KEY PERFORMANCE INDICATORS FOR LANDSIDE PROCESSES AT AIRPORTS – WHICH TO CHOOSE AND WHAT TO GAIN?

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ABSTRACT

For airport performance reviews ICAO, EUROCONTROL and several other institutions have defined so called Key Performance Indicators (KPIs). The specifications are, so far, limited to airside processes and have their focus on long-term performance evaluation. This paper extends the concept of KPIs to landside processes and makes them available for real-time airport steering, for example in the context of Total Airport Management. The goal is to provide the airport with in-time and forecasted information on specific processes thus allowing early intervention in case of upcoming disruptions. As basis for the new KPIs, the existing airside indicators are examined in regard to potential adaption possibilities for landside processes. The former timeframe is modified for pre-tactical planning and set to the day of operation. Requirements for real-time measuring as well as forecasting are taken into consideration, throughout considering ICAO guidelines. Using the so gained selection criteria, five KPAs (Key Performance Areas) and nine KPIs were chosen. For each one a clear definition and calculation method is developed and an overview of data availability is presented. To determine the impact of applying KPIs for day-to-day airport operation as well as to identifying target values, a first prototypical implementation has been installed using a microscopic terminal simulation. The results confirm the assumption that relevant performance improvements can be gained if the selected KPIs are considered as suggested.

Keywords: Airport Management, Landside Airport Performance, Key Performance Indicators

1. INTRODUCTION

No matter which study on air traffic growth one considers, they all forecast a significant increase for the coming years (e.g. EUROCONTROL 2010, Airbus 2012). Even today airports are already seen as bottleneck for the air traffic system and solutions have to be found in order to handle the upcoming challenges (EUROCONTROL 2010). The optimization of airport processes will thereby play a major role. The aim of this paper is to present one possible element for such an optimization: Key Performance Indicators (KPIs) for the airport landside[1].

Purpose and Motivation

For years air traffic and airports have been undergoing constant change but there are still more challenges they need to face in regard of the forecasted increase of passenger numbers, the achievement of political targets or growing competition among various airports (European Commission 2011). A passenger increase of 4.7 % per year until 2030 just by itself will necessitate a considerable extension of today's airport infrastructure (Airbus 2012). However, space, financial and legal restrictions will require additional methods next to the construction of new infrastructure to enhance airport capacities. This becomes even more explicit if one adds the requirements due to political targets like the ACARE goals (ACARE 2001). Here it is stated amongst others, that the time between arriving at the airport curb side and being seated in the plane must not be longer than 15 min (short haul) or 30 min (long haul) (ACARE 2001). In order to achieve this and to handle the future passenger demand, the optimization of passenger and baggage processes at the airport has to advance further. An essential component in this regard presents situation awareness, which allows for earlier and more effective action to ensure smooth process flows. Situation awareness, however, requires cooperation among the various stakeholders at an airport and availability of information on all processes for all necessary stakeholders. A significant amount of data has to be converted in real time into simple and applicable indicators with a timeframe from present to several hours in the future. So far, such indicators are not yet available for the airport landside. As they build the foundation for situation awareness and hence also for improving airport processes it is the goal of this paper to introduce Key Performance Indicators as steering mechanism for the airport landside.

Objective

The previous section described the importance of Key Performance Indicators for the optimization of airport processes and stressed the significance of their introduction to the airport landside. The objective of this paper is to identify suitable landside KPIs which can be used as steering mechanism for landside airport processes. Calculation methods have to be defined and availability of necessary data has to be assessed. Possible candidates have to be tested regarding their informative value for airport steering and their reliability. In order to enhance situation awareness all selected KPIs need to be available in real time and a forecast for several hours must be possible, too.

By implementing in a first step some elected KPIs into a microscopic terminal simulation the paper will present possible solutions for the realization of KPI usage at an airport. Also the results of the simulations will give a first impression of the potential of improvement for airport processes if using KPIs. The goal is to show, that the use of KPIs as steering mechanism will enable all stakeholders to not only improve their own performance but also to enhance the system's overall performance.

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[1] In the context of this paper **airport landside** is defined as terminal area, starting at the curb side and ending at the gate.

Outline of the paper

The aim of this paper is to present Key Performance Indicators as steering mechanism for the airport landside in order to enhance situation awareness and to enable improvement of airport processes. To introduce the topic the next chapter will give an overview of the status quo of airport KPIs with initial focus on the airside. Chapter three will thereafter explain the process of developing KPIs for the landside followed by the exact KPI selection and definition in chapter four. A prototypical implementation in an airport simulation is described in chapter five including requirements and first results. The last chapter presents a summary of expected and gained benefits for the use of landside KPIs as steering mechanism.

2. KEY PERFORMANCE INDICATORS FOR AIRPORT MANAGEMENT IN GENERAL

The term *Key Performance Indicator* is used in many fields today and even if looking only at airports very different applications can be found (ICAO 2009). The most common use at this time is as subsequently calculated values for statistical analysis and comparisons (ICAO 2009; EUROCONTROL 2009 & 2012). The next two sections will give a short overview of the different types available and of some previously defined KPIs whereat the sole focus is on airports.

General information on use and different types of Key Performance Indicators

Key Performance Indicators are according to ICAO an instrument to quantitatively express current and past performance, expected future performance (estimated as part of forecasting and performance modelling), as well as actual progress in achieving performance objectives (ICAO 2009). According to development status it is distinguished between conceptual indicators and technical indicators. The first are defined to represent exactly what is wished to be measured, but for which the required data feeds may not currently be available. The second are designed to approximate a certain conceptual indicator as much as possible (EUROCONTROL 2011). All KPIs are correlated to superior Key Performance Areas (KPAs). Those are defined by ICAO as a way of categorizing performance subjects related to high-level ambitions and expectations, like for example safety, capacity or flexibility (ICAO 2009). Both KPIs and KPAs present an essential part of performance-based management, which is a decision-making method with strong focus on desired or required results, informed decision-making driven by those desired or required results, and reliance on facts and data (ICAO 2009). A necessary premise for the success of applying KPI in any form is the cooperation of all stakeholders in a performance-based manner (ICAO 2009). KPIs should be considered together and not separately and trade-offs will have to be allowed for as it is impossible to maximize all performance goals at the same time (EUROCONTROL 2009). Also, all KPIs should be seen in specific airport context as a myriad of factors distinguishes airports from one another (EUROCONTROL 2009).

