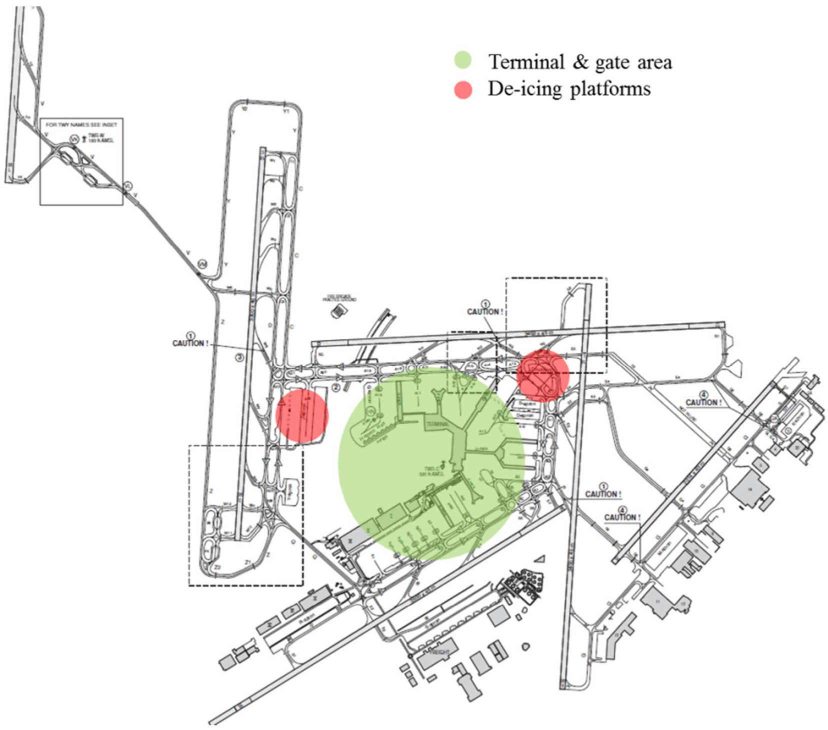

Figure 22: De-icing platforms available at Amsterdam Airport Schiphol Source: [29].

5.4.3.2 Implementation and expected benefits

The TE airport concept tries to integrate the de-icing with the taxi process as much as possible, thereby eliminating extra imposed waiting and process time due to de-icing. Two ideas are proposed to achieve this: the use of de-icing robots and in-taxi de-icing use automated de-icing vehicles.

De-icing robots – which are also proposed in the CE airport concept – allow for quick and effective de-icing of aircraft. These robots, as illustrated in Figure 23, can be attached/put on both wings and stabilizers, after which they automatically start de-icing the surfaces. As the robot is attached on the wing, the de-icing itself can be more effective compared to today's practice, as sprinkling of de-icing fluid is done as close as possible on the wing. This will reduce the amount of waste in terms of excessive fluid that is not sprayed on the surface area and therefore reduces or even eliminates the need for dedicated de-icing platforms with appropriate drainage facilities. The de-icing can take place during taxiing, given that the robots are safely attached, that they perform an automated de-icing of the whole aircraft (probably engines will require a specially tailored solution, as their surfaces are not as regular as wings and fuselage ones) and, finally, that robots safely detach and go back to its original position following a de-icing dedicated path throughout the surface movement area. If the taxi time is shorter than the time needed for de-icing, the aircraft can hold on a holding platform for the remaining time necessary for finishing the de-icing process, while still gaining time by performing part of the de-icing process during taxiing. By 2050 advanced ground movement management systems are in place, in which this process could also be integrated. Before take-off the robots are detached automatically and returned to their 'base'. In local circumstances, working conditions restrictions at the gate, holdover time[10] of the de-icing material, and taxi planning allow for this, the robot can already begin working at the gate itself.

Another possibility is to develop automatic de-icing towers which are not attached to the aircraft but run along the taxiways at the same speed of the aircraft. This can be especially useful at an airport with a longer, rather straight, taxi path to a distant located runway. A graphical representation is given in Figure 24. One major challenge with this solution is the obstacle clearance that has to be provided for the aircraft. The automatic de-icing sprinklers can roll after the aircraft's wings, thereby reducing the risk of collision with them, though collision with the horizontal stabilizer can still be a risk. A high reliability of the system is thus required. Furthermore, the automatic de-icing tower needs to have dedicated rail or asphalt on both sides of the taxiway including drainage facilities for excessive fluid. Another challenge is the length of the straight taxi path and the taxi speed of the aircraft, which shall be aligned with the time needed for de-icing the aircraft.

The expected impact of this solution is given in Figure 25. In summary:

[10] The holdover time is the *estimated* time the anti-icing fluid will prevent the formation of ice and frost and the accumulation of snow on the protected (treated) surfaces of an airplane [30].

- Both options will decrease taxi time during de-icing conditions, as de-icing will take place somewhere during the taxi phase. Both solutions aim to perform de-icing during the already existing taxi time as much as possible.
- As queuing for de-icing may also be reduced, there is a positive impact on reducing the delay levels.
- As both solutions are automated, no human visible check can be done on the aircraft's surfaces. A solution for this shall be thought of. The solution should also comply with obstacle clearance regulations and should not have the risk of the aircraft to collide with the de-icing towers.

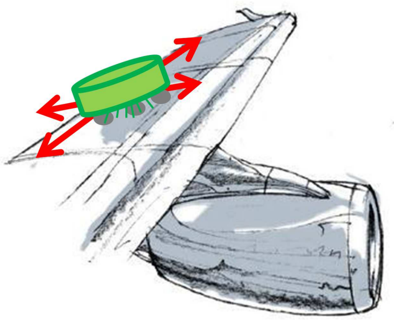

Figure 23: Automatic de-icing robots. Source: [43] wing art concept. Modified by AP2050+ consortium.

Figure 24: Moving automatic de-icing towers moving behind the aircraft's wings.

The de-icing robots will lead to less waste in terms of excessive de-icing fluid, thereby also having a positive effect for the UG airport concept. In terms of cost-effectiveness, the de-icing solution will impose high investment costs, though cost incurred by the de-icing vehicles (and staff) may be reduces and addition revenues may be generated from providing this faster de-icing process at the airport.

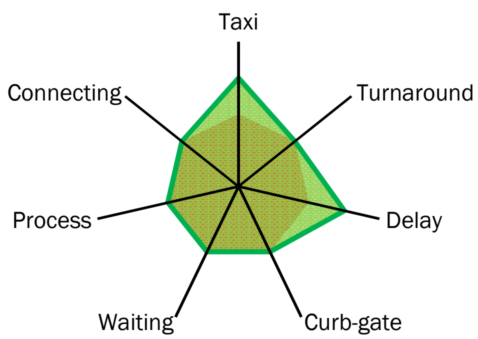

Figure 25: Expected impact of the new de-icing process on the TE KPIs.

5.4.4 Underground automated container loading

5.4.4.1 Concept description

This system is connected with the automated baggage transport and distribution system which is currently available in many airports. With this solution, which is schematically shown in Figure 26, the baggage belt specifically assigned for a flight is located not in the terminal building as it is today, but in a level below the aircraft stand position. From there, the baggage is placed into the standard containers which rise to the platform level through an elevator or lift platform.

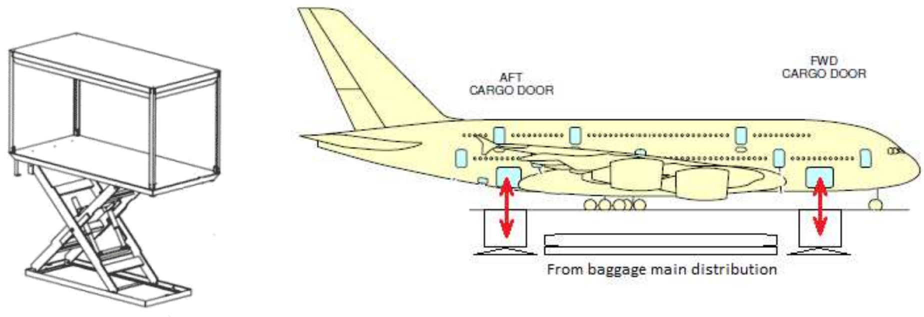

Figure 26: Schematic view of the underground container loading.

5.4.4.2 Implementation and expected benefits

The Underground automated container loading can be seen as an extension of the current system of baggage transportation. The current system consists of a highly automated railway mechanism (baggage conveyors) to distribute and transport the baggage from the passenger check-in position to a flight specific-belt. This belt is located in the curbside limit of the terminal, where the handling vehicles (baggage trucks) take the baggage to the aircraft. The new system, which implies a new infrastructure with severe costs, covers the existing distance between the aircraft and the terminal curbside. This will reduce the number of vehicles on platform as the baggage trucks. These vehicles have to move between the aircraft and the terminal and increase the platform congestion and special safety procedures should be put in place. With the implementation of this system, they will be no longer necessary, thus reducing platform occupation and increasing safety of the aircraft.

Another expected benefit is brought for the turnaround times, through the improvement of automation. Placing the aircraft baggage belt in a level below the aircraft will make the baggage distribution system to be closer to the aircraft. This benefits the loading and unloading times of baggage to and from the aircraft. As a limiting factor, this automation comes with an increase of complexity, as the system to lift the baggage to the aircraft from the lower level should take into account the aircraft positioning and the safety procedures on platform.

This solution is completely adaptable to the current airports and also to the underground pier concept. The latter puts the departure lounges, gates, and aircraft bridges underground. This will result in a clean, open aircraft stand positions with loading and boarding equipment appearing from under the ground after the aircraft has parked. Aircraft stands can be put more closely to each other and the necessity of supporting vehicles is reduced.

The underground automated container loading is an extension of the current system of baggage transportation, and covers the distance between the aircraft and the terminal. This allows reducing the number of vehicles on the platform and reduces time spent in the turnaround, as can be seen from Figure 27.

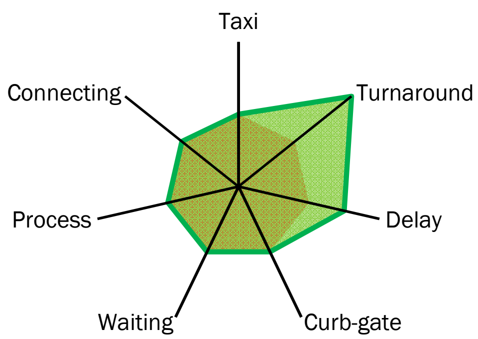

Figure 27: Expected impact of underground container loading.

5.4.5 Underground piers

5.4.5.1 Concept description

In the advanced TE airport concept all service facilities, including (part of the) departure lounges, access roads, passenger boarding gates, fuel, potable water, ground power, air conditioning, waste and luggage handling are moved underground, as illustrated in Figure 28. Passenger boarding gates and loading devices can be deployed from and retracted into the apron level, allowing an open and obstacle free apron.

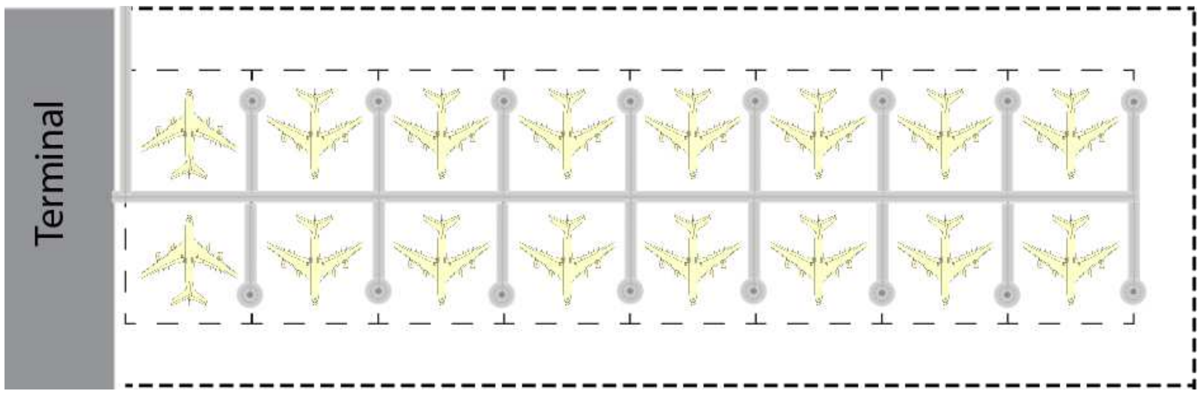

Figure 28: Apron with underground access roads.

5.4.5.2 Implementation and expected benefits

This solution proposes the construction of a complex underground set of facilities and equipment that can cater for all the needs of the aircraft and the passengers during its turnaround and boarding/disembarking processes. Although it is expected that the above-the-surface terminal part would be reduced considerably, the construction of all the underground part of the terminal and equipment would have a negative impact on the overall cost of construction. Furthermore, aspects such as future maintenance, operation in all-weather conditions, risks emerging from the new apron layout proposed in this solution (i.e.: event of a luggage transport container getting stuck in an underground facility or tunnel while being moved from the terminal to the aircraft and in a zone of difficult access) should be accurately addressed and considered during the design phase of the infrastructure.

However, the underground pier has advantages with respect to time that can add relevant value to the TE concept:

- Minimisation of taxi times:
  - The aircraft can taxi straight in and out, removing the need for coupling and decoupling pushback trucks and the need for wing walkers to check for clearance from obstacles.
- Elimination of pushback operations in some cases:
  - Pushback is not necessary anymore, as after boarding and loading the bridge and loading devices will be stored underground, after which the aircraft can taxi-out straight. This straight taxi-out can only be done when there is no aircraft standing before the other, i.e. optimal gate planning is therefore a prerequisite.
- Relief of surface activities performed by different vehicles around the aircraft:
  - An added benefit of this solution is the reduction of congestion on the apron. Due to the underground-based activities associated with the turnaround process of the aircraft the amount of vehicles transiting the apron would be minimised, avoiding interferences between vehicles and between vehicles and aircrafts. This would surely improve the efficiency of current airport turnaround activities, not only having a positive impact in the UG concept, but also minimising the probabilities of unavailability of certain equipment/vehicles at aprons when required, which would mean as well a positive impact for the TE concept.
  - At the same time, the previous benefit can have a secondary impact on the waiting time of passengers due to a more efficient performance of all the activities needed to be carried between the disembarking of passengers from the previous flight and boarding of the new passengers, such as cleaning of the aircraft, luggage loading/unloading, fuelling, etc.
- Minimisation of passenger boarding/disembarking times:
  - Passenger boarding can take place from both the front and back of the aircraft, as bridges are stowed underground when the aircraft is moving and not interfering with the wing, as illustrated in Figure 29. For example, a very large aircraft, as the A380 with up to 800

passengers, can be serviced by eight bridges, two on each side for each deck as illustrated Figure 29. A wide-body, such as the A350 with up to 400 passengers, can be boarded by four and a single aisle, as the A321 with up to 200 passengers, can be boarded with two bridges. Depending on how and when the aircraft taxies into the stand the front boarding bridges already be deployed to allow a quick disembarking process. With one bridge per 100 passengers, a ten minute boarding time would mean boarding would take place at one passengers per six seconds per bridge, which seems a reasonable value especially when using an optimal boarding sequence.

- Minimisation of travel distances:
    - Aircraft can be placed closer with respect with each other and the apron, reducing travel distances and thus time spent getting from the terminal to the gate.

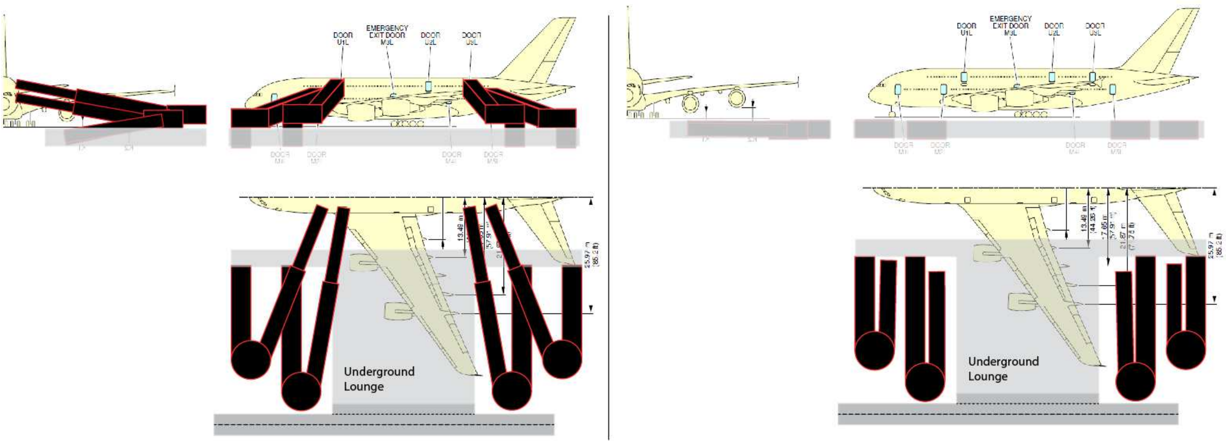

Figure 29: Illustration of A380 ground handling with four bridges at a side. Deployed bridges (left), stowed (right).

