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SIMULATING A MULTI-AIRPORT REGION TO FOSTER INDIVIDUAL DOOR-TO-DOOR TRAVEL

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ABSTRACT

Airports are intermodal hubs and natural interfaces between ground transport and air transport. In the current DLR project “Optimode.net”, an innovative approach is being developed to extend the management of an airport not only to airport landside and terminal processes but to go even further and incorporate feeder traffic in the management of airport processes. Thus providing travelers with a real door-to-door service and letting airport stakeholders benefit from efficient airport management.

Technical core of the project is a simulation environment consisting of nine different simulation models with various simulation methods and abstraction levels. In this paper the simulation environment of a multi airport region which is used in the Optimode.net project will be described in detail and also the interaction of the different simulation modules will be explained. We will also show how this complex simulation environment is used to foster individual door-to-door travel and proactive airport management.

1 INTRODUCTION

Airports are not just places where airplanes land and take-off but they are also natural interfaces between ground transport modes and air transport. In the door-to-door travel chain it is not sufficient to just focus on a small part of the journey. Attention must be paid to the interlinking of transport modes in different phases of the journey. In recent years substantial improvement could be generated in the field of airport management especially for landside and terminal processes. Concepts like A-CDM (Airport Collaborative Decision Making) (Eurocontrol 2006) and TAM (Total Airport Management) (Eurocontrol and German Aerospace Center 2006) show tangible potentials of improving efficiency and punctuality.

In the current project called Optimode.net (Optimode.net 2017), an innovative approach is being developed at the German Aerospace Center (DLR) to extend the concept of A-CDM and TAM not only to airport landside and terminal processes but to go even further and incorporate ground transport feeder traffic in the management of airport processes. Thus, the traveler gets a real door-to-door service and a reliable travel experience whereas airport operators and airlines can benefit from a more appropriate and efficient resource management using forecast and what-if capabilities (Milbredt, Grunewald and Rudolph 2017). In the Optimode.net project a research prototype system is developed to examine the optimization potential of airport operations by utilizing the Passenger-Trajectory (Milbredt, Grunewald and Rudolph 2016). The Passenger-Trajectory (see also section 3.1) puts the individual passenger into focus by monitoring and supporting the individual door-to-door journeys. To enable a real door-to-door service to passengers, feeder traffic information is included in the airport management. This is an important progress compared to earlier research prototypes (Helm et al. 2014).

In this paper we focus on the simulation environment that builds up the virtual multi airport region in the Optimode.net project. This simulation environment builds the full scale substitute for a real operational airport environment. The simulation is the base for researching the possibilities to foster individual door-to-door travel and proactive airport management. It is expected that the features of the Passenger-Trajectory will improve airport managers' situational awareness of current and future airport processes including the passengers' status more comprehensively.

Figure 1 shows the virtual multi airport region serving as the base structure for the simulation. There are the three city's A-Castle, B-Field and C-City being interconnected via road and train. A-Castle represents the largest city with over 1 million citizens and an international hub airport. B-Field has about 250.000 citizens and a small regional airport. C-City has about 500.000 citizens and a medium-sized international airport.

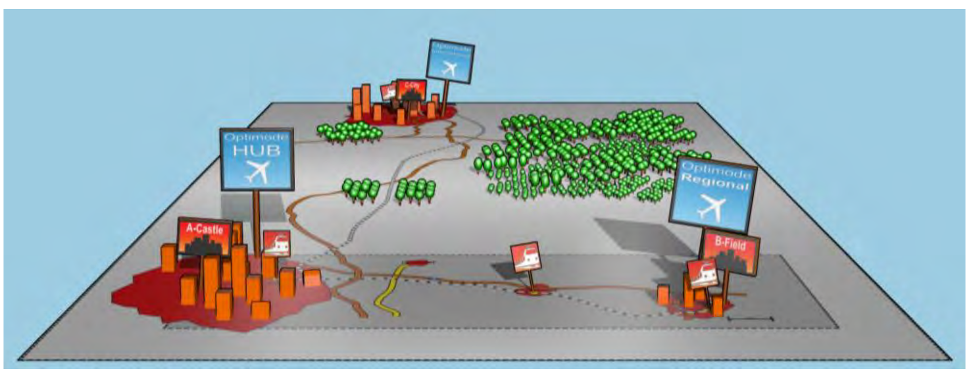

Figure 1: The virtual multi airport region of Optimode.net

2 SIMULATION OF A MULTI-AIRPORT REGION

The main scope of the following description comprises the different simulation models and the kind of simulation methods used to create this multi airport simulation including feeder traffic. Depending on the abstraction level we use a range of simulation methods from Discrete Event, Agent Based and Excel Calculation to Hybrid Simulation models.