Like the performance-based approach (PBA), KPIs can be applied in various activities like policy-making, regulation, transition planning, system design and validation, economic or operational management, and continuous improvement i.e. optimizing the system (ICAO

2009). Depending on the activity, the requirements for KPIs will vary to a great deal in regard to e.g. data quality, timeframe or real-time availability. Generally in regard of use two different groups can be distinguished with the first one being calculated post action for performance measurement as well as analysis, and the second one calculated in real-time or forecasted for pre-tactical planning. The first group is used for supporting the achievement of long-term goals or improvements and enables a consistent and continuous review of airport performance (EUROCONTROL 2011). The aim of the second group is to provide decision support for day-to-day operation by showing aberrations from normal operation for a timeframe from actual point in time to around 24 h in the future. It allows for enhanced situation awareness and with it for better understanding of the overall airport system. This will in turn enable management decisions according to best performance of the whole system instead of stakeholder specific improvements. This second group is in focus of that paper and all KPIs developed in the following sections can be assigned to it.

Summary of Key Performance Indicators available on the airport airside

The basis for any universally accepted KPAs or KPIs in the context of airport airside is set in the ICAO *Manual on Global Performance of the Air Navigation System* (ICAO 2009). It introduces 11 KPAs, namely

- *Access and equity,*
- *Capacity,*
- *Cost effectiveness,*
- *Efficiency,*
- *Environment,*
- *Flexibility,*
- *Global interoperability,*
- *Predictability,*
- *Security,*
- *Safety,*
- and *participation by the ATM community.*

Specific KPIs are not yet specifically defined. SESAR (Single European Sky ATM Research) Joint Undertaking uses basically the 11 KPAs defined by ICAO, but adds one more – *Human Performance* (EUROCONTROL 2011). Furthermore, they extend the previous definitions and cluster the KPAs according to visibility into the three groups *Societal Outcome, Operational Performance,* and *Performance Enablers*. (SESAR 2006 & 2007)

The *Air Traffic Management Airport Performance (ATMAP) framework* (EUROCONTROL 2009) takes the concept of performance-based management and KPAs/KPIs one step further, however, with restriction to aircraft movement on the ground and the nearby airspace. It addresses the five KPAs *Traffic Volume and Demand*, *Capacity, Punctuality, Efficiency*, as well as *Predictability*, and presents the development, testing and verification process of KPIs for all of these five KPAs (EUROCONTROL 2009). For the KPA *Punctuality* they introduce, for example, the KPIs *on-time arrival/departures, early arrivals, and departure delay causes*. For more detailed information and an overview of all KPIs please refer to (EUROCONTROL 2009). Next to ATMAP, the Manual for Airport CDM Implementation (EUROCONTROL 2012) presents KPIs in a similar stage of expansion. The noteworthiness there is the first mentioning of KPIs for landside aspects (gate and baggage belts) even though only very marginally.

The above introduced fundamental activities have in common their almost exclusive limitation to the airport airside or the airspace, respectively. Their focus is mainly on the achievement of long-term goals as well as constant performance review and the use of KPIs as pre-tactical steering mechanism is only addressed slightly. First advances to fill these gaps have been made in the context of Total Airport Management (TAM), a concept originally introduced by DLR and Eurocontrol in 2006 with the aim to improve the cooperation of the various airport stakeholders and with it to advance collaborative and coordinated planning of all airside and landside airport operations (Günther et al., 2006, Helm et al. 2012). In the first TAM concept as well as in later works in this field, KPAs and KPIs have been introduced as steering mechanism. They have also presented some for the airport landside, e.g. *Boarding Punctuality* or *Passenger Connectivity*; however, none have been tested or implemented so far (Depenbrock et al., Günther et al., 2006).

Some airports, like Zurich, have introduced landside KPIs for performance review, too. Though hence fulfilling the demand to cover the airport landside, those KPIs are neither used nor applicable as steering KPIs and real-time decision support

As described in this section, no KPAs/KPIs have yet been generally defined, tested and validated that allow for performance-based pre-tactical planning on the airport landside. In the following chapters this paper will try to advance this goal by introducing suitable indicators and first test results.

3. SELECTION PROCESS FOR LANDSIDE KEY PERFORMANCE INDICATORS

Both ICAO and ATMAP describe schematic methods for the development of KPAs/KPIs and introduce necessary requirements that have to be fulfilled in order to successfully apply the indicators (ICAO 2009, EUROCONTROL 2011). As those documents are generally accepted and present a standard character, the KPI development process in this paper is aligned to them. Some adaptions nevertheless had to be made due to the partly different use of the KPIs by ICAO or ATMAP compared to the aim of this paper (see previous chapter).

Method for determining possible landside Key Performance Indicators

The KPAs/KPIs introduced in this paper are supposed to be used as decision support for day-to-day operations on the airport landside and within a pre-tactical timeframe. The goal is to smooth and optimize process flows especially in situations of slight deviations from the original operational plan. To ensure, that the selected KPIs fulfil these demands the six step selection process pictured in Figure 1 was applied.

The purpose of *Step 1* is to identify objectives for improvement of airport landside processes. As starting point, potential difficulties that can arise during normal operation are collected and analysed. Due to the high number of processes as well as stakeholders, the resulting amount becomes very extensive. In the context of this work the potential difficulties have hence been clustered into ten groups which are presented below:

- *queues ,*
- *waiting times*
- *airside delays*
- *missing information*
- *journey to the airport*
- *missing information*
- *Global interoperability,*
- *baggage system*
- *room occupation rate*
- *availability of mobile resources*
- *availability of immobile resources*

After the detection of potential difficulties, the five high-level objectives *improved resource* *utilization, reduced delays, reduced costs, improved level of service,* and *reduced left behind index (LBI)* are derived and set as KPAs.

In *Step 2* a collection of possible KPIs is made by the help of literature research and expert knowledge. At this state, the goal is to obtain an extensive overview of candidates for KPIs irrespectively to e.g. feasibility, significance.