Two downsides to the underground pier are, in first place, the level changes required during boarding, which are estimated to be about 8 meters for the main deck and 11 meters for the upper deck. This requires long bridge, of about 50 and 68 meters respectively, to get a reasonable slope of 16% [23]. A moving walkway, or even an escalator is thus probably required. The lower part of the bridge, which would contain the escalator, could be steeper and the higher, extendable part could be more horizontal. As can be seen in Figure 29 the resulting (stored) boarding bridges (illustrated on scale) are not considerable larger that the aircraft's wing span. A second issue or challenge that this solution would need to solve is how can current infrastructures deal with a progressive evolution from the currently extended stands-terminals layout to the one proposed here, incorporating all the infrastructural changes needed to achieve it.

The impact on the TE KPIs is given in Figure 30. The underground pier furthermore has a slight positive impact on the KPIs for the UG airport concepts, as the use of apron service vehicles can be reduced by the use of this underground concept. However, from the CE concept's perspective, the solution has negative impact on airport costs.

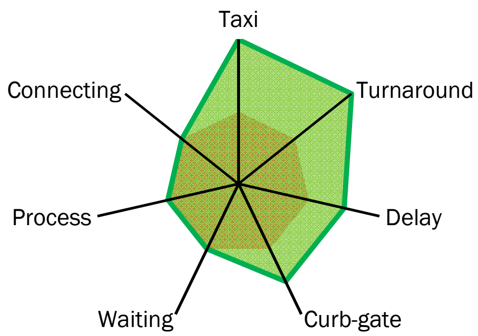

Figure 30: Expected impact of the underground pier on the TE KPIs.

5.4.6 Automation of turnaround processes

5.4.6.1 Concept description

Some services existing today for the turnaround can be improved through an increase in automation. If the several turnaround processes are coordinated, the time efficiency of the aircraft servicing improves. The main achievement of this will be an optimized turnaround time and an increase of predictability. For achieving this, the automation should be applied to the following processes:

- Passenger handling (all passengers disembark and board the aircraft)
- Cargo (equipment positioning/removal and cargo exchange)
- Refuelling
- Cleaning
- Catering (toilet servicing and potable water servicing)
- Ground handling servicing

5.4.6.2 Implementation and expected benefits

The current situation, with some processes already automated, includes some procedures which are time consuming and that could be improved if new systems are applied. The common point for these processes is that they have to be performed with the aircraft at full stop in its stand position as several servicing vehicles have to move around it and position. The servicing points should be designed and located in order to:

- Minimize access time
- Allow simultaneous access to all critical service points
- Minimize the risk of damage to aircraft by ground support equipment

In the current situation, the stand positions next to the curbside are designed following these premises. For making these services automated, one of the main solutions is to make the aircraft a part of a ‘lean servicing concept’, where the aircraft arrives to its standing position and the service points are available as soon as it arrives. These service points are flexible and can adapt autonomously to the aircraft size or stop position respect to the terminal building. This could be done with special belts or pipelines which connect the terminal directly with the stand position. With this solution the number of ground vehicles needed is reduced, with it also the risk of collision and the reliability of the turnaround operations regarding time needed to perform them. This system should have the condition of adaptability in order to give service to the majority of the aircraft types and sizes.

Additionally, the option of a multipurpose finger has been considered as adequate in order to improve adaptability of the airport to several aircraft sizes and reduce the space needed for servicing the aircraft. This finger would feed the aircraft directly from the terminal building providing the fuel, energy, catering goods baggage, passengers, etc. within the same structure.

The main expected impact is the reduction of the time spent by the aircraft in the airport, which is one of the business objectives of the A/C companies. This also brings benefits to the passengers, as the boarding and deboarding will be reduced.

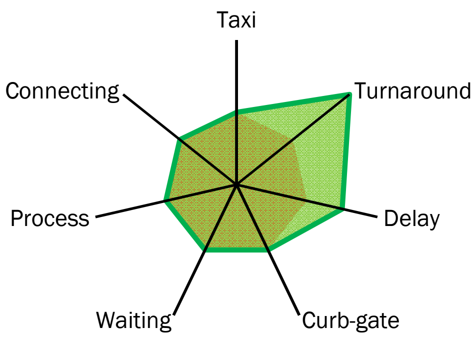

Figure 31: Expected impact of automation of turnaround processes.

5.4.7 Electric guided taxi system

5.4.7.1 Concept description

This solution consist of a moving platform or electric towing system which moves the aircraft through the taxiways once it has landed, allowing the aircraft to turn off its engines throughout the taxi, placing in the stand and push-back operations. This can be also thought as an automated guided system to move the aircraft in the airport.

5.4.7.2 Implementation and expected benefits

This system allows the movement of the aircraft in the platform area without using the engines to gain speed and wasting valuable quantities of fuel in the process. It should allow fast taxi-in and taxi-out operations to be competitive and reliable. There will be no need to push-back using the engines or a special towing vehicle on platform.

The system will also allow the correct and precise positioning of the aircraft with respect the terminal building. An increase of the accuracy in the turnaround process increases the predictability and improves the efficiency of the other processes involved in the turnaround (from in-block to off-block).

The system can be a towing system which adapts to the nose landing gear wheel and pulls the aircraft following a rail network system or a moving platform which pulls the aircraft also following a guiding system. The layout of the towing system could be adapted to existing airports or to the circular terminal concept. It can also be integrated with the underground and high-pier concepts.

The expected impact affects mainly the positioning of the aircraft and the taxi times positively. Another benefit is the all-weather operations, as this system is capable of autonomous operation under low visibility conditions. However, the electric guidance and towing system can highly increase the costs of operations, effect that can be balanced given the fact that the airline costs of operations can be highly reduced taking into account the fuel that is saved with this solution.

A simplified layout of this solution is shown in Figure 32. Once the aircraft has landed in the runway, it will reach an specific position (shown as a red block). From this position, a rail towing system will hook up the front landing gear of the aircraft. These holding positions can be modified along the runway length, adapting to the distance needed for the aircraft to stop after landing. With a pulling mechanism, and following the rail (dotted line), the aircraft would be taken from the runway to its stand position (taxi operation). Once the aircraft has arrived to its stand position, finished the turnaround processes, it is again pulled by the rail mechanism from the standing position to the specified runway needed of departure. This way, the engines can be started upon arrival to the runway and not before, avoiding additional fuel consumption, or wasted time due to acceleration of the aircraft.

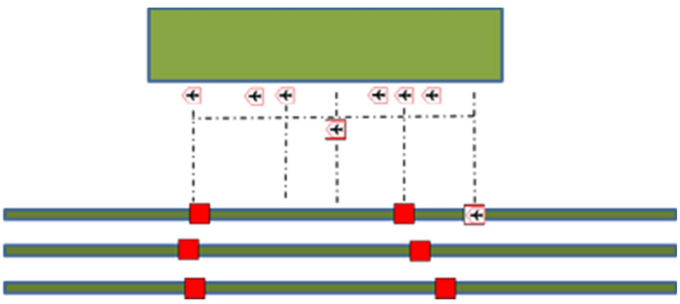

Figure 32: Schematic view of the electric guided taxi system.

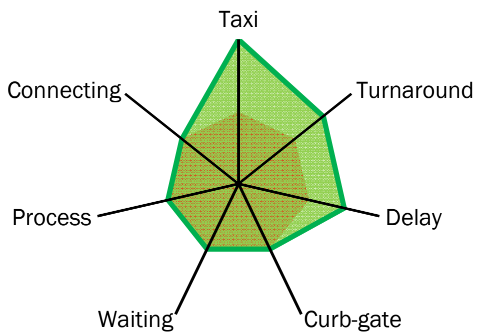

Figure 33: Expected impact of guided taxiing.

5.5 Landside processes

This section discusses the solutions provided to cope with the expected key bottlenecks for landside processes.

5.5.1 Walkthrough security corridor

5.5.1.1 Concept description

In 2050 the security process is proposed to be combined into a single, non-stop check. This check will have the functionality to check the passenger's identity, as well as checks for forbidden and dangerous items in any luggage. Manual checks are only necessary when deviations are detected. Prototypes of this walkthrough security have already been proposed by the International Air Transport Association (IATA) [24], as can be seen in Figure 34.

5.5.1.2 Implementation and expected benefits

The security corridor will be implemented as a 'tunnel' through which the passenger will walk. Using advanced security equipment the identification of the passenger, the contents of any luggage, and the passenger's body will be checked without the need of performing previous actions such as withdrawing certain objects from hand luggage (e.g. laptops or electronic devices), removing belts, etc. These actions currently suppose an important contribution to the bottlenecks present in security checks. The scanning equipment will be evolved into systems that do not require the passenger to stand still or the baggage to be placed on a special belt. Currently research is performed on these type of security systems, as the limitations of current security equipment in terms of capacity are recognised. The Airport detection and Tracking Of dangerous Materials (ATOM) FP7 project is one of the projects investigating active and passive radar sensors [41]. Experiments are done to test radar-based full-body screening of moving passengers [42]. This technology would be suitable for a more evolved security check corridor. Once a passenger is screened and requires a manual check, the passenger can be 'pulled out' of the flow without disturbing the flow within and towards the corridor. Research is also carried out into passive, continuous security systems, which could for example continuously monitor the whole terminal or lounge. These systems will help to improve the airport's security, though the advantage of having a security 'corridor' is that passengers carrying forbidden goods can be filtered out rather easily and without disturbing natural passenger flow within the terminal. As such, dedicated security 'checkpoints' are expected to still exist in 2050, added with passive security equipment.

Figure 34: IATA's security checkpoint [Source: IATA].

Passengers currently suffer from long waiting and processing times at the different security checks. The single, non-stop security walkthrough is expected to provide a high processing time and little waiting time[11]. Furthermore, less human control and interference is necessary in the process. Therefore, high benefits are expected for the passenger in terms of their throughput time. Consequently, installing the same ratio of security check corridors per passenger as is currently done with manual security checks, less queuing is expected. Also, combining passenger identification and the security check will reduce the amount of processes (i.e. one single process as opposed to two separate processes).

The expected impact of this solution on the TE airport concept's KPIs is given in Figure 35. Introducing this security check concept allows for quicker passenger processing time and reduces, through less queuing, the passengers waiting time and delay. This lead to a more seamless journey from the curbside to the airport's gate. The solution furthermore is expected to have positive impact for the CE airport concept, as it will reduce aeronautical costs (security staff) in the long term.

[11] The waiting time is dependent on the required capacity in terms of passengers, the capacity of the system, and the amount of walkthroughs installed.

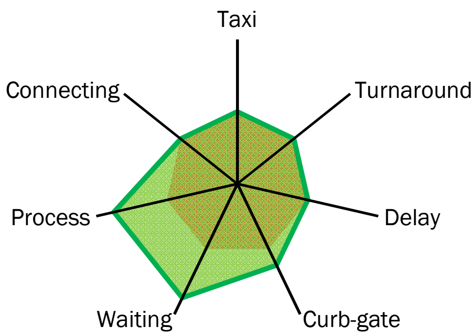

Figure 35: Expected impact of walk through security.

5.5.2 Automated People Movers

5.5.2.1 Concept description

High speed people movers would be fast and integrated systems to move the passengers from the terminal building to the aircraft standing position. They can also be though as vehicles to be used from the place where the passenger arrives to the terminal (intermodal connection). In this case, the APMs can integrate the check in and security processes within the vehicle.

5.5.2.2 Implementation and expected benefits

High speed APMs are vehicles owned by the airport or private companies which would be fast and integrated with the airport services. They will move the passengers from the terminal building, or a specific platform where the users will board, to the aircraft standing position. It could integrate other airport processes if they are not carried out before boarding to the APM, such as the check in and security processes.

The APM will take the passenger (or small group of them) from the platform located next to the intermodal connection point in order to decrease throughput times. There, the APM will be able to read the passenger and its baggage so that to obtain information about their selected flight and the position of the aircraft, as shown in Figure 36. Shared and updated information is needed for this process. Then, the vehicle will move to the aircraft position at high speed.

This way, the APMs reduce the walking distance for passengers and eliminate way finding problems, and decreasing processing time. These vehicles can be also improved by allowing them to carry out the check in and security processes related with the passenger and its baggage. In such way, these processes can be decentralized from the airport terminal and provide additional space to allow the movement of passengers. Also, it will allow the companies know the exact position of their passengers, i.e. using a low priced RFID chip, as they check in as well as baggage, increasing the predictability of times spent for each passenger, knowing the position of the vehicle from the aircraft. Connecting passengers can be also transported to their next aircraft.

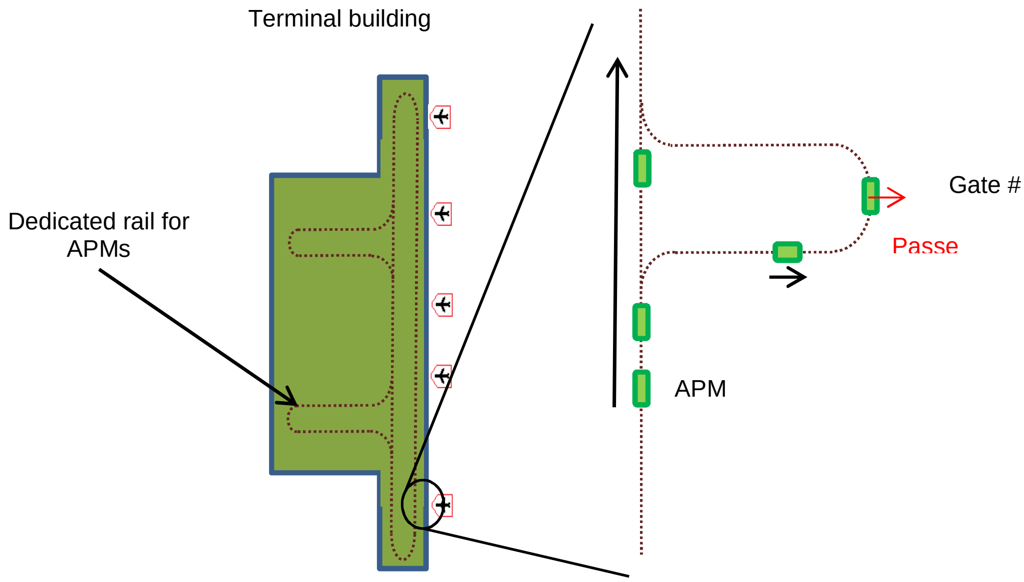

Figure 36: Schematic view of the operation of APMs for passengers in the terminal.

Upon implementing large APM systems at the airport, the airport can consider the movement of (parts of) the terminal more towards the runway. This would reduce taxi time for the aircraft, and adds only little time to the curbside-to-gate time for the passenger by elongating the APM system. Doing this would be useful for airports that currently need expansion, are of medium- or large size, and consistently use the same runways. Smaller airports often already have terminals located near the single runway that they have, and this proposal is therefore of less interest for them. Large airports that have an alternating runway use might also benefit less from this proposal, as a centralised terminal is more suitable in this case.

APMs for transport within the terminal improve passengers experience in airports and assure that the passengers are at the boarding gates on time for departure. They also include the baggage transportation. These systems will transport hundreds of passengers in one day so the cost of maintenance is expected to be high. It is also expected to increase the energy consumption.

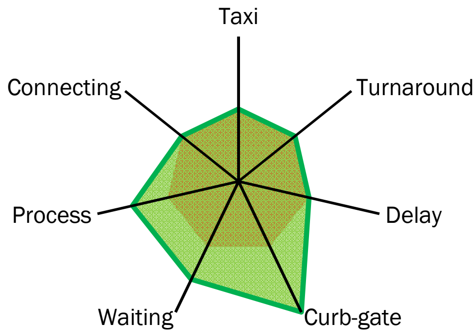

Figure 37: Expected impact of APMs.

5.5.3 Using mobile devices to sequence passenger boarding

5.5.3.1 Concept description

The implementation and broad use of mobile devices will come together with several way finding and localization options. An idea of a current version of such applications is given in Figure 38. One of the features expected to be useful is the sequencing of passengers within the aircraft cabin as they arrive, reducing the boarding and queuing and congestion problems that are found today. It also assigns a seat for every passenger as they arrive so that the cabin movement of passengers is fluent.