To provide a global overview of the whole simulation in Optimode.net, the overall system architecture is described first.

2.1 System Architecture

Figure 2 depicts the modular system architecture as a whole. This modular design for the overall system as well as for each tool has been chosen to allow flexible changes of single functionalities and hence the system behavior. This enables system validation in different modes and from different perspectives of stakeholders. As there are three different institutes with differing core expertise and locations collaborating in the project the modular design also allows for flexible and independent testing and development.

The system architecture is divided into three main tool clusters. The first tool cluster is the simulation environment that is the substitute for a real operational airport environment. If the Optimode.net project will succeed and gets implemented into the real world, this tool cluster will be replaced by real airport operational data. The simulation environment cluster contains the distributed simulators for the railway system / public transport and simulators for each airport in the modeled cities that build up our Distributed Virtual Environments (DVEs) (Fujimoto 2000). The airport simulators in each city are again differentiated in airport landside and airport airside modules. All Simulators in this clusters run in real-time execution in lockstep with wall-clock time and with a scope of one day of operation (Perumalla 2006). Each simulator runs on a different machine. The details of each simulators will be described in detail in the next sections. The second tool cluster is the Optimode.net Toolsuite with the different tools that are needed for enabling a proactive passenger management (see section 3.2). The goal of the Toolsuite is to provide the airport operator with an early situational awareness, decision support and an efficient resource management. Highlights of the Toolsuite (see section 3) are the simulation based what-if probing and the forecast.

The third tool cluster is the Integration Environment with the central MySQL Optimode.net database. This cluster cares for connecting the Simulation Environment with the Toolsuite as well as for synchronizing, exchanging results and for interactions within the overall simulation.

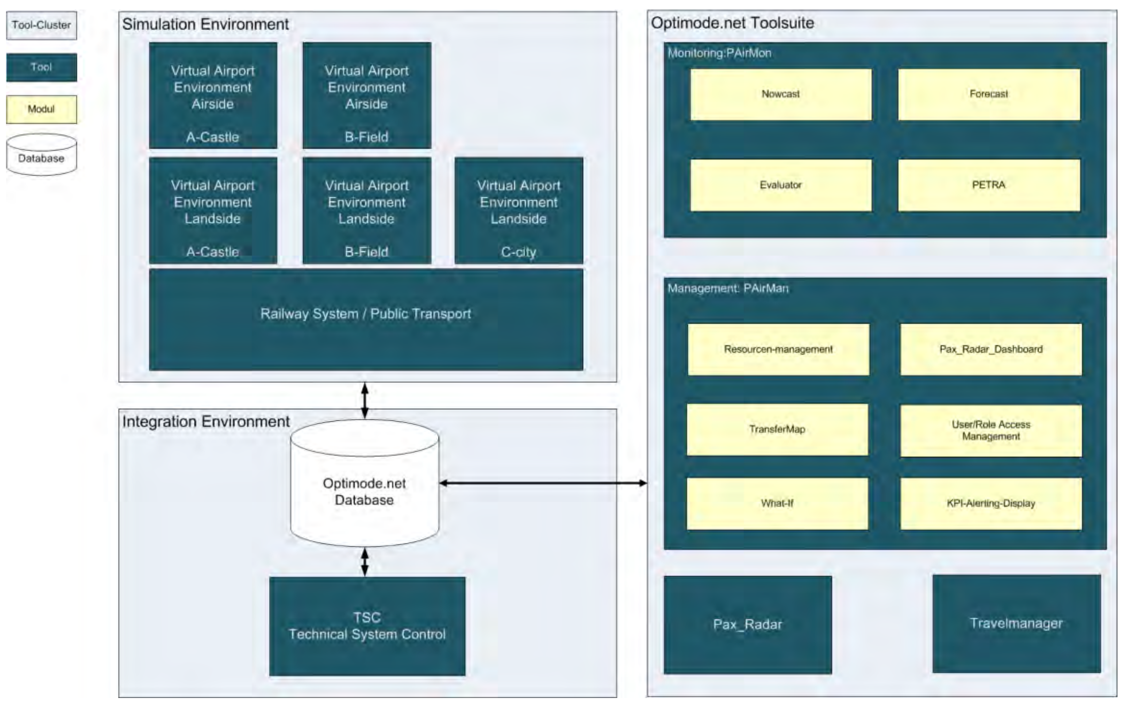

Figure 2: Optimode.net System Architecture

The Optimode.net database contains all necessary master and dynamic data as well as system parameters and resulting data of the single modules. Master data is a fixed set of data that will not be modified during a system run and contains e.g. details about worldwide airports, airlines and aircraft.