The comparison of the accumulated KPI candidates according to pre-defined criteria takes place in *Step 3*. A description of the selection criteria applied in this paper is given in the next section and the chosen KPIs are introduced in chapter 4.

Step 4 is necessary to allow the use of the selected KPIs as decision support. Standard values for normal operation need to be defined for each KPI as reference. If deviations from these standard values occur during operation, they will indicate the need for activity in the respective area. For this aspect local conditions have to be taken into consideration and adaptions have to be made for each airport.

With the definition of the KPIs completed, they can be implemented in the airport system. *Step 5* is consequently the execution phase and the beginning of delivering benefits (ICAO 2009). Premise for this step is the availability of all necessary data and respective data quality. In the context of this paper, this step could only be partly realized. A detailed description of the prototypical implementation is presented in chapter 5.

Step 6 serves the purpose of continuously keeping track of the performance of the application of KPIs as steering mechanism on the landside. It ensures that the assumed improvement of airport operation is monitored and succeeds according to expectation. This step will need to go on as long as the KPI approach is in use. As the focus of this paper is a prototypical implementation, *Step 6* has not yet been considered.

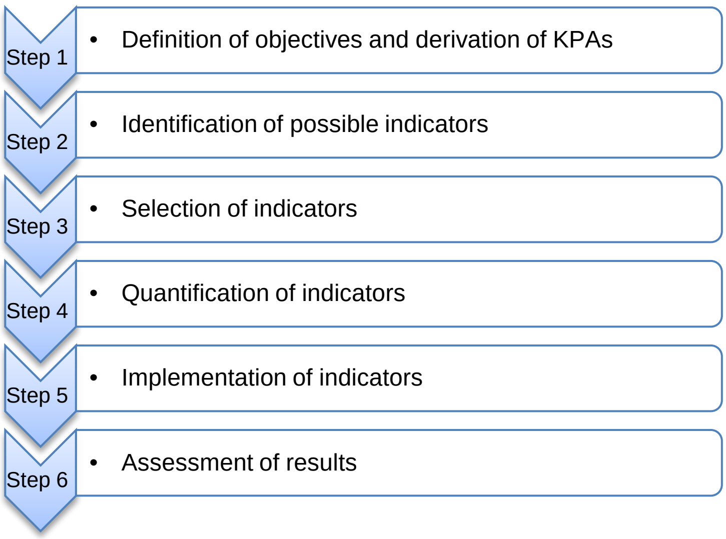

Figure 1 – Selection process applied for developing landside steering KPIs

Selection criteria

The regulation EC 691/2010 (European Commission 2010) which lays down a performance scheme for air navigation services (ANS) and network functions prescribes that:

> *"Key performance indicators should be selected for being specific and measurable and allowing the allocation of responsibility for achieving the performance targets. The associated targets should be achievable, realistic and timely and aim at effectively steering the sustainable performance of air navigation services."* (European Commission 2010)

Even though those requirements were formulated for KPIs in the context of ANS performance they can and should also be applied for steering KPIs on the airport landside. The same is true for the expanded version given by ATMAP which adds amongst other the criteria *drive the desired behaviour* and *accountable/manageable* (EUROCONTROL 2011).

The main selection criteria used in this work in order to define suitable landside KPIs as steering mechanism are presented in Table 1.

Table 1 – Selection criteria for steering KPIs on the airport landside

Criteria	Description
• ***Significance***	• KPI has the ability to monitor respective airport activity • Changes in performance should be clearly recognizable in KPI value changes
• ***Number of covered objectives***	• Each objective defined in chapter 2 needs to be covered by at least one KPI • KPIs covering several objectives are preferred
• ***Measurability***	• General ability to be measured is prerequisite • Direct measurement of KPI is possible or need of expressing the KPI in terms of supporting metrics • Performance is quantitatively expressed • Abidance to privacy regulations
• ***Data availability***	• Necessary investments to provide required data • Sufficient data quality is a prerequisite • Necessary data granularity
• ***Real-time ability***	• Calculation of KPIs has to be possible in real-time • KPIs should be able to be forecasted for a timeframe of 24 hours

Besides the above descripted selection criteria one more aspect needs to be considered for real-time steering of airport operations: the overall number of KPIs. Operators have to be able to keep an overview of changes in the KPI values. The final number of KPIs should hence be kept to a reasonable amount, but will vary with airport size, airport goals and technical equipment. The selected KPIs in the framework of this paper are illustrated in the next chapter.

4. DESCRIPTION OF SELECTED LANDSIDE KEY PERFORMANCE INDICATORS

According to the selection criteria introduced above, five KPAs and nine KPIs have been chosen, so far. To gain acceptance to these KPIs by stakeholders at an airport and for enabling any form of implementation, a clear definition of KPIs is necessary. Answers have to be available to questions regarding the reason for their selection, calculation methods or data availability. This chapter addresses those aspects for all of the chosen KPAs or KPIs, respectively, and will give some information on the current possibilities of implementation.

Delay

Applying the presented selection criteria, *Delay* has been chosen as one of the five KPAs. In general, delay defines the time span between a planned event and the actual entry of this event. In air traffic usually the scheduled and actual on-block respectively off-block times of a flight are used to determine the delay. If the delay exceeds more than 15 minutes a flight is considered as unpunctual (Grunewald 2006). The comparison of the scheduled and planed off-block times (SOBT vs. AOBT) or on-block times (SIBT vs. AIBT) of a flight can only be a rough indicator that operations are disturbed. A detailed cause for the disturbance, e.g. due to weather, disturbances in ground handling, assigned flight routes, cannot be derived from this comparison. For the purpose of steering landside processes more suitable timestamps have to be found as reference to determine delays.