Figure 38: Mobile device assisted boarding sequence.

5.5.3.2 Implementation and expected benefits

This application will be mobile based and will be managed by the aircraft operator company. It combines alerting services (Implementation of local ICT functions to alert passengers) with enhanced logistics through the application of ICT and sensors throughout the airport. Considering that all the passengers would be used to the mobile devices to carry out several processes (such as check in), it will be easily extended to other processes. With this system, the passengers are sequenced following a passenger sequencing method to board in the aircraft as they arrive to the waiting room or close to the aircraft.

This is achieved with an ICT system located at the terminal which detects the position of the passenger through its mobile device and also authenticates its owner. Communication and detection procedures should be in place. It then applies an algorithm to provide place for the passenger following a proximity sequencing pattern. This allows passenger to know not only its position in the boarding queue, but also the aircraft company to know the position of all passengers to be boarded (also if any passenger is going to be late). Also helps the company to measure the loading of the aircraft.

This solution can be extended to other services, such as placing the passengers in the aircraft.
It also enables the passenger to connect to the airport terminal network which recognises him/her as a valid passenger and provides all necessary information about the flight. The extensive use of mobile applications reduces the cost of implementing other systems and saves money. Passengers would benefit from the reduction of boarding times and the knowledge of their exact position in the cabin.

The passengers are sequenced to board in the aircraft as they arrive or following a proximity sequencing pattern. This allows passenger to know their position in the boarding queue, but also the A/C company to know the position of all the passengers to be boarded (also if any passenger is going to be late). Also helps the company to measure the loading of the aircraft

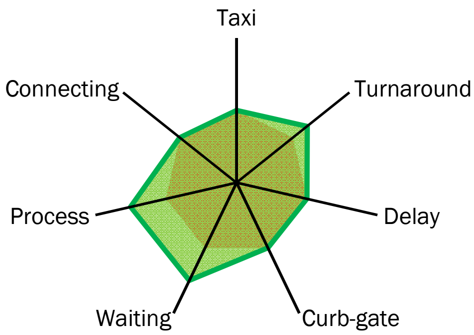

Figure 39: Expected impact of mobile boarding.

5.5.4 Fast baggage sorting and containerising system

5.5.4.1 Concept description

Baggage sorting will be done in 2050 quite similarly as today, but with a focus on time-efficient processing. Baggage scanners will have been improved to achieve higher system reliability and a lower error and delay level. Solutions such as Radio-Frequency Identification (RFID) chips either built-in suitcases or attached with a label can help in achieving this aim. Furthermore, besides more time-efficient scanning and sorting, in 2050 baggage systems will consist of more baggage robots that could also automatically and quickly load aircraft containers with luggage. This will reduce the need for manual baggage loading into the aircraft.

5.5.4.2 Implementation and expected benefits

The advanced baggage system that is foreseen in the TE airport concept essentially consists of at least three features: (1) conveyor belt with higher speeds, (2) quicker scanning and sorting systems with higher reliability, and (3) increased use of robots & automatic container loading (Figure 40). While technology to enable these systems already exists partly, it is expected to be developed further and reach certain maturity and implementation towards 2050 so that human intervention is minimised in all the processes associated with luggage handling.

On the other hand, the morphology of baggage handling systems such as conveyor belts and scanning systems will likely stay the same in the next decades, meaning that scanning machines can maybe be reduced in size, but will resemble the ones that currently perform scanning activities and conveyor belts may change the system used to provide movement to them, but it's intrinsic objective of carrying the baggage from one place to another establishes physical limits (usually associated with common luggage dimensions) that nowadays have already been reached or almost reached. Given these assumptions, solutions (1) and (2) won't be 'handicapped' from the infrastructure point of view, as they don't need any radical change or adaptation of the current airport infrastructures to embrace them. Moreover, it is expected that improvements in scanning and conveyor belts/baggage transportation solutions will enforce their integration. Solution number (3) may face some more challenges, but it is expected that its origin is more related to the state-of-the-art technology, its robustness, and its reliability rather than in the airport infrastructure capability to include it.

Figure 40: Automatic container loading using a luggage robot arm (Source: Grenzebach, [38]).

The benefits that these new solutions on fast baggage sorting will bring to the airport 2050 are summarised below:

- Minimisation of luggage travel time between check-in and the aircraft: Solutions (1) and (2) will result in a higher processing speed of luggage and higher reliability of the systems, which results in less delay of luggage.
- Minimisation of the time each passenger spends on luggage-related: The quicker and almost fully-automated baggage process will allow the passenger to spend less time at the airport, which is beneficial for the passenger throughput time. Currently the baggage process may be a critical process from a throughput time perspective.
- Minimisation of the aircraft's turnaround times:
  - Future baggage systems are foreseen to be able to automatically load baggage in containers (3), which are ready for loading into the aircraft once the aircraft has been unloaded from the previous flight. Loading robots will be a crucial tool in this process, providing for a more accurate and quicker loading process compared to manual container loading. The loaded containers can be loaded quickly into the aircraft, as opposed to the conventional loading of individual baggage items.
  - The above mentioned solutions would suppose reduction on the number of vehicles and equipment transiting on the apron. This can improve the delays induced by interferences between vehicles during turnaround activities, thus obtaining a smaller turnaround time for the aircraft.

The expected impact on the TE KPIs is given in Figure 41. Note that the passenger's time spend in the terminal is expected to be reduced due to the quicker baggage sorting process, allowing the passenger to arrive on the departure airport later than today's practice. This positive impact can only be achieved when a high reliability of the system is assured. Advanced baggage systems furthermore have a positive impact on the KPIs for the CE and UG concepts, most notably due to the reduced amount of services vehicles at the airport and the reduction in staff costs (which is considered larger than the initial investments costs in these systems).

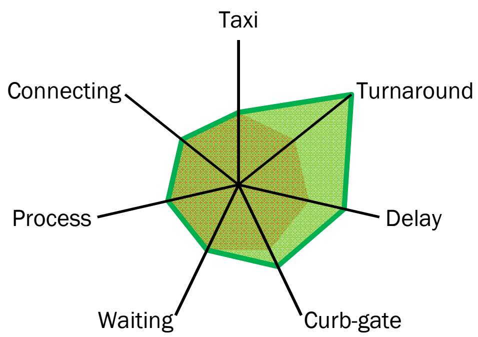

Figure 41: Expected impact of advanced baggage sorting systems on the TE KPIs

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5.5.5 Automatic displaceable seats for passenger boarding

5.5.5.1 Concept description

This concept affects also the aircraft structure and therefore is a solution that has to be validated with the aircraft manufacturers. It consists of a special movable platform with the seats on top, which is placed in the terminal building and has a dedicated rail system allowing the correct positioning of the seats into the aircraft once the passengers are seated. It has the advantage of providing the waiting room service before boarding, as passenger seat in their places upon arrival. The boarding process is made automatically as the seat is placed inside the aircraft with the passenger already seated and its baggage placed. For this purpose, these seats would have an integrated baggage place that is adapted to the aircraft.

5.5.5.2 Implementation and expected benefits

For this solution, there are several ways of placing the seats within the cabin once the passenger is seated.

The first considers a unique platform containing all the seats and baggage placing. This unique platform fits in the aircraft structure so that no displacements can cause structural problems. This structure allows the passenger to seat as they arrive and stay physically in the terminal but in a dedicated space. In this case the boarding of passenger is made at one time, as the platform moves from the terminal inside the aircraft.

The second case (shown in Figure 42) option is more complex, as takes into account the movement of individual seats or rows of seats. This requires more complex systems to manage the movement of seats as the passengers get seated. The seats could be placed so that they are distributed individually with the baggage compartment or could be grouped in sections.

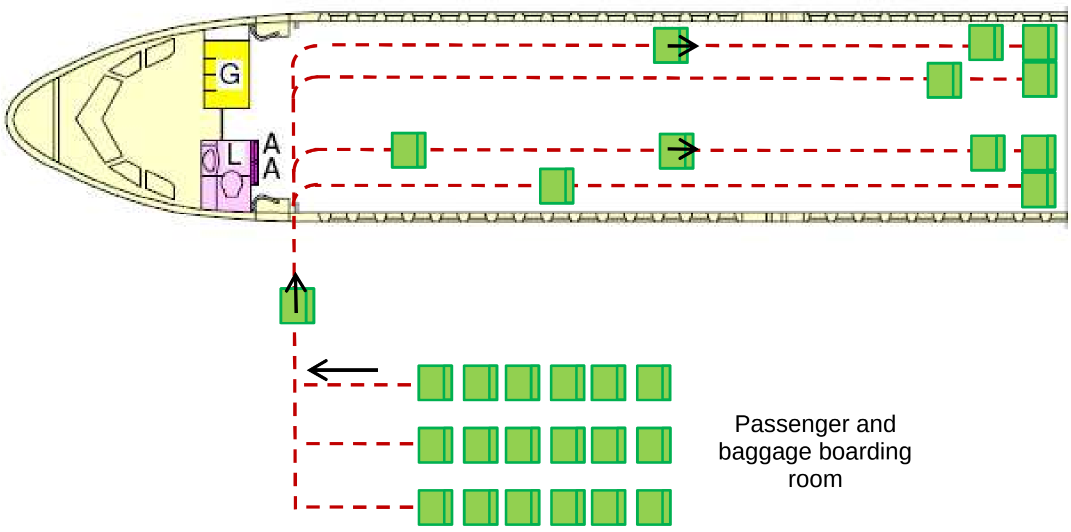

Figure 42: Layout of boarding for automated displaceable seats.

In both cases, the availability of seats as passengers arrive and their positioning reduce the queue problems and the boarding times of the passenger. The seats will integrate the positioning of the hand baggage, greatly reducing the current corridor congestion problems and also offering the option of re-sequencing the passenger on board for optimal transfer to the next flight in case this is needed.

Once the aircraft arrives, the deboarding procedure will be symmetric to that of the boarding, so that the passengers are deboarded in order and without corridor flow disruptions. Each passenger would leave its place taking the time needed.

The complexity of this system is very high and will bring some problems like compatibility. The boarding system would need to be adaptable for different aircraft sizes and row numbers, as well as the spaces between seats when they reach their specified position. This would also bring difficulties regarding the structure of the aircraft and additional weight.

The main impact of this solution affects the boarding and deboarding times, which is one of the most time-consuming processes of the turnaround taking into account the aircraft manual.
While it is clear that this solution will be a good option for improving passenger experience in terms of time efficiency, it requires complex systems for the platforms and the interface terminal /aircraft which might increase the positioning times and the costs of operation. Similar solutions can be developed for other processes such as catering, which are included in the automation of turnaround processes solution.

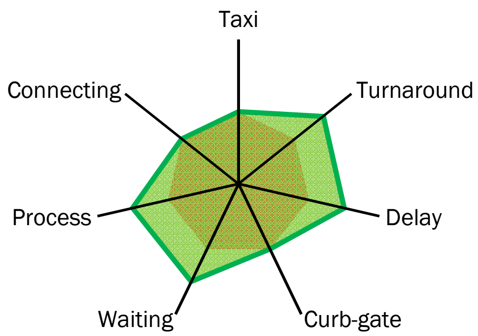

Figure 43: Expected impact of displaceable seats.

5.6 Intermodal transport services

The advanced TE airport concept has the objective to have seamless intermodality. While this can be reached by integrating different modes of transport in certain infrastructure, the TE airport concept also foresees electric (personal) taxis for door-to-airport transport will become essential in reaching intermodality and increase the time available for flying.

5.6.1 Electric taxis for door-to-airport transport

5.6.1.1 Concept description

In 2050 environmental sustainability and fuel prices will have pushed all transport modes towards more efficient means of enabling mobility, including all kinds of road transport. This opens the possibility to develop an airport-dedicated electric taxi network that will bring passengers from their door to the airport's curbside and vice versa, performing particularly well in sparsely populated areas, where access to mass transport is not cost effective and congestion on roads is limited. This transport mode will be highly enhanced by new information systems and data availability on passengers location, schedules and road traffic, which will generate optimal pick-up schemes for a passenger o group of passengers.

Another expected improvement is that taxis will be also automatic (self-driven). This will turn taxi into a more cost-effective transport mode and is therefore more accessible for travellers. Moreover, the flexibility given by any road transport mode will make them also suitable for densely populated areas.

5.6.1.2 Implementation and expected benefits

Airports or a combination of different investors which may have interests in this solution, such as municipalities around the airport, will provide the economic resources to deploy a suitable taxi fleet, depending on its demand.

Electric taxis, as schematically shown in Figure 44, will enable direct connection from the curbside to the next landside airport process. During this journey, several elements will minimise the connecting time with respect to the total door-to-door journey time, while making taxi mode more accessible for travellers:

- **Optimal pick-up scheme:** the appropriate information sharing and availability will enable the taxi network to determine an optimal pick-up scheme, considering the suitability of picking up travellers who come from geographically close points and requested the taxi service, road traffic, flight departing times of each of the passengers, luggage carried and total distance travelled from home-to-airport.
- **Automatic, electric-powered taxi (AET):** Technology will enable self-driven cars and electric engines will be already of common use in road transport modes. This will have a good impact on UG and CE concepts if the total journey is considered. Regarding TE concept, using all available information on road traffic and gate allocation of traveller's aircrafts will minimise the time needed for each passenger on its door-to-door journey. Furthermore, better predictability of the time required to travel from home-to-airport will be ensured.
- **Availability of information on passengers location and estimated time of arrival to the airport curbside:** Mobile devices providing information to the traveller will have an important role in 2050+ air transport. Before being picked up, each passenger will confirm its location. The time and location where the passenger is picked up will be sent immediately to the airport, which will reveal to the airport the time of arrival of the passenger's to the curbside. This information will be relevant for airport and airlines, as they will know if their passenger's will arrive to the airport on time and if there has been any disturbance such as rerouting due to traffic.
- **Updated information sharing with the passenger:** At the same time, updated information on flight schedules, gates, and any changes on them will be sent to passengers, altogether with applications that will enable the passenger working or shopping for goods during the journey that will be ready to be picked up after disembarking at the arrival airport. This allows the passenger for optimal use of the transport time in the AET.

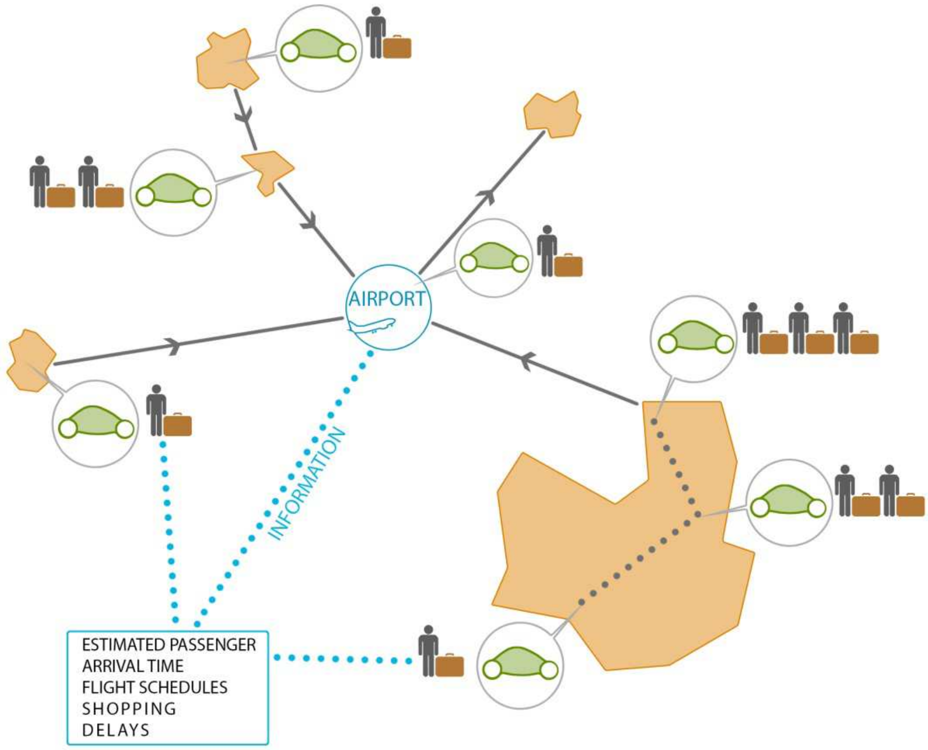

Figure 44: Schematic view of the AET solution.