Delay Passenger Boarding

Before departing passengers can enter the aircraft, they have to complete a chain of different processes. Simultaneously, the aircraft they wish to fly with has to be ready for boarding. These two process chains, passengers and aircraft, proceed separately from each other until their joining at the gate. There the aircraft as well as all passengers have to be ready at the right time. If one or both of these process chains are not finished at the planned time a delay will occur. This delay can be classified as an airside delay, if it is caused by the handling of the aircraft or as a landside delay in case of a disturbance in the passenger flow within the airport terminal. Both cases result in an interruption of smooth process flows and hence the need for steering and adjustment of parallel, semi-autonomous operations becomes necessary. An early recognition of such deviations can help to reduce the impact or to avoid it at best. Regarding the landside, measurements of delay at the gate can provide an indication of deviations in terminal processes, e.g. too long queues at security or check-in.

To measure *Delay Passenger Boarding* adequate timestamps are necessary. With the implementation of A-CDM 16 milestones were introduced (EUROCONTROL 2012), which can be used to monitor the actual aircraft process from take-off at the outstation over turn-around at the airport until take-off again. The principle of these milestones[2] can be transferred to the landside by defining milestones for landside process points. As the off-block time of the aircraft (AOBT) is already one milestone it appears expedient to include the boarding of passengers by defining the start and end of boarding as checkpoints. On the basis of a planned start (SSBT) and end (SEBT) of boarding, a delay at this process can be determined by a comparison with the actual times (ASBT, AEBT). The *Delay Passenger Boarding* can be computed as follows:

$$\text{delay}_{\text{boarding}} = AEBT - SEBT - (ASBT - SSBT)$$

[2] Principle means that at certain process points, additionally to the originally planned times (schedules), timestamps are collected during operations (actuals) as well as are estimated and updated with a certain time horizon (estimates).

Figure 2 illustrates the correlation of the different times and the influence of landside and airside disruptions.

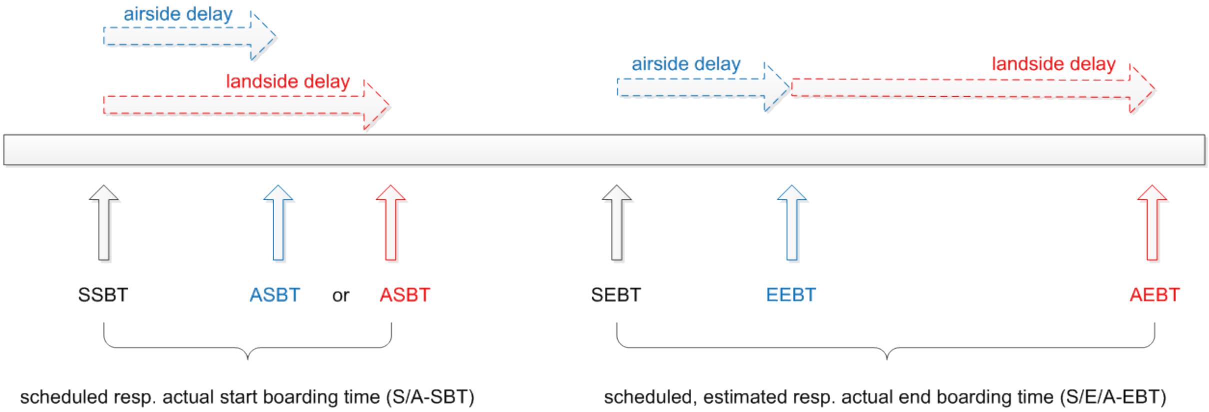

Figure 2 – Delay Passenger Boarding

Delay Baggage Delivery

Contrary to the *Delay Passenger Boarding* which focuses on departing passengers, baggage delivery is relevant for arriving passengers. Hence, this KPI is only relevant for arriving aircraft.

At baggage carousels passengers are waiting to recollect their baggage after their flight to leave the airport terminal as speedy as possible. Delays for baggage recovery can occur during the process of baggage delivery. This comprises the time span between the actual on-block time of an aircraft (AOBT) and the arrival of the first resp. last piece of baggage at the carousel. Therefore, both types of delay can occur: an airside delay due to ground handling activities at the apron or a landside delay due to disruptions within the baggage handling system.

To calculate a delay, it is necessary to define boundaries in which the baggage delivery normally should be carried out. Nowadays, airport operators often sign service level agreements with their ground handlers with a commitment to such boundaries. By determining the baggage delivery time airport operators can measure the performance of the ground handler and the adherence to the agreed service levels. Data availability is ensured by collecting the AOBT of the aircraft and the point in time when the first and last piece of baggage is placed on the conveyor of the baggage handling system[3]. The delay at carousels can be determined by taking into account the actual process time within the baggage handling system. With the defined boundary and measured timestamps during operations the actual *Delay Baggage Delivery* can be determined and decided if suitable actions have to be taken. Since the baggage process is not yet modelled within the simulation environment (cf. chapter 5) this KPI will not be implemented and calculated further on.

Level of Service

The IATA Airport Reference Manual (IATA 2009) includes amongst others Level of Service (LoS) Standards for congestion assessment. It is thought as design objectives for airport

[3] This is technically realized as the loader presses a switch with beginning and ending the loading process.

dimensioning and enables the estimation of necessary space for passenger processing. Landside processes are evaluated in regard to flow as well as delay and classified into six levels from A (Excellent) to F (Unacceptable). For each of these levels maximum waiting time and minimum available space per passenger are available. With respect to airport steering, these aspects are also suitable to be used as KPIs and the ICAO values present good reference for normal operation at an airport. However, for any kind of implementation, the detail level has to be increased and calculations have to be made separately for all process stations to allow for assignment of accountability. Furthermore, the aspect Queue Length is added as third KPI next to Waiting Time and Passenger Density for the KPA Level of Service.

Queue Length

Before actually entering a plane each passenger has to check-in, pass security as well as passport control (if applicable), and needs to pass through boarding control. Especially during peak hours, resources at process stations are often not sufficient and long lines of passengers start to be built. The result on the one hand is congestions in the terminal area possibly blocking access ways or emergency exits and disturbing other processes at the airport. On the other hand, passengers need considerable more time to complete all necessary steps of the process chain leading to reduction of passenger comfort (queues are perceived as very stressful and daunting) and potentially also to aircraft delays. As consequence, high costs for delays may arise and passenger satisfaction for the airport may decrease. Prevention of overly long waiting queues has consequently a positive effect not only for Level of Service but also for the other four objectives introduced in chapter 3.