Even though this solution trespasses the boundaries established for the TE concept, its advantages and characteristics have a positive impact on minimising the passengers' connecting time during the journey, as it is shown in Figure 45. The solution furthermore has positive impact for the UG airport concept, as the taxis will be automatic and electric.

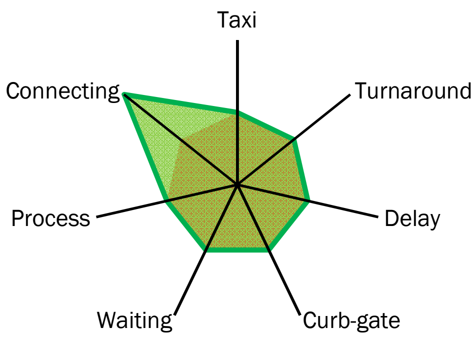

Figure 45: Expected impact of electric taxis for door-to-door transport.

5.6.2 Integrated guidance system

5.6.2.1 Concept description

The integrated guiding system is a proposed solution to cope with the five bottlenecks regarding intermodality at the airport in the 2050+. Even though parts of it might be out of scope of the project, it has been included in the document due to the relevance of the intermodal processes and the need of incorporating a solution that provided seamless intermodality in ariports. Thus, it contains several elements that together try to add a positive impact on the concept's aim to minimise the connecting time needed during a door-to-door journey. The elements, shown schematically in Figure 46, focus mainly on information sharing, better guidance, and elimination of uncertainties and are as follows:

- Better information provision:
  - How to go to the airport: The passenger will be assisted in finding the best mode of transport to travel to the airport, taking personal information into account. The advice will be based on all information, such as the flight, modes of transport, current traffic advice, etc. This information can for example be captured using an Intermodal System Wide Information Management (SWIM)[12] system. Applications ('app'-like) will exist to support this process and help the passenger choose a transportation mode to the airport, including the suggested departure time based on the current situation.
  - Where to park: Passengers arriving by car can be guided towards the parking place that is most time-efficient for them, taking into account the flight the passenger needs to take, the applicable terminal entrance, and availability of the parking spaces.
  - How to walk: From the parking space (or other places in the intermodal area, e.g. train and metro stations), clear and unambiguous walkway guidance is given towards the baggage drop-off point and 'passenger transportation'-entrance. Dynamic signage on a per passenger base can help to decrease uncertainties in time needed for the passenger to reach the airport's terminal. Applications on mobile devices can also assist in providing this guidance.
- Passenger arrival scheduling: From the airport's perspective, information is available from the Intermodal SWIM on which passenger will arrive at what time and location at the airport. Using this information, the airport can apply dynamic allocation of airport resources (e.g. baggage drop-off points and passenger transportation), which will result in a decrease in processing and waiting time of certain processes and will contribute to minimising the connecting time.
- Dedicated intermodal area including baggage drop-off: The airport will have a dedicated area for intermodality, which consists of parking spaces, stations for different modes, and the aforementioned facilities. Early baggage drop-off points will be available in this area to allow the passenger to hand-in his/her luggage as soon as possible. This will ease in the passenger's transfer to the terminal, as no heavy luggage will have to be carried.
- Passenger transportation to terminal: In order to eliminate the long physical (walking) distance that is currently present at several European airports, transportation facilities should be used. This can be achieved by for example using APMs (as discussed in section 5.5.2) or modes that provide an individual way of transportation for the passenger. Guidance through dynamic signage and/or mobile devices with guidance functionality will include these modes of transport.

[12] The CE airport concept (D4.3, [21]) elaborates on this Intermodal SWIM solution.

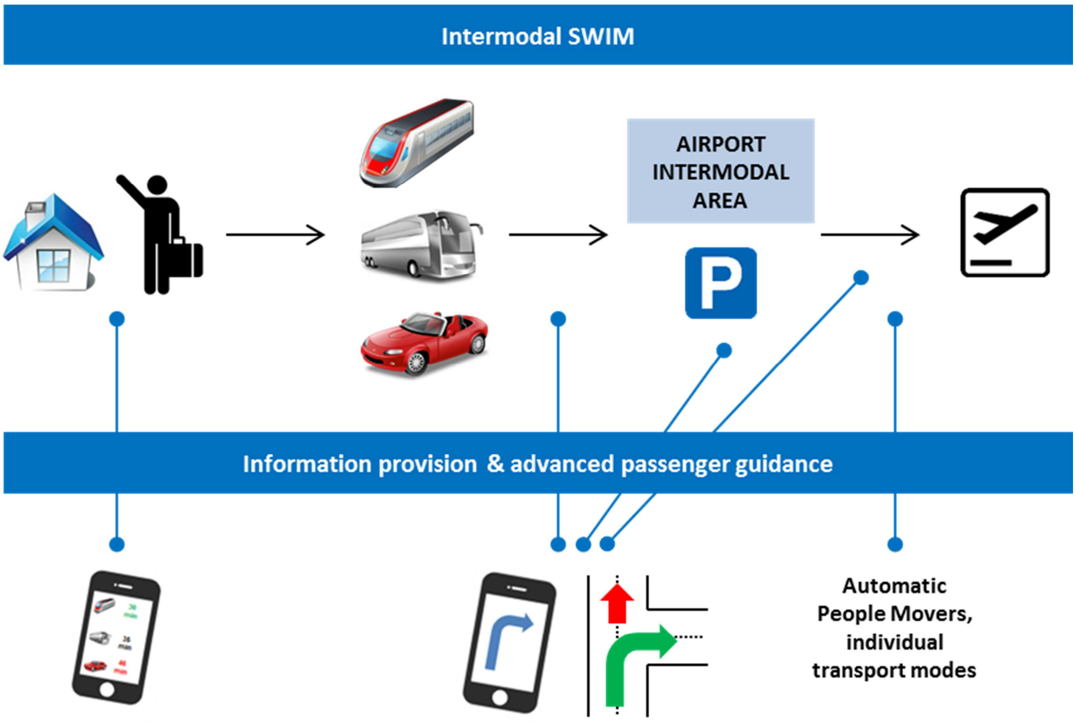

Figure 46: Overview of the integrated guidance system in the intermodal process.

5.6.2.2 Implementation and expected benefits

This new solution is expected to have positive impact on minimising connecting time by specifically addressing the bottlenecks that are expected to exist in this area for 2050+. This positive impact is achieved by speeding up the passenger's transfer and transportation processes between modes. Improved system-wide information provision and guidance will help the passenger to achieve a time-efficient journey. The expected impact is summarised in the radar plot in Figure 47.

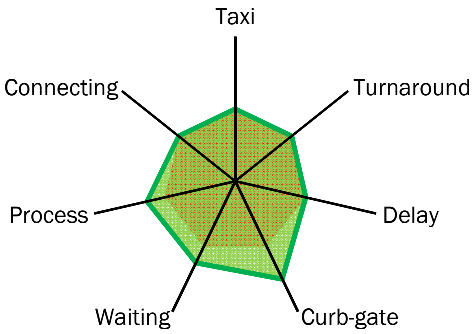

Figure 47: Expected impact of the integrated guidance system.

5.7 Infrastructure

This section discusses the infrastructural changes that will contribute to the TE airport concept.

5.7.1 Circular terminal building

5.7.1.1 Concept description

The circular terminal makes efficient use of limited space available at airports. By arranging aircraft stands and the terminal in a circular way, a large amount of aircraft can stand next to each other. This is a solution that can be applied to large airports with expansion problems. A schematic representation in given in Figure 48. Aircraft are furthermore placed more close to each other, thereby reducing the MCT, and the overall distances in the terminal are reduced. With this solution, an integrated A-SMGCS is needed in order to avoid or manage properly the congestion of the intersecting areas.

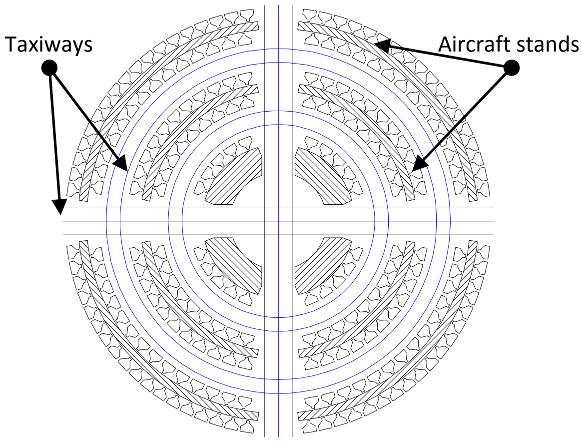

Figure 48: Aircraft stands arranged in a circular way.

5.7.1.2 Implementation and expected benefits

The implementation of a circular terminal concept is expected to be useful especially at airports that are constrained by available space, but want to growth in terms of airside (aircraft stand) capacity. A combination with the underground solutions proposed in this airport concept may even increase the potential benefits. At the same time, it will also reduce taxi times because thanks to the particular disposition of the taxiways (in blue in Figure 48): fast taxiing is enhanced from the stands to the runways through wide and two directional taxi lanes, reducing the number of crossings in the way. The terminal building and concourses will be as they are today except that they will have circular shapes. Passengers will still be boarding and disembarking through fingers and all handling will be carried out as it is done today.

It is expected that the concept has positive impact for both aircraft as well as passenger throughput. As the aircraft are placed more closely to each other, a smaller terminal is required, thereby minimising the passenger's time spent from curbside to gate. Connecting passenger may profit from a short MCT, making the airport more attractive from a hub perspective.

The expected impact is given in Figure 49.

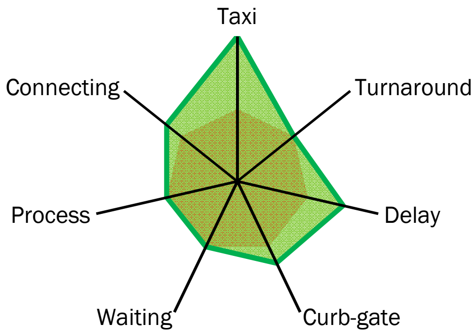

Figure 49: Expected impact of the circular terminal.

5.7.2 High pier concept

5.7.2.1 Concept description

The high pier concept layout, as shown in Figure 50, is similar to that of a hangar and has a building placed above the stand position of the aircraft. This way, the passengers terminal is placed above the aircraft. The stand positions are placed in columns so that the building is perpendicular to the aircraft taxiways and the runway. This way, the aircraft has to be placed exactly below the building. The passenger movement is carried out in this building, and the gates are above the aircraft. The boarding will be made from platforms hanging above the aircraft stand position. With this layout, the boarding and servicing of the aircraft are separated so that the boarding is made from a higher level and does not interfere with other turnaround processes.

5.7.2.2 Implementation and expected benefits

The high-pier is an unconventional pier which is located above ground and allows the aircraft to taxi-in and -out underneath it. This means that the terminal and passenger bridges are located above the aircraft stand position, thereby clearing the apron area for the turnaround processes to be carried in parallel. Passenger bridges can be moved down to be connected to the aircraft once it arrived at the aircraft stand, while the baggage loading and the other turnaround processes can be carried out in parallel in the ground floor level.

The main advantage of the high pier is the reduction in taxi time due to the elimination of the pushback procedure. Thus, the infrastructure should be considered as a 'drive-through' hangar. Furthermore, boarding and deboarding of passengers is not interfering with the other turnaround processes and thus reduces turnaround waiting times. This high pier furthermore acts as a protection ‘roof’ for the aircraft, which is especially useful in severe weat her conditions. The need for de-icing may be reduced by this, sometimes resulting in an even shorter taxi time. The layout of the terminal, forming one column, would bring shorter taxi times for those positions closer to the runway, but could be disadvantageous for those positions farther, especially if the airport has many movements.

An additional advantage is brought by the possibilities of use of the terminal building as an intermodality area. If a train or APM vehicle infrastructure is possible in this terminal building, without causing infrastructure problems, it would be possible to have the passenger arriving to the gate of its aircraft from this vehicle, thus greatly reducing their time walking in the high pier terminal. This vehicle would have to combine the check in and security processes.

The disadvantages would be all the structural problems related with high tail planes like the 25 meters of the A380 and to allow the straight taxi-in and –out and the weight and wind loads that have to be considered for high buildings with few supporting points. Additionally to the loads problems, the platform for boarding/deboarding should be adaptable to the plane door configuration (time of adaptability of the platform), adding additional limitations to the building. Another challenge might be the accessibility of the passenger bridges, as was also described in the underground pier-solution.

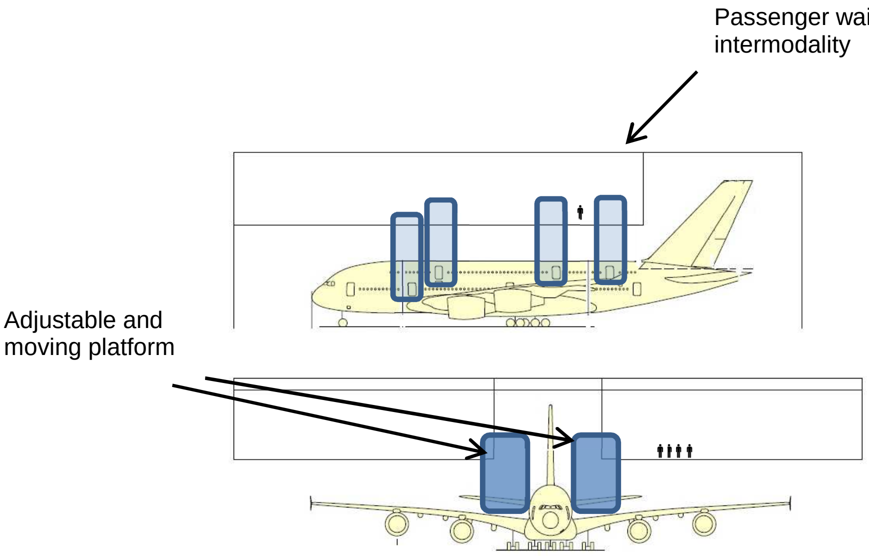

Figure 50: Schematic view of the high pier concept.

The expected impact of the high-pier concept is given in Figure 51.

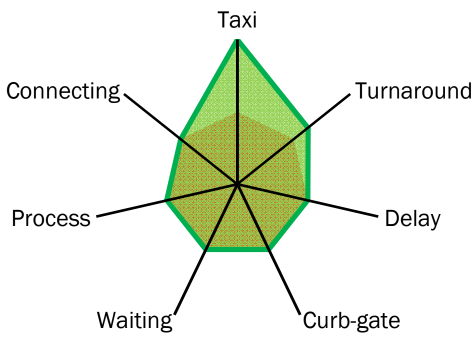

Figure 51: Expected impact of the high-pier concept.

5.8 Summary of the advanced Time-Efficient concept

The latter sections discussed the elements that form together the TE airport concept. While the benefits of the individual elements are indicated, this section gives the reader an overview of the benefits of the total airport concept, by combining all solutions to one TE airport concept. The concept description will start at the beginning of the passenger' journey.

5.8.1 From home to airport curbside

From densely populated areas, such as large cities, the most efficient way to the get to the airport is by dedicated public transportation or private vehicles. System-wide (real-time) information management will allow the passenger to be guided in choosing the most time-efficient transportation mode to the airport. Electric taxis become an option when travelling from sparsely populated areas, where access to mass transport is not cost effective and congestion on roads is limited.

What will be different in 2050 is that cars and thus taxis will most likely be electric and fully automatic (self-driving). It is expected that they will be more cost effective and thus accessible for travellers. The airport, that knows the time the flight departs well in advance, will take into account travel times and plan an electric taxi to pick up the passenger on time. The schedule of the Automated Electrical Transports (AETs) is continuously optimized with respect to all passengers who need to be taken to or from the airport. This will ensure predictable transport from the passenger's door to the airport curbside.

Before the passenger is picked up, the location of the passenger is confirmed and the passenger is signalled by a portable device where and when the AET will pick him up. Mobile devices providing information to the traveller will have a very important role in 2050+ air transport. During the ride to the airport, the passenger is updated of any changes in plans and can use his time in whatever fashion he likes (e.g. for working or shopping for goods, which he can pick up after disembarking at the arrival airport). This allows the passenger for optimal use of the transport time in the AET. The airport and airline are able to track his progress and will get notified if any disturbances occur, such as rerouting due to traffic, and will know his estimated time of arrival at the terminal.

The passenger is dropped off in front of the entrance to the passenger terminal, after which the AET will drive to its station to recharge and wait for its next ride. If the passenger favours shopping at the airport, the AET can arrive earlier to provide this extra time to the passenger. This allows the passenger to have control over the schedule.

On the public transport side, the probable increase in use of this mode as a way to reach the airport brings attention to the fact that new solutions have to be developed in order to ease the home-to-airport journey for the passengers. This is necessary to increase the reliability on the transport network, so that buffers taken due to low predictability of the time needed to get to the airport are minimised. All public transport will gather in the airport's intermodal area, where optimal passenger guidance has matured. Additionally, early baggage drop systems and better information systems can help airlines, airports, and passengers to achieve better coordination and knowledge on the transport network status and the delays (either from passengers or aircraft).

5.8.2 Curbside to passenger boarding

The passenger then enters the terminal, where he can insert possible pre-tagged baggage into the baggage drop off. Check-in is moved to the beginning of the travel process and can possibly be combined with the reservation of the AET. He then proceeds directly to the security point, where he enters a walk through security corridor, which detects any unsafe objects he might be carrying on him or in his hand luggage. If anything is detected, an additional scan is made. Customs related checks can be done also in the walk through security check. This will reduce buffers and waiting times in the present security process.

At the other side of the security corridor the passenger gets to a row of Automated People Movers (APMs). When he gets in, his mobile phone will pass on the passenger's data to the APM and the APM will send an update to the airline and drive the passenger straight to his underground gate. With a sufficient velocity any gate can be reached well within several minutes. This avoids the walking distance for the passenger and also eliminates any way finding problems.

When the APM arrives at the gate, the passenger gets off and the APM drives to the next required location. The passenger picks up any items he may have ordered earlier and is now ready to board.

5.8.3 Airside operations

When boarding begins, the passengers are signalled to board on their mobile phone. A pre-defined optimal boarding sequence can be used in order to quickly board the aircraft. The passenger boarding bridges can be stored underground and connects the underground gate with the aircraft doors. Catering is also loaded using a similar bridge. Baggage is processed using a fast baggage sorting and containerising system, which will allow ready-to-load containers to be available when the aircraft enters the stand. An underground container loader is available to quickly load the pre-loaded containers into the aircraft. Several other turnaround related processes are also automated.

When all passengers are boarded, the door is closed and the boarding bridge is automatically retracted. All loading facilities will be placed underground. Given that push back might still be necessary, electric motors attached to the aircraft's gear can facilitate this, thereby eliminating the need for a push back truck.

When the aircraft is ready for departure, it has to taxi to the runway. Two solutions for the taxi process exist. Firstly, electric taxiing assisted by Advanced Surface Movement Guidance and Control System

(A-SMGCS). Optimisation of all taxi movements will reduce the risk of congestions and delays and will enable seamless taxiing to the runway. The information used for this optimisation can be retrieved by A-CDM, which should be fully integrated by 2050+. The aircraft starts its engines several minutes before take-off during the taxiing phase and can take-off immediately.

For runways that are located more distant from the taxi stand a high-speed taxi train is provided. The aircraft will taxi using its electric motor to the train, after which the aircraft is transported to the runway by the train system.

Note that in applicable weather conditions de-icing will be either automated and speed up or will be unnecessary due to the use of anti-icing materials on aircraft.

5.8.4 Arrival to airport terminal

After the aircraft has landed one of the aforementioned solutions will be used to allow for quick taxiing to the gate. At the gate, the underground bridge and the container loading systems are connected automatically, the door is opened and the passengers can begin to disembark. At the end of the bridge APMs are again waiting to bring passengers to the terminal, where they retrieve their baggage shortly after it has been processed by the fast baggage sorting system, and exit to the curbside.

Transfer passengers are taken by the same APMs to the gate of their next flight, thereby reducing the Minimum Connecting Time (MCT). If the transfer time is larger than the MCT, the passenger can use the APMs to move to the terminal area and back to the connecting aircraft at the right time.

5.8.5 From airport curbside to destination

At the curbside AETs are waiting and when the passenger gets on, the passenger’s mobile phone will send the data to the AET so it knows where to go. After the passenger is dropped off at his destination, the AET drives to his next customer or a holding area. If the passenger is using public transportation, guidance is available for the passenger through for example mobile information devices and dynamic signage, to enable a seamless continuation of the passenger’s journey to his/her destination.

This chapter proposed the advanced TE airport concept. The different elements in the concept are elaborated in detail, including a discussion of the expected impact of each of the solutions has. The next chapter will discuss a first assessment of the concept, which was established in a validation workshop with industry experts.

6 Value assessment of the Time-efficient airport concept

This chapter discusses the validation of the Time-Efficient (TE) airport concept, which is based on the outcomes of the first validation cycle in WP3. The results are obtained from the second validation workshop held on June 19, 2013 at the Polytechnic University in Madrid. The goal of the workshop has been to determine together with a large audience of external stakeholders the most appropriate concept ideas supporting the cost-effective, ultra-green and time-efficient airport of 2050+. To accomplish this, the workshop was split up in five parts [39]:

1) a brainstorm to select concept ideas from the initial list of ideas, and create new ones, assuming five different roles (i.e., airport, airline, passenger, ANSP, industry)
2) an expert judgment exercise (ΔV definition) to prioritise the relevant attributes/KPIs per concept (example attributes: average taxi time, emissions, aeronautical costs)
3) a strategy game to rank the ideas per role selected in 1), from 5 (best) to 1 (worst), and identify the priorities of each stakeholder
4) an expert judgment exercise (ΔV assessment) to assess the impact of each concept idea on each concept attribute/KPI, from ++ (very positive impact) to -- (very negative)
5) a concluding exercise to link three ideas that could work together in order to improve the overall efficiency of the airport in terms of time, as isolated ideas can improve certain processes, but not the overall efficiency of the airport´s layout

This chapter presents the post-analysis of the workshop results and shows the expected benefits of the TE airport concept's ideas presented in previous chapter. This chapter thereby focuses on the conclusions that can be made for the TE airport concept, whilst the workshop report [39] focuses on general conclusions from the workshop in terms of methodology and validity. This chapter furthermore investigates which ideas from the Ultra-Green (UG) and Cost-Effective (CE) airport concepts could be beneficial for the TE airport concept.

The chapter is structured as follows. Section 6.1 summarises the TE's operational changes to the airport's invariant processes as proposed in the previous chapter. Section 6.2 presents the value function that is established by expert judgement to assess the relevant attributes per concept, after which Section 6.3 & 6.4 discuss the validation results of the experts gaming and judgement sessions respectively. The chapter is concluded in Section 6.5 with a discussion of the combinations of ideas that could together be most beneficial to the TE airport concept, an overview of the best individual ideas, a perspective of the TE airport concept, and a discussion on recommendations for further development.

6.1 Identification of operational changes in the Time-Efficient concept

The TE airport concept solutions presented in the previous chapter propose several operational changes to the airport's invariant processes. These processes, which would otherwise have remained unaltered (invariant) over time, will need to be modified to implement the concept ideas proposed in the previous chapter. These modifications can be summarised as follows for each invariant process:

- **Airside process**: The TE airport concept proposes both the use of electric engine taxiing and (electric) guided taxi systems. The first solution requires modifications on the aircraft, while guided a guided taxi process at least requires modification to the airside and makes the taxi process dependent on the airport's infrastructure. However, both solutions are expected to quicken the taxi process, especially in combination with an optimal taxi planning and control using the systems (e.g. A-SMGCS) available in 2050.
- **Turnaround process**: Several ideas are proposed to improve the turnaround process. In general, these solutions include the automation of several turnaround processes. For unloading and loading baggage and other goods, underground loading devices are proposed that deploy from underground if necessary. This requires an infrastructure change, but also reduces the amount of apron vehicles necessary and allows for faster unloading and loading of the aircraft. Another innovative idea is to use automatic seat loading (including hand luggage) instead of the current boarding process, which has heavy impact on the aircraft layout and airport operation.
- **Passenger transport**: For door-to-airport transport electric taxis are foreseen. In order to benefit in terms of time-efficiency, the concept proposes to have a centralised, airport operated, system of electric taxis driving from and to the airport. This would allow for an optimised planning and operation of the taxis. Also inside the terminal an increased use of Automated People Movers (APMs) is foreseen, as these have the benefit of transporting passengers quickly to the gate, thereby also eliminating way finding and long walking distances. Several pre-boarding processes could be integrated in these APMs. To optimise the boarding process, passengers are called on-time using their mobile information devices. Security checks are comprised in a walk through security corridor, in which the passengers and luggage are checked for dangerous goods without stopping. The latter solution is a severe change compared to today's operations.
- **Baggage transport**: Fast baggage sorting is required to enable time-efficiency for the passenger. The TE airport concept also proposes the automatic loading of baggage in containers, e.g. by the use of robot arms. This will enable a quick loading process of the baggage into the aircraft.
- **Infrastructure**: The TE airport concept proposes some radical infrastructural changes in order to achieve time-efficiency. Moving the terminal pier and the loading devices underground has the benefit of a clean apron area, which allows for a straight taxi-out (i.e. no pushback necessary). However, it also involves large infrastructural investments in underground facilities. The circular terminal concept allows for more aircraft stands in areas with spatial limitations. This also concentrates aircraft stands and thereby reduces distances between terminal and aircraft and connecting flights. The high-pier concept moves the terminal and loading facilities upwards, such

that the aircraft taxis 'under' the terminal while the passenger and baggage movements are above the aircraft. This has similar advantages as the underground pier, but also requires severe infrastructural changes.

- **Intermodality**: The concept proposes better information sharing and guidance for the passenger in the intermodal process, both for the home-to-airport journey as well as at the curbside and in the intermodal area of the airport. Automatic Electric Taxis (AETs) are proposed for an optimal home-to-airport journey, though different forms of public transportation are suggested to be improved by using dedicated infrastructure.

During the validation workshop the concept ideas were presented in a simple, short format and participants were encouraged to think of the changes the ideas have on the airport's operation. From this an expert judgment of the expected impact on the seven time-efficient attributes aircraft taxi time, turnaround time, delay, passenger curb to gate time, process time, waiting time, and connecting time between modes was made for each idea chosen in the gaming session.

6.2 Composing a value function to evaluate the concept

This section discusses the value function for the TE airport concept, including the weights used in it.

6.2.1 Determination of the value function

The value function was established from a high-level in WP2, as is described in the Concept Development Methodology in D2.1.2 [4]. The low-level objectives per concept where established iteratively throughout the project, and for the further definition of the value function. Recalling the value function from D2.1.2:

$$\Delta V(AP_{2011}^{2050}) = \lambda_E \left(\frac{E_{2050}}{E_{2011}}\right) + \lambda_M \left(\frac{M_{2050}}{M_{2011}}\right) + \lambda_S \left(\frac{S_{2050}}{S_{2011}}\right) \quad (1)$$

Where ΔV represents the change in value provided by the solution, λ_i represents the weight of the different objective areas, and *E*, *M*, and *S* refer to economics, mobility, and sustainability respectively. Taking ω_i as the weight of the specific low-level attributes *i*, t_j as time, and δ as delay level, the time-efficient element *M* in equation (1) can be described further by its low-level attributes in the form:

$$\left(\frac{M_{2050}}{M_{2011}}\right) = \omega_1 \left(\frac{t_{\text{taxi,2050}}}{t_{\text{taxi,2011}}}\right) + \omega_2 \left(\frac{t_{\text{turnaround,2050}}}{t_{\text{turnaround,2011}}}\right) + \omega_3 \left(\frac{\delta_{2050}}{\delta_{2011}}\right) + \omega_4 \left(\frac{t_{\text{curb-gate,2050}}}{t_{\text{curb-gate,2011}}}\right) + \omega_5 \left(\frac{t_{\text{waiting,2050}}}{t_{\text{waiting,2011}}}\right) + \omega_6 \left(\frac{t_{\text{processing,2050}}}{t_{\text{processing,2011}}}\right) + \omega_7 \left(\frac{t_{\text{connecting,2050}}}{t_{\text{connecting,2011}}}\right) \quad (2)$$

Similarly, the low-level objectives of economics and sustainability can be included. The (final) value function that has been used during the workshop includes 16 low-level objectives in total. Workshop participants had the opportunity to propose new attributes to be included, but these were not taken into account during the final, quantitative analysis of the workshop results.

6.2.2 Determination of the weight factors

The weight factors were determined per concept from expert judgement during the WP3 validation workshop. All stakeholders (airport, airline, passenger (user), Air Navigation Service Provider (ANSP), and industry) were asked to – *from a time-efficiency point of view* – give:

1) a division of importance to the weights for the three areas λ_i
2) give a division of importance to the weight factors of the low-level objectives ω_i

The weight factors given by the experts were averaged from the different stakeholder roles during the workshop. The final division for the Key Performance Areas (KPAs) is given in Figure 52.

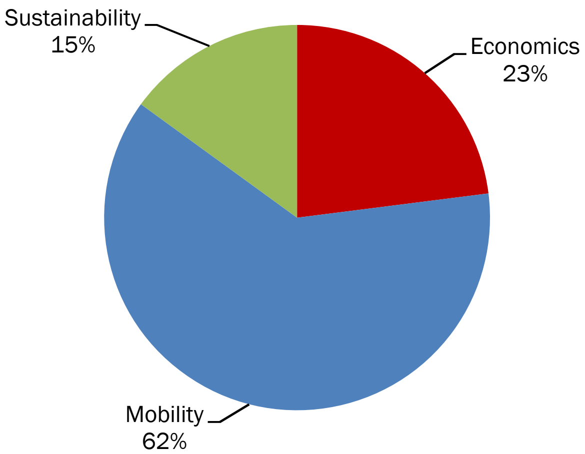

Figure 52: Division of importance of the three KPAs for the TE airport concept.

The division for all low-level objectives, i.e. including those related to the CE and UG airport concepts, is given in Table 20. Note that the results in this table express the relative importance of each low-level objective for time-efficiency, with weights adding up to the value 1 for each concept.

Table 20: Division of importance of all low-level objectives for the TE airport concept.

Low-level objective	Importance for Time-efficiency (i.e. weight factor)
Economics	
Reduce Aeronautical Cost	0,33
Reduce Non-aeronautical cost	0,19
Increase Aeronautical income	0,27
Increase Non-aeronautical income	0,21
Total	*1,00*
Mobility	
Minimise taxi times	0,09
Minimise turnaround time	0,14
Minimise delays	0,17
Minimise travel time through airport	0,16
Minimise waiting time between processes	0,08
Minimise processing time	0,08
Minimise connecting times between modes	0,28
Total	*1,00*
Sustainability	
Keep noise within or below legal limit	0,28
Reduce energy use	0,20
Reduce emissions	0,21
Optimal use of resources (recycling)	0,18
Optimal use of water	0,13
Total	*1,00*

A few notes can be made from the results. First of all, in the TE airport concept sustainability and economics still play an important role in the determination of the added value. Mobility is most important with a weight of 62%. Regarding the low-level objectives of mobility, it can be seen that minimising the connecting time between nodes is one of the main drivers of being time-efficient. In total, more importance is given on being time-efficient from a passenger's point of view compared to the aircraft's point of view. The latter observation is in line with the idea of the TE airport concept in which aircraft are enablers for the air transport system.

Besides the determination of the weight factors, experts were also asked to assess the completeness of the value structure. One interesting missing attribute was introduced during the gaming session: social working conditions should be part of the area sustainability, as sustainability is more than being environmentally friendly.

6.3 Expert judgment of the Time-Efficient concept solutions

6.3.1 Set-up of the validation workshop

The validation of the ideas was performed in two ways: (1) an expert judgment gaming session and (2) a value assessment of the chosen ideas[13]. The gaming session included all ideas developed in WP4, including the UG and CE concept ideas[14]. The set-up of this gaming session can be found in the validation workshop report [39].

6.3.2 Results of expert gaming session

In the gaming session, experts were asked to select in a strategy game the 25 best time-efficient ideas and rank them by assigning scores to them (through the 'game'). Table 21 lists the selected ideas in the order of the score given by the experts. These results reflect which concept ideas are favourable according to the different stakeholders. The TE idea with the highest score is the automation of the de-icing process. In applicable weather circumstances this solution is believed to have considerable positive impact on the time-efficiency of the aircraft and thus also of the passenger. Other TE ideas that are believed beneficial are the walk-through security check corridor, the high-speed aircraft taxi system, and the electric taxi for door-to-door transport.