The KPI *Queue Length* is defined as the number of persons waiting in line in front of a process station in order to pass through. Automatic measurement can be achieved with help of cameras and software for image recognition. To enhance the informative value and to abstract it according to human absorbing capacity, the average queue length is calculated over all opened lanes/counters of each separate process station. In case of security this means one value for all neighbouring lanes and in case of check-in as well as boarding all available counters for the respective flight. In addition to these local values, the maximum queue length of each kind of process station (i.e. check-in, security, passport control and boarding) is calculated for the whole airport. An interval of 1 min is chosen for updating and recalculation.

Waiting Time

The KPI *Waiting Time* is closely connected to the *KPI Queue length* and shows similarity in many of the above introduced aspects. They address the same objectives and formation as well as consequences are accordant with only a slight shift of the main focus from congestion to delay.

Like Queue Length, also this second LoS KPI could be automatically measured using cameras. In the context of this paper, waiting time is however not yet measured directly but calculated using the queue length (given in number of persons) and the mean of an empirical distribution function for the processing time:

$$Avg.Waiting\ Time = Avg.Processing\ Time * Queuelength$$

For aggregation the same methods apply as used for Queue Length. An interval of 1 min is once more chosen for updating and recalculation, too.

Passenger Density

In the description of the KPI *Queue length* consequences of congestions in terminals are already briefly described. The KPI *Passenger Density* extends the area of attention from only queues to the overall terminal area. It hence allows for detection of congestions due to lost passengers, obstacles, etc., and presents a possibility to monitor smooth flows independent of process stations.

The KPI *Passenger Density* is defined as number of persons per area [m^2]. Automatic detection is possible again by using cameras. Any form of data aggregation has to be decided separately for each airport according to the specific airport layout. In the framework of this paper an overall implementation could not yet be achieved (cf. chapter 5). This leads to the decision to exemplarily use the areas in front of the security controls due to their comparatively high frequentation. Like before, an interval of 1 min is chosen for updating and recalculation.

Left Behind Index

One of the most important quality parameters in baggage handling at airports is the so-called *Left Behind Index* (LBI). It expresses the percentage of baggage left behind compared to the sum of departed baggage pieces. *Left Behind* in this context means that the baggage couldn't be transported with the same aircraft as the passenger due to performance problems or disruptions in the baggage handling system. The $LBI_{baggage}$ is not implemented further in this paper because of a missing simulation environment as already mentioned above.

The LBI for baggage can also be transferred to passenger processes. Analogue to the $LBI_{baggage}$ the LBI for passengers expresses the percentage of passengers who missed their flight compared to the sum of all departing passengers. Departing passengers in this context are local passengers starting their journey at the respective airport and transfer passengers. Only passengers who missed their flight due to disruptions or delays during operations are considered for calculating the $LBI_{passenger}$. Therefore, passengers are not taken into account if they for example forget time while shopping and consequently arrive at the gate too late.

At present the LBI for baggage is calculated as percentage for one day. For purpose of steering actual operations this is not sufficient as this percentage can only be used for post-operational evaluation. Hence, the calculation of the $LBI_{passenger}$ cannot be transferred on a one-to-one basis, but has to be modified. During operation the change of the LBI is important to observe possible disruptions in process flows. So, not only the actual percentage is relevant but also the development of this percentage. Therefore, the $LBI_{passenger}$ is calculated as an average value over two groups of time horizons:

1. LBI 120/60/30: Average percentage left behind passengers compared to sum of departing passengers for flights of the last 120 minutes, 60 minutes and 30 minutes.

2. LBI 60/30/20: Average percentage left behind passengers compared to sum of departing passengers for flights of the last 60 minutes, 30 minutes and 20 minutes.

These time horizons are elected as a first step and can be changed dependent on the purpose of the implementing airport or the number of flights at the respective airport.

Utilization

Utilization describes in this context supply and demand of process stations. It is chosen as KPA to monitor efficiency of terminal resources and to counterbalance inadequate use of resources both for over- and under-supply. It comprises in parts aspects of the other KPAs, but offers a clear and easily comprehendible overview regarding resources. This allows for real-time decisions regarding the adaption of the number of process stations in service.

Passenger Volume vs. Capacity

A mismatch of passenger volume and available capacity will lead to long waiting queues and times (in case Volume > Capacity) or to unnecessary high costs (in case Volume < Capacity) together with all the respective consequences described before.

For the calculation of this KPI, passenger volume is described as the number of all departing and arriving passengers including any transfers. Capacity is in this case defined as the number of all process stations in service and able to fulfil the respective requirements (separate treatment for check-in, security, etc.). The KPI Passenger Volume vs. Capacity itself is calculated as the ratio of the two values. Needed data on the opening status of resources as well as on passenger volume should be available in the airport database. In regard to data aggregation the same methods as for the KPI Queue Length apply with the precondition, that the overall passenger volume is apportioned and assigned to respective resources. As the granularity of this KPI is lightly lower compared to the others, an interval of 5 min is chosen for updating and recalculation.

Economics

The economic analysis of activities and processes at airports plays an increasingly important role, as airports are seen to a growing extent as commercial entities with activities going beyond the provision of infrastructures for air transport. Besides the pressure to become more efficient in terms of resource use, airports lay a particular emphasis in becoming more attractive to passengers in order to maximize non-aviation commercial revenues. The economic valuation of terminal processes can help in this regard to use resources more efficiently and to provide better services to passengers. For the analysis of process efficiency, the calculation of costs and the monetisation of waiting times can provide an adequate framework, as shown in the following KPI.

Generalised Costs of Terminal Processes

Besides the physical parameters like queue lengths and waiting times, the Generalised Costs of Terminal Processes can be a valuable KPI for optimisation purposes. The perspective for this is a holistic one – we do not only bear in mind the costs incurred by the suppliers of the processes (airline, airport operator, public authorities), but also the costs incurred by the passengers being involved in the processes. Generally, we consider in our model three cost components: process costs incurred by aviation stakeholders for running the task stations, waiting costs for passengers and left-behind costs, incurred by operators due to passengers not processed in time causing departure delays or reaccommodation costs. The KPI is the sum of these costs, with the aim to minimize them. The calculation of the cost KPI requires as inputs the total waiting time of passengers KPI, which is then monetised with time cost per waiting hour. Total costs can be minimised when the additional costs incurred by the opening of additional task stations is less than the sum of monetised waiting times of passengers and left-behind costs.