Some ideas of the two other concepts were also considered beneficial in terms of time-efficiency. The biometric identification of passengers and microwave and THz for homeland security are believed to decrease the processing and waiting time of the affected passenger security processes. The synthetic vision in the cockpit was originally meant to decrease the airport's cost, but can also have a positive effect to the time-efficiency in severe weather conditions, as aircraft may have the ability to fly closer to each other thereby increasing capacity in these conditions. Several TE ideas were not chosen by the experts during the gaming session and are thus found less beneficial for time-efficiency. No value assessments have been made for these solutions by the experts. These are:

- Electric taxiing to and from the runway using A-SMGCS: Experts do not expect to gain time during the taxi process compared to conventional taxiing.
- Underground automated container loading: Experts expect less flexibility, which may result in additional delays.
- Fast baggage sorting and containerising: Experts do not see added value for time-efficiency in this solution.
- High pier concept: Experts do not see added value for time-efficiency in this solution.

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[13] For a complete description of the validation workshop, the reader is referred to the WP3 Validation Plan [6] and Workshop Report [39].

[14] Two TE airport concept ideas were excluded from the validation workshop in order to have a workable amount of concept ideas: *the Mobile device boarding [TE8]* was combined in the CE idea *Intelligent ICT supported airport* and the *Electric taxi engine* was merged with similar ideas stated in the UG and CE airport concepts.

Table 21: Ranking of ideas from expert's gaming session.

Idea	Concept	Points
Idea 28: Biometric identification of passenger	CE	24
Idea 18: Automatic de-icing	TE	22
Idea 27: Microwave and THz for homeland security	CE	21
Idea 8: Synthetic vision for cockpit	CE	20
Idea 29: Walk through check corridor	TE	17
Idea 11: High speed a/c taxi system	TE	17
Idea 26: Door-to-door transportation of baggage	CE	17
Idea 10: Electric taxi for door-to-door airport transport	TE	16
Idea 9: Configurable Platform Runways and Taxiways	UG	16
Idea 6: Remote Tower	CE	15
Idea 22: Underground pier	TE	15
Idea 23: Automation of the turnaround processes	TE	14
Idea 36: Door-to-door integrated transport chain	All	13
Idea 16: On-Board self-boarding gate	CE	11
Idea 38: Intermodal SWIM	CE	10
Idea 2: Magnetic levitation for take-off/landing	UG	10
Idea 12: Electric Guided Taxi System	TE	9
Idea 20: Automatic People Movers	TE	9
Idea 37: Intelligent ICT supported airport	All	7
Idea 5: 3D Holographic HMI TWR-Apron controller position	CE	7
Idea 25: Automatic Displaceable seats	TE	5
Idea 34: Circular Terminal Concept	TE	4
Idea 1: Dual split threshold runway	UG	4
Idea 3: Electric Engine accelerators for take-off	UG	4
Idea 24: Automated moving seat system	UG	3

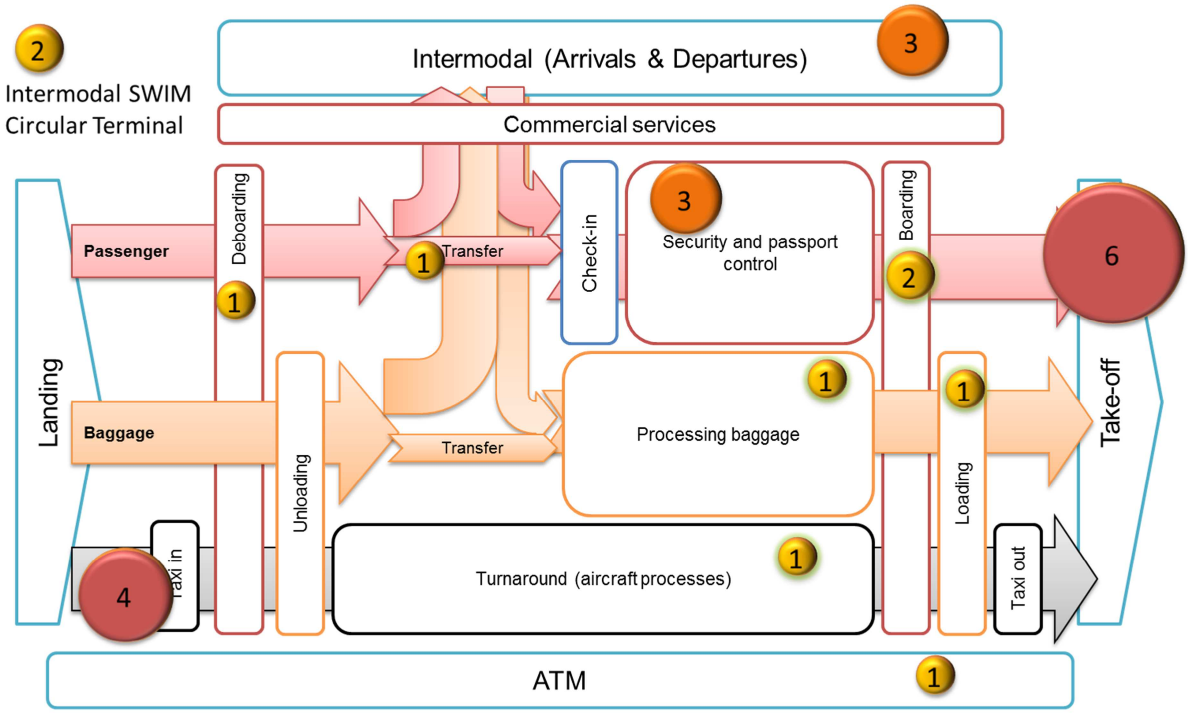

Figure 53: Ideas chosen by experts and placed on the invariant processes chart.

The selected ideas listed in Table 21 were placed on the invariant processes chart to clarify their position and relation to the specific airport processes. Figure 53 shows the invariant processes chart with the amount of chosen ideas per process in the expert's gaming session. Most ideas chosen are related to the take-off and the taxi-in/-out phase. 7 ideas have been chosen related to the passenger process, e.g. security and boarding. As such, experts concluded both that these areas have opportunities for improvement and that promising solutions exist for these and related areas.

A review of the invariant process chart made by experts showed that expect modifications in the location of some of the processes. Especially some of the passenger related processes (check-in and security check) may move to another time during the journey or even before the journey. Also, experts could not agree on the location of commercial services. Some experts expect no commercial services within the airport by 2050, while others do. Also baggage drop-off could be moved out of the airport terminal in order to improve time-efficiency. Many solutions require changes to the airport's infrastructure and could therefore also be (partly) placed outside of the invariant processes – similarly as the circular terminal.

6.3.3 Improvements to the Time-Efficient concept solutions

For some ideas improvements were suggested during the gaming session, which are summarised in Table 22 and which could improve the time-efficiency of the ideas considered.

Table 22: Suggested improvements to some of the ideas.

Ideas	Proposed improvement
Idea 8: Synthetic vision for cockpit	Functionalities that could be added are: • Wake turbulence detection • Weather situation • Surface surveillance By doing this aircraft can fly closer to each other and the aircraft throughput/capacity can be increased in several scenarios, i.e. normal and bad visibility operations.
Idea 22: Underground Pier	Move the whole terminal underground; which will allow for a clear airport platform, thereby adding to time-efficiency.
Idea 37: Intelligent ICT supported airport	Add commercial needs to this solution, in order not to lose non-aeronautical revenues due to an increased time-efficiency. This proposal allows the passenger to use commercial services at any time during the journey, for example during the journey from home to the airport's curbside.
Idea 5: 3D Holographic HMI TWR-Apron controller position	Include SMAN services to assist the pilot during taxi movements, thereby increasing reliability of the taxi process, decreasing average taxi times and delay levels.
Idea 11: High speed aircraft taxi system	Electronic speed control done by Total Airport Management (TAM)
Idea 7: Electric ground movement	Optimise operations and adapt them for low visibility conditions, to achieve high performance also during these conditions
Idea 12: Electric guided taxi system	Replace rails/glides with contactless systems, such as an electromagnetic system
Idea 20: APMs	Combine with a city terminal to move passengers from the terminal to the aircraft outside the city
Idea 19: Fast baggage sorting & containerizing	Combine with a permanent baggage tag to eliminate the attachment of a baggage tag every journey, either at home or at the airport.

6.4 Value analysis of the Time-Efficient concept solutions

In a subsequent expert judgment exercise (the ΔV assessment), the experts were asked to assess the impact of each of the selected concept ideas on all value attributes. This assessment was done using a simple scale ranging from ++ (very positive impact) to -- (very negative impact). Using this assessment together with the value function established in Section 6.2 the added value for idea can be calculated. The results of this calculation are given in Table 23.

6.4.1 Most value-adding ideas

Using the calculated added value, another ranking of ideas could be made. Note that this ranking, based on the added value calculated from expert assessment by scale (from ++ to --) is different from the ranking obtained in the strategy game discussed in the previous section. From the TE airport concept, automatic displaceable seats, the electric guided taxi system, and the walk through security check corridor are expected to provide the most value to the TE airport concept. Idea 27 with new security technology is expected to add most value to the concept, as this will cause several security processes to be improved and speed up.

Table 23: Expert's value assessment of ideas for the TE airport concept.

Ideas	Concept	ΔV
Idea 27: Microwave and THz for homeland security	CE	60,6
Idea 25: Automatic Displaceable seats	TE	44,0
Idea 12: Electric Guided Taxi System	TE	39,4
Idea 1: Dual split threshold runway	UG	38,4
Idea 29: Walk through check corridor	TE	35,7
Idea 28: Biometric identification of passenger	CE	35,1
Idea 10: Electric taxi for door-to-door airport transport	TE	33,4
Idea 9: Configurable Platform Runways and Taxiways	UG	33,3
Idea 16: On-board self-boarding gate	CE	32,1
Idea 20: Automatic People Movers	TE	29,4
Idea 11: High speed a/c taxi system	TE	27,3
Idea 37: Intelligent ICT supported airport	All	26,9
Idea 24: Automated moving seat system	UG	25,4
Idea 26: Door-to-door transportation of baggage	CE	24,9
Idea 34: Circular Terminal Concept	TE	22,9
Idea 18: Automatic de-icing	TE	22,7
Idea 23: Automation of the turnaround processes	TE	22,2
Idea 38: Intermodal SWIM	CE	20,9
Idea 22: Underground pier	TE	20,0
Idea 3: Electric Engine accelerators for take-off	UG	11,1
Idea 8: Synthetic vision for cockpit	CE	9,7
Idea 36: Door-to-door integrated transport chain	All	5,0
Idea 5: 3D Holographic HMI TWR-Apron controller position	CE	0,3
Idea 2: Magnetic levitation for take-off/landing	UG	-1,7
Idea 6: Remote Tower	CE	-2,3

6.4.2 Validation of the time-efficient specific ideas

In order to analyse the impact of each solution in more detail, the following sections show two radar plots. The left plot indicates the impact of the idea on the seven value attributes related to time-efficiency. The right plot shows the value contribution to the three airport focuses (Key Performance Areas (KPAs)), which is calculated using the composed value function. The latter plot is thereby also indicating from a high-level perspective how the chosen ideas are affecting sustainability and economics.

6.4.2.1 Automatic displaceable seats

The use of automatic displaceable seats is having a positive effect on the throughput time of both the passenger and the aircraft. The aircraft's turnaround time can be shorter as the passenger boarding process will be replaced by 'loading' a single platform of seats, baggage, and passengers. This will also reduce the possibilities of delays. The passenger benefits from a shorter process and waiting time.

As such, the impact of mobility is considered highly positive, whereas the impact on economics is neutral (cost increase for the airport, but revenues may also increase) and the impact on sustainability is negative due to the increased use of energy.

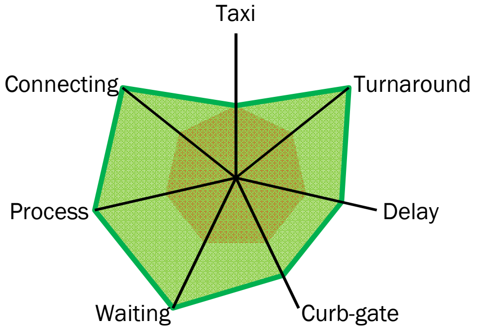

Figure 54: Impact of displaceable seats on TE attributes.

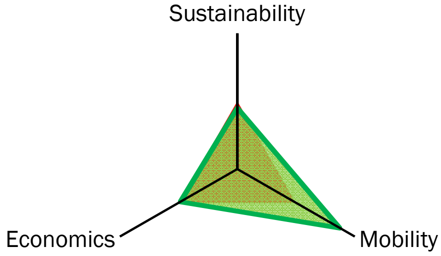

Figure 55: Impact of displaceable seats on KPAs.

6.4.2.2 Walk through security check corridor

The walk through security check corridor will have a highly positive impact on minimising the throughput time for the passenger. Airport throughput, process, waiting, and even connecting time are expected to decrease by replacing current security processes with a walk through solution, which will eliminate or at least reduce the amount of manual steps in the security screening process. This will lead to less queuing and thus a faster process and waiting time, which consequently result in less time spend at the airport, thereby also minimising connecting time between nodes.

The idea therefore has a high positive impact on mobility, however, due to increased non-aeronautical cost it is expected to have negative impact on economics. Energy consumption is expected to reduce compared to the scenario where this solution is not implemented, resulting in a positive effect on sustainability.

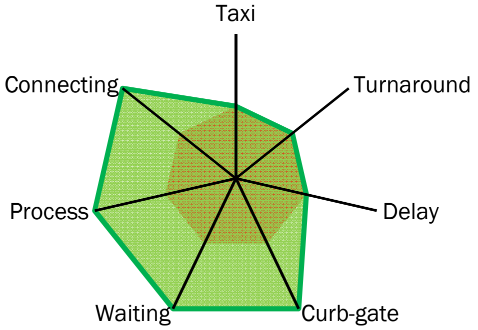

Figure 56: Impact of a walk through security check on TE attributes.

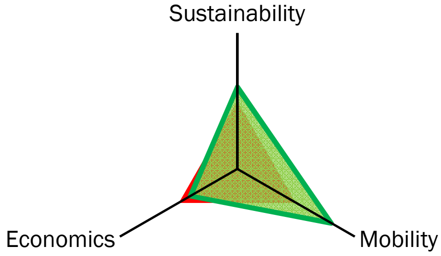

Figure 57: Impact of a walk through security check on KPAs.

6.4.2.3 Electric guided taxi system

The electric guided taxi system is present in all three concept documents and is expected to decrease the aircraft's taxi and turnaround time, as it moves the aircraft quickly from and towards the runway. Due to this systematic way of taxiing, delay levels are expected to decrease. The results also show a positive pact on the passenger's curbside to gate time, though as the solution is not affecting this KPI this result is considered incorrect.

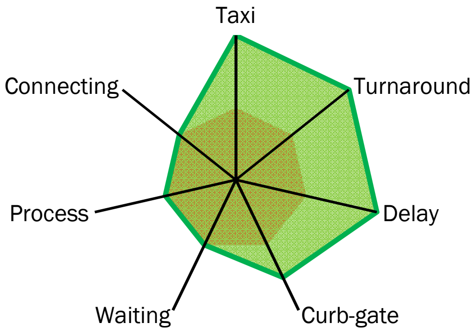

Figure 58: Impact of guided taxiing on TE attributes.

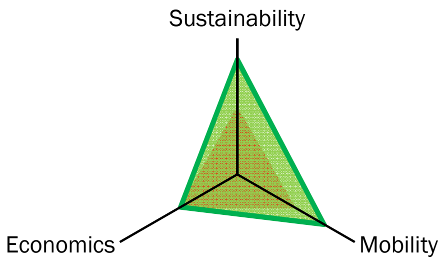

Figure 59: Impact of guided taxiing on KPAs.

The idea also has positive impact on KPA sustainability, as it will eliminate the taxiing with conventional jet engines. How positive this impact is, is of course dependent on the taxi distance. The impact on economics is neutral, as the idea will increase revenues but also increase the airport's cost due to the system.

6.4.2.4 Electric taxi for door-to-door airport transport

Adding electric taxis for door-to-airport transportation positively impacts the passenger's mobility. The solution will not only contribute to less delays and a lower connecting time, but also has the potential to reduce processing and waiting time of the passenger, by integrating different processes such as security checks and shopping into the home-to-airport journey.

The idea has positive impact on sustainability as electricity-based and as the airport can gain revenues of it, it can have a positive effect on economics.

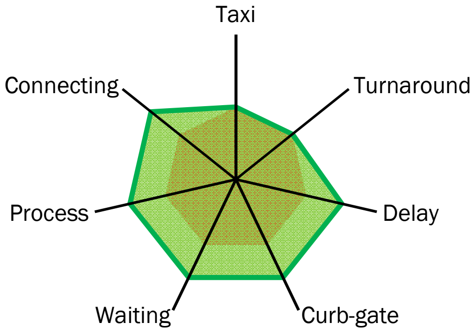

Figure 60: Impact of electric taxis on TE attributes.

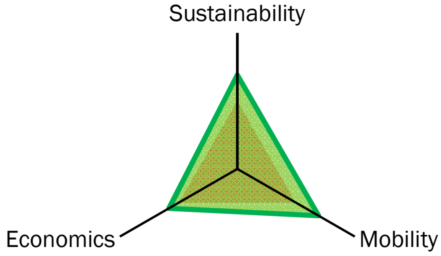

Figure 61: Impact of electric taxis on KPAs.

6.4.2.5 Automatic People Movers

The use of APMs is expected to highly decrease passenger process, waiting, and connecting times. The time spent by the passenger between curbside and the gate can also be reduced, as the use of APMs eliminates way finding and long walking distances.

While thus having positive impact on mobility, increased energy use will result in a negative impact on sustainability. The effect on economics is again considered as neutral. Investments and maintenance cost for the APM system increase the airport's non-aeronautical costs, but on the other hand revenues can be expected for offering this type of service, including its benefits in terms of mobility.

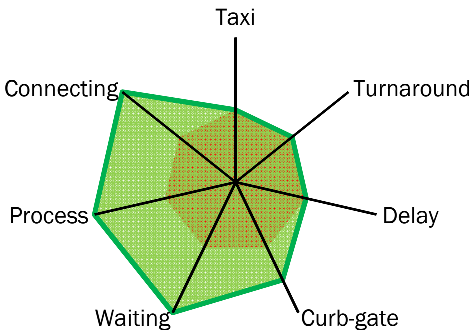

Figure 62: Impact of APMs on TE attributes.

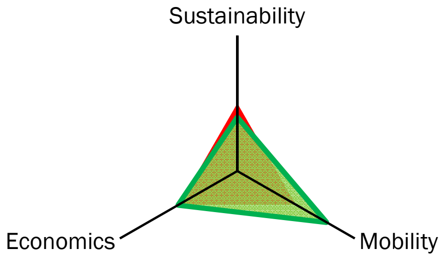

Figure 63: Impact of APMs on KPAs.

6.4.2.6 High speed aircraft taxi system

The high speed aircraft taxi system is expected to increase the aircraft's taxi and turnaround time and delay levels, especially at airports with distant located runways. This solution has no impact on connecting time and passenger throughput time.

By reducing the use of jet engines during taxiing, the solution has positive impact on sustainability. Aeronautical cost will increase with the required infrastructure, while aeronautical revenues can also be increased for this service. Therefore the impact on economics was estimated neutral during the validation workshop, although details necessary to make a more precise approximation were not available.

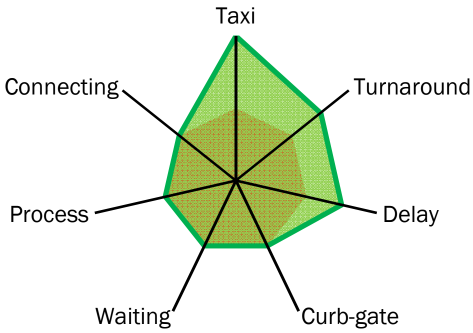

Figure 64: Impact of the aircraft taxi system on TE attributes.

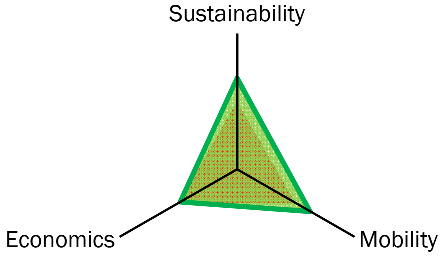

Figure 65: Impact of the aircraft taxi system on KPAs.

6.4.2.7 Circular terminal concept

The circular terminal is especially expected to result in a reduction of taxi times, as taxiways and runways are located next to each other. The foreseen positive impact for the passenger curbside to gate time is not present in the expert judgment, instead, the impact on the passenger's throughput is considered neutral.

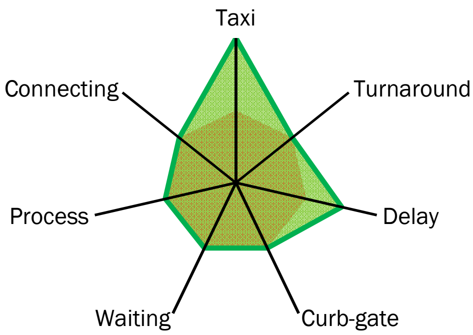

Figure 66: Impact of the circular terminal on TE attributes.

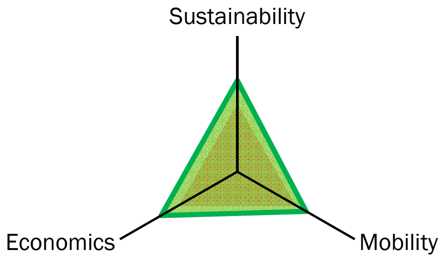

Figure 67: Impact of the circular terminal on KPAs.

The solution has a positive impact on sustainability due to the reduction of taxi distances and thus the reduction in jet engines use. Fewer costs are foreseen for the investment and maintenance in the runway and taxiway system, which results in a positive impact on the airport's economics.

6.4.2.8 Automatic de-icing systems

Automating the de-icing of and on the aircraft will decrease the taxi time when de-icing would be necessary. Furthermore due to a faster processing time less delay is expected before departure.

The reduction of currently used de-icing material also results in a positive impact on sustainability and the reduction of staff and de-icing vehicles will decrease cost in the long run.

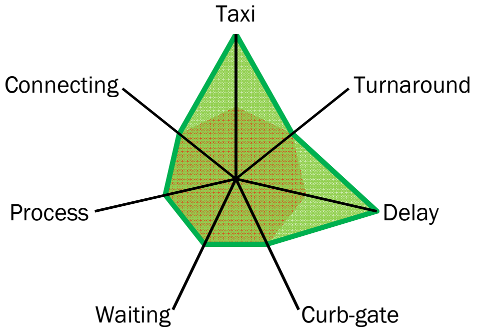

Figure 68: Impact of automatic anti- and de-icing on TE attributes.

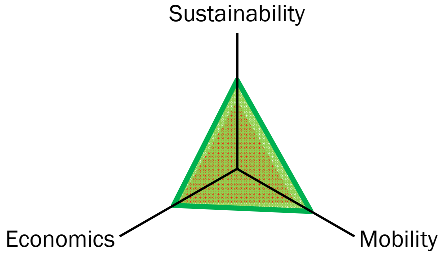

Figure 69: Impact of automatic anti- and de-icing on KPAs.

6.4.2.9 Automation of turnaround processes

The turnaround process can be faster when automating the turnaround process. Due to the better availability of turnaround equipment and less dependency on ground staff less delays are foreseen.

Additionally, positive impact is foreseen on both sustainability and economics, due to the decrease in necessary apron vehicles and the decrease in staff cost respectively.

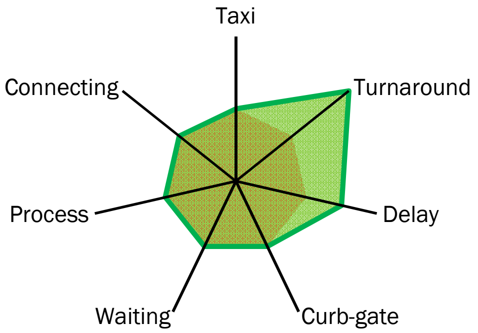

Figure 70: Impact of the automation of turnaround processes on TE attributes.

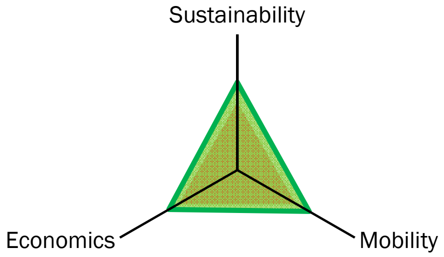

Figure 71: Impact of the automation of turnaround processes on KPAs.

6.4.2.10 Underground pier

The underground pier is expected to lead to shorter turnarounds and less delays. Furthermore the passenger process, waiting, and throughput time are improved. The latter is due to the fact that aircraft can be placed more closely to each other.

Underground constructions are in general more expensive, causing a negative impact on economics. Sustainability will improve. Experts further made the note that less flexibility is one of the disadvantages of underground constructions. In contrast with normal terminal and pier constructions, underground piers cannot be easily expended and make the airport therefore less flexible and scalable.

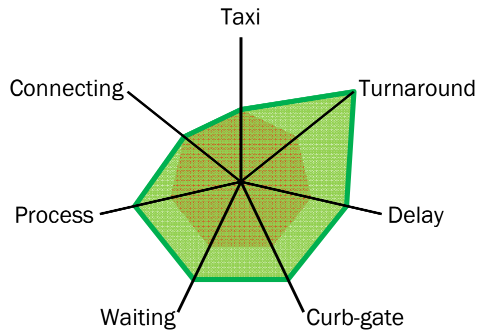

Figure 72: Impact of the underground pier on TE attributes.

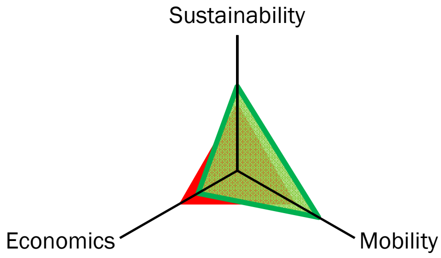

Figure 73: Impact of the underground pier on KPAs.

6.4.3 Limitations to the analysis

The preceding sections showed the valuation of the impact of solution on the KPIs, as expected by aviation experts. It should be noted that this analysis is based on the opinion of one or more experts. As such, the results are just a first estimation of external experts (not involved in the project) of the impact that solutions have. More information on the workshop methodology and its validity can be found in the workshop report (D3.3, [39]).

6.5 Summary, perspective, and potential of the Time-Efficient concept

The previous sections discussed the results of the validation of ideas in the TE airport concepts. This is based on the outcomes of an expert gaming session and the expert's change-impact analysis. A list with 'best' ideas follows out of both analyses.

6.5.1 Best ideas for the Time-Efficient concept

Figure 74 lists the best ideas coming out of the value analysis (left side) and expert judgement (right side). Half of the ideas following from the analyses are considered to be most promising from *both* analyses, which are displayed in the centre of the figure. The walk through security check corridor and the electric taxi for door-to-airport transport are considered as the most beneficial ideas of the TE airport concept. Furthermore, the advance homeland security, biometric identification, and configurable platforms – ideas originating from the UG and CE airport concepts – are also considered to be highly beneficial for the TE airport concept.

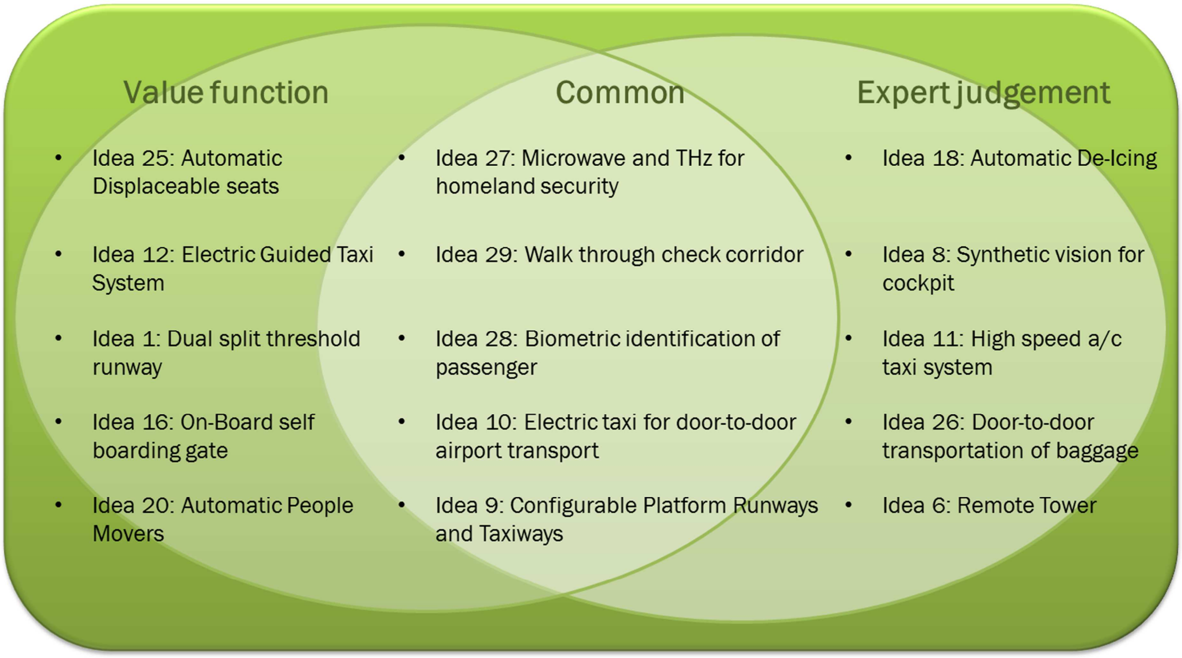

Figure 74: Best ideas from expert judgment, value assessment, and combined.

6.5.2 Expert's most promising combinations of ideas

As a last part of the validation workshop, when the experts were familiar with the ideas of Airport 2050+, they were asked to write down a combination of three ideas that could work together to improve the overall efficiency of the TE airport concept. The results of this are given in Table 24.

Table 24: Expert's judgment on the best ideas for the TE airport concept.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Idea I	Idea 23: Automation of turnaround processes [TE13] (including ideas 13, 17, 19)	Idea 27: Microwave and THz metrology for homeland security	Idea 11 : High speed taxi [TE2]	Idea 7: Electric ground movement [TE1]	Idea 27: Microwave and THz metrology for homeland security
Idea II	Idea 7: Electric ground movement [TE1]	Idea 13: Automated apron services	Idea 13: Automated apron services	Idea 31: Shielding TOL operations with vegetation	Idea 22: Underground pier [TE4]
Idea III	Idea 38: Intermodal SWIM	Idea 30: Self-cleaning materials	Idea 23: Automation of the turnaround processes	Idea 1: Dual threshold runway	Idea 25: Automated displaceable seats [TE14]

It can be seen that most experts choose a combination of ideas that are affecting different airport areas (i.e. landside, airside, infrastructure, and intermodal). Especially combining an automation of the turnaround process, microwave security technology, and electric and high-speed taxi solutions is expected to lead to time-efficiency, as this 'package' of solutions positively affects all low-level objectives of the TE airport concept. This information is valuable for the integration of concept ideas at the end of the validation in WP3.

6.5.3 Synthesis and potential of the Time-Efficient concept

From the aforementioned validation results some general conclusions can be made. Ideas that were proposed in the TE airport concept often have a positive on either or both the passengers and aircraft' throughput time. They furthermore often go hand-in-hand with the objective with respect to sustainability. The new ideas often induce new aeronautical or non-aeronautical cost for the airport, but on the other hand may introduce a new type of revenue by regarding the idea implemented as a service to airlines or passengers.

Ideas proposed in the two other airport concepts were also found to be beneficial in terms of time-efficiency, some of them are even regarded more beneficial than the ones proposed in the TE airport concept. Additionally, although the validation has its limitations, the outcomes shall be taken into account in the continuation of the development of a TE airport concept as a reference.

Combining the best ideas of all validation analyses in this chapter results in (1) a set of TE ideas that could be worked out further, (2) a set of ideas originating from other concepts that interested to work out further in terms of time-efficiency, and (3) a set of TE ideas that are considered valuable for the UG, CE, and an integrated airport concept. These results are given in Table 25. Note that the experts were not told from which airport concept the several ideas were originating (i.e. the game was not biased in that sense). It is therefore interesting to see which ideas are considered most time-efficient and from which concept they are originating.

Table 25: Recommendations for further development of the TE airport concept.

1. Recommended TE ideas to be further developed	2. Recommended CE/UG ideas to be further developed for the TE airport concept	3. TE ideas that were found most valuable for the CE & UG airport concepts (or an integrated (mixed) airport concept)[15]
Walk through security check corridor [Idea 29/TE6]	Microwave and THz for homeland security [Idea 27/CE]	Electric ground movement [Idea 7] (valuable in: CE, UG & mixed)
Electric taxi for door-to-airport transport [Idea 10/TE10]	Biometric identification of passenger [Idea 28/CE]	Walk through security check corridor [Idea 29/TE6] (valuable in: CE, UG & mixed)
Automatic displaceable seats [Idea 25/TE14]	Configurable platform runways and taxiways [Idea 9/UG]	Electric guided taxi system [Idea 12/TE15] (valuable in: CE, UG & mixed)
Electric guided taxi system [Idea 12/TE15]	Dual split threshold [Idea 1/UG]	Automatic People Movers [Idea 20/TE7] (valuable in: UG & mixed)
Automatic People Movers [Idea 20/TE7]	Synthetic vision for the cockpit [Idea 8/CE]	High speed aircraft taxi system [Idea 11/TE2] (valuable in: UG)
Automatic de-icing [Idea 18/TE3]	On-board self-boarding gate [Idea 16/CE]	Automation of turnaround processes [Idea 23/TE] (valuable in: mixed)
High speed aircraft taxi system [Idea 11/TE2]	Remote tower [Idea 16/CE]	Fast baggage sorting and containerising [Idea 19/TE] (valuable in: mixed)

[15] Abbreviation between brackets () yield the concept (UG/CE/mix) in which this solution was found valuable.