Process costs incurred by aviation stakeholders include labour costs and the variable component of costs for the operation of a task station, such as check-in counter rental fees or electricity costs for the operation of a security lane. Fixed costs are not included here, as these costs are not relevant for the decision-making process in the operational perspective whether or not to open a particular check-in counter or security checkpoint, as fixed costs will be incurred irrespectively the opening times of the process station. In our model, we assume that the variable process cost component is proportional to the opening of a task station. For the exemplary calculation of the security process, we have assumed a variable cost component per hour of 150 € for running a security lane. While actual costs differ depending on wage levels, contractual arrangements with passenger handling service providers and airports, we have oriented this figure at actual costs for running security lanes at German airports.

Waiting costs of passengers are caused, because waiting in a queue incur time costs for the time that is not available for other activities and the discomfort of waiting. Theoretically, the monetary valuation of waiting times could be derived with stated preference studies asking for the willingness to pay to avoid e.g. a queue at the check-in counter. For this paper, we have relied on the existing literature, which provides some examples for the valuation of waiting time. Most studies analysing travel and waiting time costs (e.g. Abrantes and Wardman 2011) find that waiting time is valued higher than in-vehicle travel time. Moreover, it has been shown that the waiting time is valued differently depending on the length of the waiting period. Shorter waiting times are valued less per minute than longer waiting times. Finally, it should be noted that time valuation is dependent on trip purpose and income levels. Abrantes and Wardman (2011) have calculated a waiting time cost in public long-distance traffic of around 14 € per hour, applicable to the situation in the UK. Assuming that income levels for air passengers are higher than in railway traffic, we assume that waiting in line as compared to other activities available at the airport (working in an airport lounge, shopping or reading) could be valued with 20 € per hour. Generally, it should be noted that reduced waiting time at check-in, security and border control does only reduce overall travel time, when passengers arrive later at the airport. For a given passenger arrival pattern at the airport, the main short-term benefit is the reduction of the discomfort of being queued.

With left-behind costs we refer to the costs for the rebooking of passengers when they miss their flight due to bottlenecks in airport processes, such as check-in, border control or security. Left-behind costs will only be incurred in case a process station cannot handle all passengers until a pre-defined cut-off point is reached, after which departure delays would be caused. For instance, if passengers are queued at the security check-point and the scheduled departure time for an aircraft is reached, the airline has two choices: either departing without the passengers not yet on board or delaying the flight. In the latter case, costs incurred per flight are estimated by the University of Westminster (2011) at 72 € per minute on average, including airline costs and delayed passengers' opportunity costs. In the former case, airlines could avoid delay costs, at the expense of re-accommodating passengers to another flight and paying additional expenses such as hotel accommodation. In our model, we assume that any passengers left behind need to be re-accommodated, at the expense of 500 € per case, which includes hotel accommodation, new flight tickets and process costs.

5. PROTOTYPICAL IMPLEMENTATION

This chapter describes the deployed simulation environment and a prototypical implementation of the selected KPIs - as far as possible at the moment. The gained simulation data and analysis results allow for a first impression of the applicability of the defined KPIs.

Simulation environment

The microscopic simulator *TOMICS* (Traffic Oriented MICroscopic Simulator) was used as reality replacement in this research paper. The software allows the modelling of passenger movements with focus on airport terminals. A generic airport model forms the basis to map airport specific processes and the order of these processes to the simulation.

Only processes of the landside part of an airport are modelled at this point in time. The process chain starts with the arrival of a passenger at the airport. A specific distribution for each flight schedules the passenger arrival behaviour. The first step is the check-in process and consists of check-in counters or self-service kiosks. Passengers with online check-in are considered only for dropping off their baggage. To enter the security area, all local passengers must pass the security gates. As transfer passengers already arrive within the security area in this generic airport model, there is no need to pass security. In dependence on the flight destination a passport control is necessary. All landside processes of the airport are completed as soon as the passenger leaves the gate to enter the aircraft. Seating, ground control and taxiing are not part of this simulation. Baggage is considered till the drop off at a check-in counter. Further baggage processes are not part of this paper.

To concretize the simulation environment: the examined time horizon lies between 9 am and 6 pm, there are 104 departing flights for 7,175 local passengers and 1,049 transfer passengers, and 123 arriving flights with 9,816 passengers.

The demonstration of the KPI usage for airport management is carried out by two simulation runs with different settings. The baseline scenario considers a standard day with a strong disturbance. Much more passengers than expected will arrive at the airport in a shorter time. Disturbances in the land-landside connectivity for example may result in late arrival of passengers at the airport. Transfer passengers whose arrival flight is behind schedule might also cause a shift in the planned airport capacity usages. Within the simulation of the baseline scenario KPIs are measured but no management action is performed due to diverging values.

The optimized scenario does actively use KPIs for airport management. Disturbances are recognized early enough to initiate countermeasures to keep KPI values in an acceptable range. For example more security lanes can be opened earlier to reduce the upcoming peak of passengers.

Acquisition methods of necessary data

The aim for evaluation of a simulation run is a minute-by-minute calculation for each KPI. Each single minute airport sensor data (camera data, pass-by points) are exported by the simulation and evaluated by several tools to finally gain the KPI values.

The simulation model is built up by simulation rooms. Each room is observed by cameras that are able to locate persons. For each task station (check-in counter, security lane, etc.) in a virtual room one camera has been installed, but at least two and maximal 30 per room. The more cameras the more exact is the recorded position of a passenger. To ensure data privacy passengers are located anonymously, they are not identified or tracked. As the simulation holds the exact position of each person, a sensor simulation is first blurring and then exporting all recorded data.

Next to the cameras, the second important data sources are checkpoints where a passenger has to identify himself with his boarding pass. Thus, the number of passengers is known for those that are checked-in, have passed security or are boarded for a flight.

The location of passengers forms the basis for waiting queue or passenger density calculations. The tool *Queue Observer* determines the length of queues at each opened task station. The algorithm takes the current coordinates of passengers at the airport as input. At an airport positions of the passengers can for example be recorded by cameras installed at relevant points. As virtual simulation rooms are observed here, the known and exact passenger positions are blurred and recorded by the sensor simulation.

By using a greedy-algorithm the input data of the sensor simulation is evaluated. In a first step all recorded persons are assigned to exactly one task station. The minimal Euclidean distance (according to the simulation in a two-dimensional space) between the passenger and a task station is the decisive factor. In a second step the size of a queue in front of a task station is calculated. In doing so, the coordinates of a task station are taken as base-coordinates. The person with the minimal distance to these base-coordinates counts to the queue if the distance does not succeed a predefined value, the maximal gap. To examine further distant persons the base-coordinates are set to the last found person within this queue. If there are no more passengers within this maximal gap, calculations for this task station are done and the queue determined.

Table 2 – Overview over all defined KPIs and their implementation status (I=Implemented; D=Defined)

KPI	Short Description	Status	Data
Delay	Delay caused by landside processes.	D	• Refer to definition
Queue: CheckIn:T1-4	The maximum of the average queue size at flight or alliance related check-in counters at each terminal (T1-4).	I	• Task station queues
Queue:CheckIn	Maximum of KPIs Queue:CheckIn:T1-4	I	• Task station queues
Queue: Security:T1-4	The average queue length at security lanes at each terminal (T1-4).	I	• Task station queues
Queue:Security	Maximum of KPIs Queue:Security:T1-4	I	• Task station queues
Wait: CheckIn:T1-4	The maximum of the average waiting times at flight or alliance related check-in counters at each terminal (T1-4).	I	• Task station queues • Average process times at check-in counters
Wait:CheckIn	Maximum of KPIs Wait:CheckIn:T1-4	I	• Task station queues
Wait: Security:T1-4	The average waiting times at security lanes at each terminal (T1-4).	I	• Task station queues • Average process times at security lanes
Wait:Security	Maximum of KPIs Wait:Security:T1-4	I	• Task station queues
PaxDensity: Security:T1-4	Passenger density in the area around the security lanes.	I	• Measured passenger count in security area
PaxDensity: Security	Maximum of KPIs PaxDensity:Security:T1-4	I	• Measured passenger count in security area
LBI:120/60/30 **LBI:60/30/20**	Left behind index calculated as the average amount of passengers who missed their flight the last x/y/z minutes.	I I	• Passenger status • Flights (booked passengers)
Utilization	Utilization of airport resources.	D	• Airport resource capacity.
Economics	Generalised cost: sum of variable cost of operating task stations, time costs of queued passengers, costs for the re-accommodation of passengers left behind	D	• Task station queues • Task station opening times • Time costs for waiting, Operating costs of task stations

The queues can now be used for evaluation of the level of service at an airport. They can also be taken for decision support to open additional task stations or to close unused ones presumably reducing operating costs at an airport.

Finally all KPI calculations are performed considering the definitions in chapter 4. Some of the KPIs are calculated on terminal area level (check-in, security, and gate) and others are highly aggregated on airport level. Currently KPIs are calculated by using sensor systems only. In future work it is planned to integrate an airport prognosis tool that will allow a much earlier reaction on disturbances and with it the improvement of KPIs and airport management.

Analysis of simulation results

With the modelled simulation environment several simulation runs were conducted. As described above, the simulation contains two scenarios, firstly the baseline scenario (KPIs not taken into account) and secondly the optimized scenario (with KPI consideration. For each scenario three simulation runs were conducted in order to allow for statistic distributions (e.g. process times) given in the simulation environment. Afterwards average values are calculated for each minute of the reported KPIs for the two scenarios.

Figure 3 highlights exemplarily the two KPIs *Queue Length* and *Waiting Time* for the security in terminal T1 for both scenarios (without and with KPI consideration). All values are reported per minute and calculated as a 10 min floating average to smooth huge fluctuations. Figure 3 presents the development of both KPIs over the simulated day and it can clearly be seen, that knowledge about the actual development is very helpful for steering operations since passenger behaviour is very difficult to predict. Resources are planned on experience and past passenger behaviour, but slight changes can have a great impact on the actual utilization of available resources.

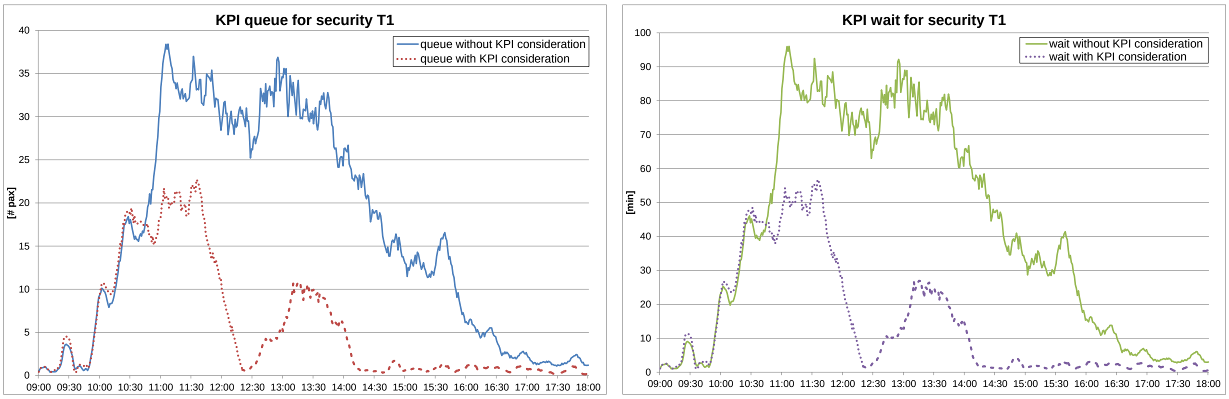

Figure 3 – KPIs queue and wait for security T1 (10 min floating)

Both KPIs, *Queue Length* and *Waiting Time*, show a significant improvement since appropriate actions are taken during the simulated day. In the simulated case the measurement implemented was an adjusted opening and closing of lanes at security controls. Regarding costs, this was not cost intensive, since the average number[4] of opened lanes over the day stays relative constant with a maximum of five in both scenarios.