7 Conclusions and recommendations

The 2050+ Airport project develops three airport concepts for the future of 2050 and beyond. These three Airport Concepts are the Time-Efficient (TE) airport concept, the Ultra-Green (UG) airport concept, and the Cost-Effective (CE) airport concept. The Concept Development Methodology of Work Package (WP) WP2 provides the guidance to the development of each of these concepts.

This document reported on the development process and the final outcomes of the TE airport concept. It outlined why the concept is developed, the requirements, the goals it intends to achieve, and how existing and expected bottlenecks and challenges in current airport operations are proposed to be adapted, to achieve time-efficient operations for the year 2050 and beyond.

The expected growth in air transportation would take place only if the European Transport industry is able to meet its targets by enhanced mobility and improved service provision for door-to-door travelling. The objective to enable four hour door-to-door travel for 90% of European travellers [3]. In order to meet this objective, the European Transport Network should improve significantly, which means that the connectivity through the critical nodes of the network has to improve. The network of nodes has to expand to offer full coverage, and a customer focused service provision has to offer the door-to-door connectivity and to meet the requirements for user-friendliness, seamless connectivity and punctual and undelayed service provision.

The airports are the nodes of this European Transport Network and, even if parts of the network are present and are functioning well, the network is far from complete and far from providing full network and door-to-door services. In a competitive world, constrained by limitations, the airports of Europe have to expand and enhance their operations, strengthening their role in the network. This justifies the development of a Time-Efficient (TE) airport concept for 2050+, improving seamless operations and removing delays and other drawbacks in travelling whenever possible.

The objective of the TE airport concept is to maximise value through efficient and effective air transport operations. This means that the air transportation enabler (airline operator) needs to provide the required services to the passenger and that they all need to come together at the airport and receive support in managing the traffic flows seamless through the air transport system, of which the airport is the pivotal part. Thus, the whole process must allow the passengers to depart from their point of origin, be transported to the airport, and board the aircraft without any disruption. To achieve time efficiency, the following objectives must be satisfied:

- Minimise throughput time for airlines
- Minimise throughput time for passengers
- Ensure seamless intermodality

This document proposed several solutions that contribute to a TE airport concept for 2050+, such as a walk through security check corridor, electric taxis for door-to-airport transport, an integrated (intermodal) guidance system, Automated People Movers (APMs), and underground piers. The solutions affect one or more invariant processes – i.e. the processes that are assumed to be present in air travel of 2050+. For each solution the possible benefits for a 2050+ airport concept have been given by analysing their impact on the Key Performance Indicators (KPIs) of the three extreme airport concepts considered.

A first assessment of the elements in the TE airport concept has been made by industry experts during an interactive validation workshop. This workshop resulted in an initial validation of the expected benefits to time-efficiency of the ideas developed in the 2050+ Airport project. The most promising ideas from the TE airport concept in terms of time-efficiency are:

- Walk through security check corridor
- Electric taxi for door-to-airport transport
- Automatic displaceable seats
- Electric guided taxi system
- Automatic People Movers (APMs)
- Automatic de-icing
- High-speed aircraft taxi system

Several ideas from the two other airport concepts (UG and CE) are expected to be beneficial for the TE airport concept, which includes: microwave and THz for homeland security; biometric identification of passengers; configurable platform runways and taxiways; and dual split thresholds. The other way around, several ideas proposed in this document are also found to contribute to the UG and CE airport concepts. The results of the validation workshop – part of the first validation cycle – give an indication on what ideas are worthwhile elaborating further. The second validation cycle will further validate the TE airport concept using simulation, thereby quantifying the impact the solutions have on the 2050+ Airport.

After the finalisation of the validation (WP3), WP5 will draw conclusions of the worked performed throughout the project with the three airport concepts, of which this document is thus a pivotal part, developed in WP4 as main input. During this final work package an integrated concept of operations, which should maximise the value of all three focus areas (CE, UG, and TE), will be developed. Furthermore recommendations for further research will be provided in this concluding part of the project.

Acronyms

A-CDM	Airport Collaborative Decision Making
A-SMGCS	Advanced Surface Movement Guidance and Control System
AET	Automated Electrical Taxi
ALDT	Actual Landing Time
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
APM	Automated People Mover
APU	Auxiliary Power Unit
ATC	Air Traffic Control
ATCT	Tower control
ATFCM	Air Traffic Flow and Capacity Management
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATOM	Airport detection and Tracking Of dangerous Materials
ATOT	Actual Take-Off Time
BWB	Blended Wing Body
CAD	Context Architecture Description
CE	Cost-Effective
CFMU	Central Flow Management Unit
C-I	Change-Impact
CT	Connecting Time
CTOT	Calculated Take-Off Time
DCB	Demand Capacity Balancing
DE	Delay
DG	Directorate General
DMAN	Departure Manager
E-OCVM	European Operational Concept Validation Methodology
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
EIBT	Estimated In-Block Time
ELDT	Estimated Landing Time
EXIT	Estimated Taxi-in Time
FUM	Flight Update Message
GBAS	Ground Based Augmentation System
KFA	Key Focus Area
KPA	Key Performance Area
KPI	Key Performance Indicator

ICT	Information and Communications Technology
MCT	Minimum Connecting Time
PBO	Performance Based Operations
PT	Processing Time
SBAS	Satellite-Based Augmentation System
SESAR	Single European Sky ATM Research
SETA	Single European Transport Area
SMAN	Surface Manager
SWIM	System Wide Information Management
TA	Taxi Time
TE	Time-Efficient
TMA	Terminal Manoeuvring Area
TOBT	Target Off-Block Time
TSAT	Target Start-Up Approval Time
TT	Travel Time
TTOT	Target Take-Off Time
TU	Turnaround Time
RFID	Radio-Frequency Identification
UAS	Unmanned Aircraft System
UG	Ultra-Green
VOM	Value Operations Methodology
WP	Work Package
WT	Waiting Time

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Appendix A Milestones of the airside processes

Table 26 gives an overview of the different milestones that exist in all airside processes. Figures 22-26 give a detailed view of the most important turnaround and departure processes.

Table 26: Overview of milestones in the airside process.

Network process
Milestone 1 - Flight plan presentation (ATC flight plan activation) Milestone 2 - CTOT allocation Milestone 3 - Updated Take-Off Time estimate Milestone 4 – Take-off from outstation or ADEP (departure airport)
Arrival process
Milestone 5 - Update of the ELDT Milestone 6 - Final Approach Milestone 7 - Aircraft Landed Milestone 8 - In-Block
Turnaround process
Milestone 9 - Position passenger bridge / stairs Milestone 10 - Disembarking of passengers Milestone 11 - Cabin Services Milestone 12 - Boarding of passengers Milestone 13 - Remove passenger bridge/stairs. Milestone 14 - Cargo/baggage handling. Milestone 15 - Aircraft Services. Milestone 16 - Towing or pushback. Milestone 17 - Air conditioning
Departure process
Milestone 18 - Establishment of the pre-departure sequence Milestone 19 - Start up request Milestone 20 - Start up approved Milestone 21 - Off-blocks Milestone 22 - Taxi-out Milestone 23 - Take-off

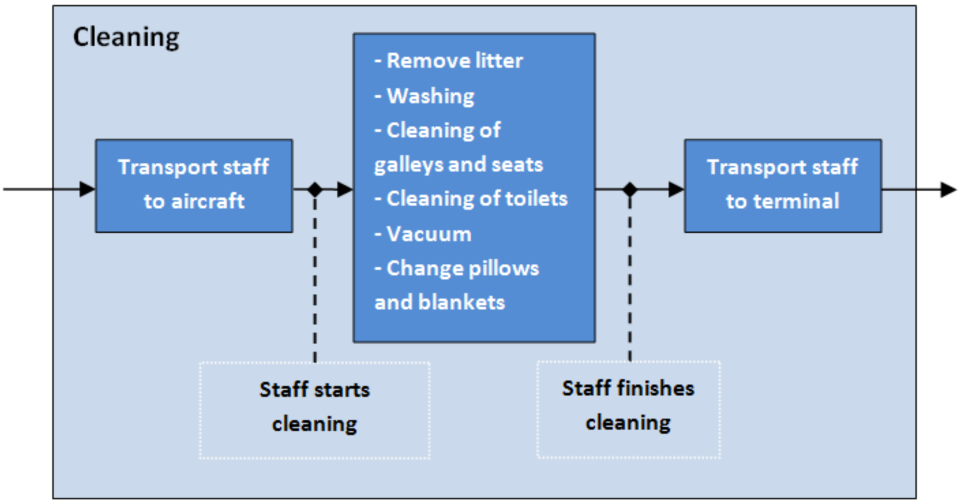

Figure 75: Cabin services process.

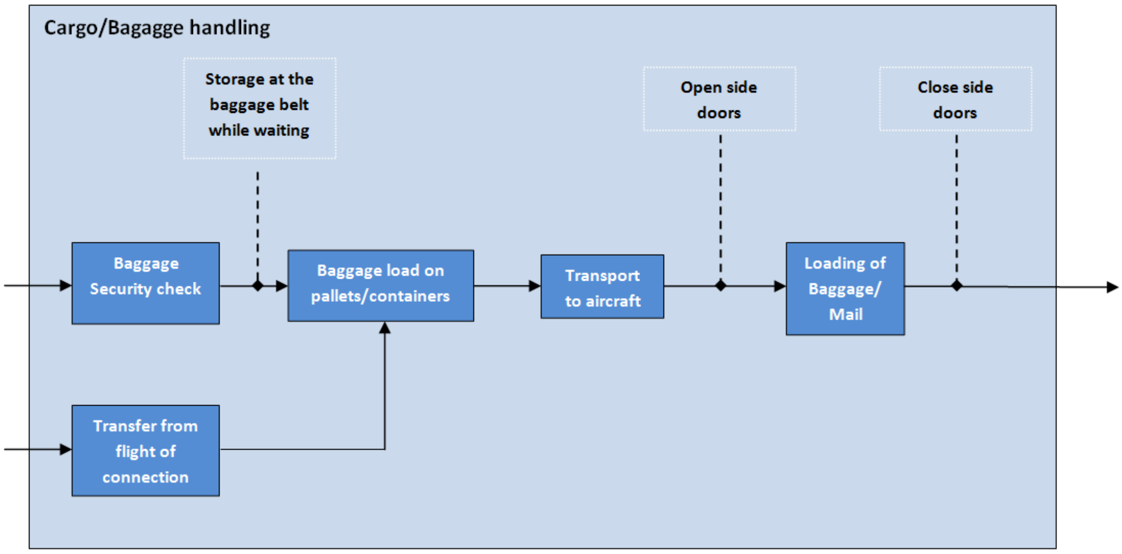

Figure 76: Cargo and baggage handling process.

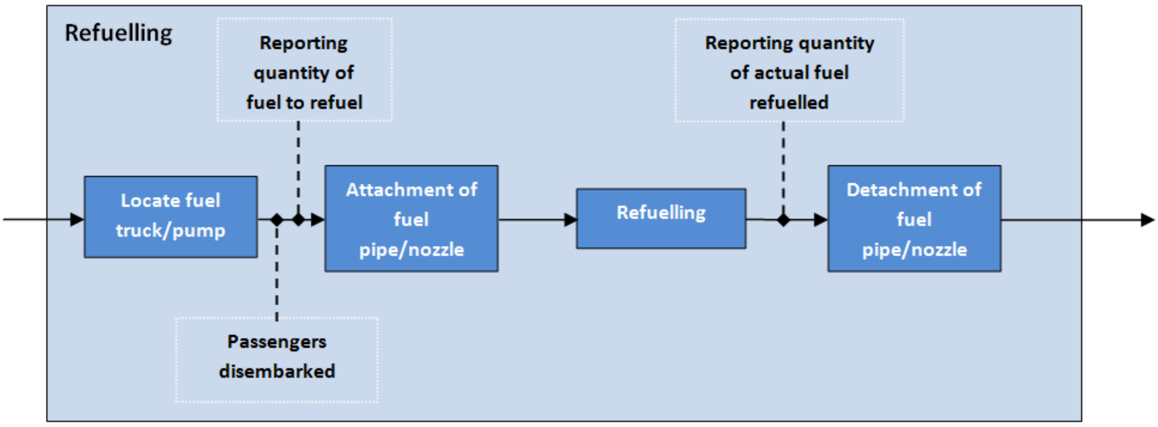

Figure 77: Refuelling of the aircraft during the turnaround.

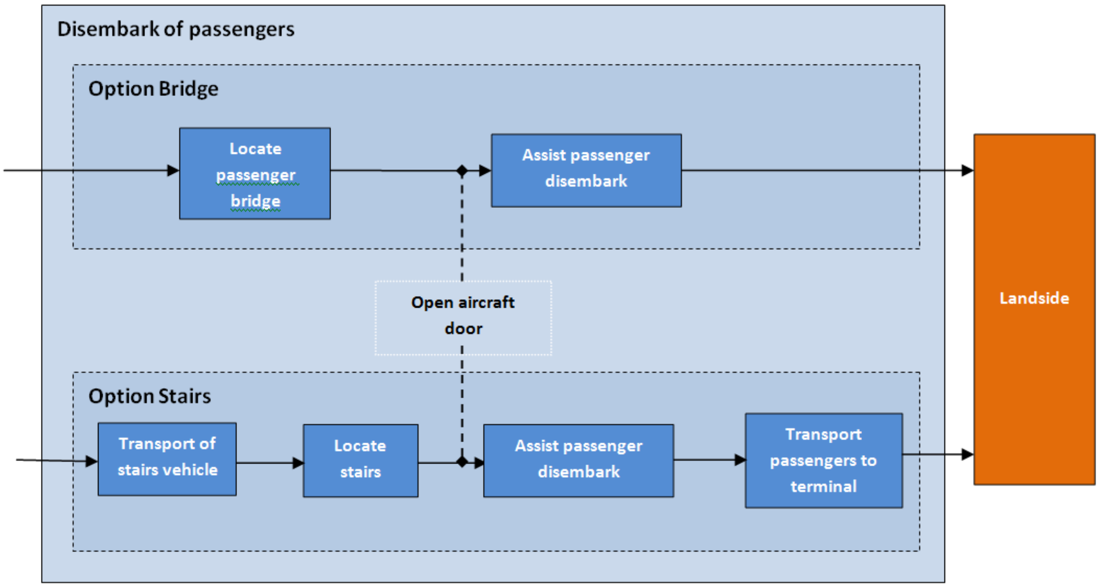

Figure 78: Disembark of passenger process summary.

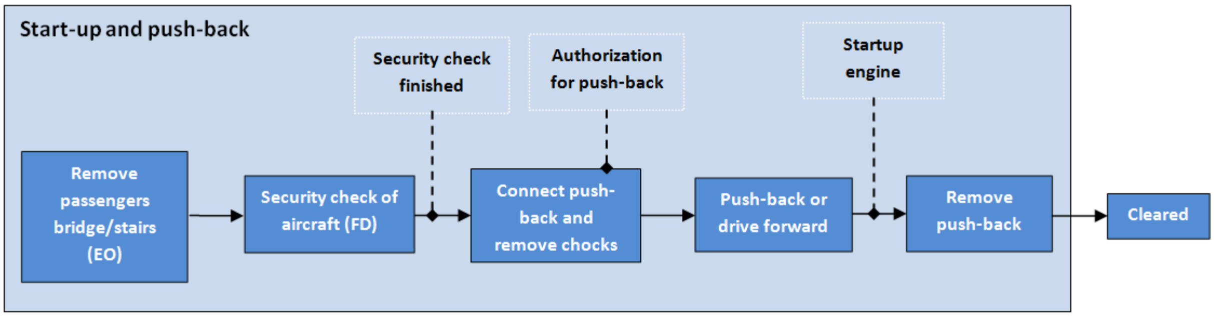

Figure 79: Start-up and push-back process summary.