Next to the queue and waiting time indicators all other implemented KPIs (cf. table 2) have been calculated and evaluated. For both scenarios, table 3 contains calculated statistic results of all KPIs for selected areas (terminal T1, T2 and the maximum value of all areas of the respective KPI). For statistical analysis, the average and standard deviation is depicted as well as the maximum value occurring over the whole day. Next to the results of the scenarios, the percental improvement of the average value is depicted. For example, the KPI

[4] On average there were 3.42 opened lanes without consideration versus 3.66 opened lanes with consideration.

Queue Length of security T1 is reduced by 66 % compared to the scenario "without KPI consideration".

Table 3 –Results of KPIs for selected areas for both scenarios

		Without KPI consideration			With KPI consideration			Improvement of Avg. [%]
		Avg.	Dev.	Max.	Avg.	Dev.	Max.	
Queue check-in [# pax]	T1	1.93	2.53	10.67	1.93	2.63	11.00	
	T2	2.33	3.00	11.33	2.44	3.22	11.33	
	all	6.21	5.14	31.00	6.29	5.51	31.00	
Queue security [# pax]	T1	16.34	13.64	49.67	5.58	7.23	27.67	66
	T2	5.13	6.72	40.67	3.11	2.80	16.00	39
	all	18.11	13.12	50.11	9.60	7.91	30.00	47
Wait check-in [min]	T1	1.73	2.28	9.60	1.73	2.37	9.90	
	T2	2.10	2.70	10.20	2.19	2.90	10.20	
	all	5.59	4.63	27.90	5.66	4.96	27.90	
Wait security [min]	T1	40.86	34.10	124.17	13.96	18.08	69.17	66
	T2	12.81	16.81	101.67	7.78	7.01	40.00	39
	all	45.27	32.81	125.28	23.99	19.77	75.00	47
Density Security [# pax/m²]	T1	0.10	0.09	0.31	0.04	0.05	0.21	57
	T2	0.18	0.18	0.98	0.13	0.10	0.44	24
	all	0.19	0.18	0.98	0.14	0.10	0.44	28
LBI 120/60/30 [%]		5.39	4.73	19.09	3.59	4.09	17.44	33
LBI 60/30/20 [%]		5.11	4.74	19.09	3.37	4.01	17.44	34

It can be seen that the check-in area was well planned, since the KPIs show acceptable results and no actions become necessary. Slight changes between the scenarios arise from statistic distributions given in the simulation environment.

Concerning the KPI *Costs*, we find that the consideration of KPIs for terminal processes results in substantial benefits for passengers, as the generalized time cost for waiting at the security check in comparison to the situation without KPI consideration is reduced by almost 50 % (from more than 103,000 € to 55,000 €). This is achieved by a better planning of security lane opening times and comes only with a very small increase in variable costs for the longer opening time (2 hours) compared to the situation without KPI consideration. The result also shows that even when a much smaller value of time for waiting than the 20 € per hour used in this study will be applied, economic benefits can be reached when airports increase the efforts to reduce waiting times of passengers. From the airport management perspective, not only the increase in process costs should be considered, but also the revenue potentials for airport retailing and food and beverage services, when passengers save time in the terminal processes and feel more comfortable.

Concluding it can be assessed that the simulation environment was appropriate to calculate KPIs. Nevertheless, more simulation runs will be needed for a broader statistic basis, even though an enhancement of derived results is conceivable.

Table 4 – Results of KPIs for selected areas for both scenarios

	Baseline	Optimized
Total Security Lane Opening Time [min]	4,570	4,690
Variable Costs of Security Lanes [€]	11,425	11,725
Avg. Waiting Time Security [min]	45.3	24.0
Passenger Throughput Security [Pax per day]	6,872	6,885
Total Waiting Time Security [min]	311,075	165,211
Total Waiting Cost [€]	103,692	55,070
Total Cost of Security Process (Time Costs and Variable Process Costs) [€]	115,117	66,795

6. EXPECTED BENEFITS AND RESULTS

The introduction of KPIs as steering mechanism for landside operations has the intention of enabling enhanced situation awareness and thus improving overall terminal performance. By providing decision-makers with real-time and forecasted information on deviations from the aspired course of events, they can use this knowledge to set priorities, make the most appropriate trade-offs, choose the right solutions and perform optimum resource allocation (ICAO 2009).

In chapter 5 a description of the implementation of five of the nine introduced KPIs was presented. For the present, it is only a first prototypical implementation and not all planned KPIs can yet be calculated. Slight adaptions had to be made due to data unavailability and the forecast of KPIs is not yet operating. Even though, the results are very promising regarding the expected benefits stated above. The KPIs clearly display the situation in the terminal and if compared to standard values indicate deviations from normal operations. The simulation results also show that if airport operators use the knowledge gained with help of the KPIs and actively interfere in on-going processes to keep the KPI values in a normal range, overall performance improvements can be gained.

Based on these first simulation runs, it can be assumed that by integrating the rest of the selected KPIs and especially by adding the forecast the results can be further improved (Urban 2012). With the presented KPIs covering all major aspects of terminal processes it is expected to gain benefits for the overall system performance but also for all stakeholders involved. Taking the idea of landside KPIs even one step further and combining them with airside ones, e.g. in the context of Total Airport Management, additional advantages can be expected (Depenbrock, 2011).

Next to placing this work into a bigger context, several other aspects could be analysed in future research projects in regard to improving the KPI approach. With data quality and availability increasing constantly, new forms of automatic data provision should be examined. The now defined KPIs are formulated in a general manner so they can be applied at any airport without major adaptions. For reasons of revision and possibly of additions to these KPIs, an implementation at very specific airports should be undertaken.

Concluding it can be assessed that by applying KPIs as steering mechanism in airport management a transition to active performance-based operation becomes possible. Instead of reacting after deviations from the operational plan have already occurred, forecasted KPI values allow for enhanced situation awareness even before anything has happened hence enabling early action. The magnitude of unplanned incidents and their implications on other airport processes can be reduced and overall performance can be improved.

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