The dynamic data is structured in scenarios that specify the behavior of a system run. A scenario is described by its schedules for flights, public ground transport and process points. Additional information is provided concerning in- and outbound connections of transfer passengers. As process points must be operated by personnel a human resources pool is also part of the database. The Technical System Control (TSC) tool controls information about the active system run and creates also timestamps to synchronize the system modules. The latest timestamp that is distributed to the central database is used to synchronize the modules to that time barrier. Also each single modification of the schedule is tracked by the TSC to allow detailed reconstruction of events and their impacts on the entire system.

2.2 Airport Simulation Landside

One of the main research areas of the Optimode.net project is the large international hub-airport of A-Castle. The term “landside” is defined as the area where a passenger enters the airport until leaving it through the gate into the aircraft or vice versa. The simulation model for A-Castle can handle 40-60 million passengers per year, up to 400.000 flights and two terminals. The airport simulation of B-Field can handle 192.000 passengers and 35.000 flights per year. C-City airport has a passenger volume of approximately 16 million passengers per year distributed over some 160,000 flight movements.

All airport landside simulations are created with the simulation software Anylogic. Anylogic is a multi-methods simulation software that supports system dynamic, discrete event and agent based modeling. It is also possible to mix these simulation methods within one model.

To have a detailed abstraction level as reality replacement and development environment, the airports of A-Castle and B-Field are modeled with the microscopic pedestrian simulation and social force model of Anylogic. The Anylogic’s Pedestrian Library is tailored and extended for specific needs of the simulated airports. Refinements for example are applied to the queue selection algorithm for the security lanes as well as to the simulated passenger behavior in the waiting queues and before the security checks. Anylogic’s standard algorithm, in which passengers only choose once upon arrival the queue with the smallest number of actual waiting passengers, is not sufficient in this case. The algorithm is augmented by an additional check considering which queue is closest to the passenger if queue lengths of the queues in choice only differ by a small amount. To also cover the situation where queue lengths develop differently after a passenger already has chosen a queue, every 3 simulated minutes and when a new queue opens, the simulation checks for each passenger whether there is a “better” queue in that sense. Depending on distance and queue length the passenger may then even opt to change the queue as can be observed in real life (Jung, Classsen and Rudolph 2015). Figure 3 shows a screenshot of the simulation of the security area in terminal 1 of the airport in A-Castle. The airport of C-City is only used as a feeder airport. Therefore, the airport is modeled in a higher abstraction level using an event-based model. There are also higher abstraction event-based models of the airports A-Castle and C-City that are used in the forecast and what-if simulations to gain higher computational performance (see section 3.2). The results of the simulation are stored in the Optimode.net database. Before writing the results, a fuzzy filter is implemented to reduce precision of the full digital simulated system to a level of diffuseness you would gain with today’s sensor systems in a real airport environment. Thus the management tools “know” where people are located at the airport but cannot identify persons individually, unless this person passes a checkpoint, thus providing identification. Vice versa changes in the real world are passed to the ideal simulated world, thus allowing for active and dynamic airport management as in real life.

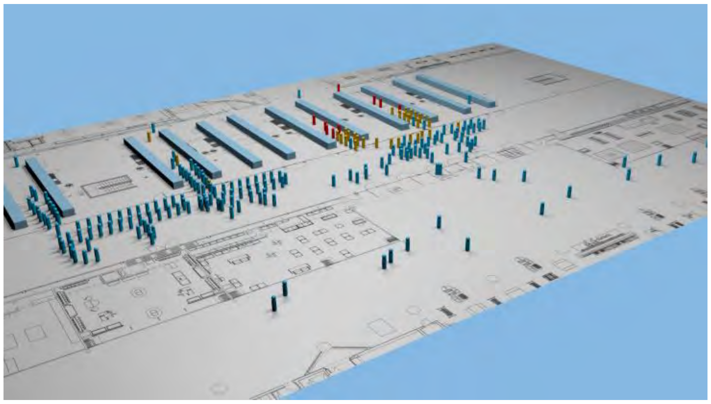

Figure 3: Simulation of security area (A-Castle)

All simulation models have the capability to react on changes during runtime. The changes are performed via the management tool PAirMan (see Figure 4). Changes are stored in the database where the simulation models can receive relevant updates. By selecting a flight the user is able to change the target off-block time by moving the right end of the bar graph representing that selected flight. To switch the gate position, the operator can drag and drop a flight to a new gate row. The user has also the possibility to change resources like check in counters or security lanes including their respective staffing.

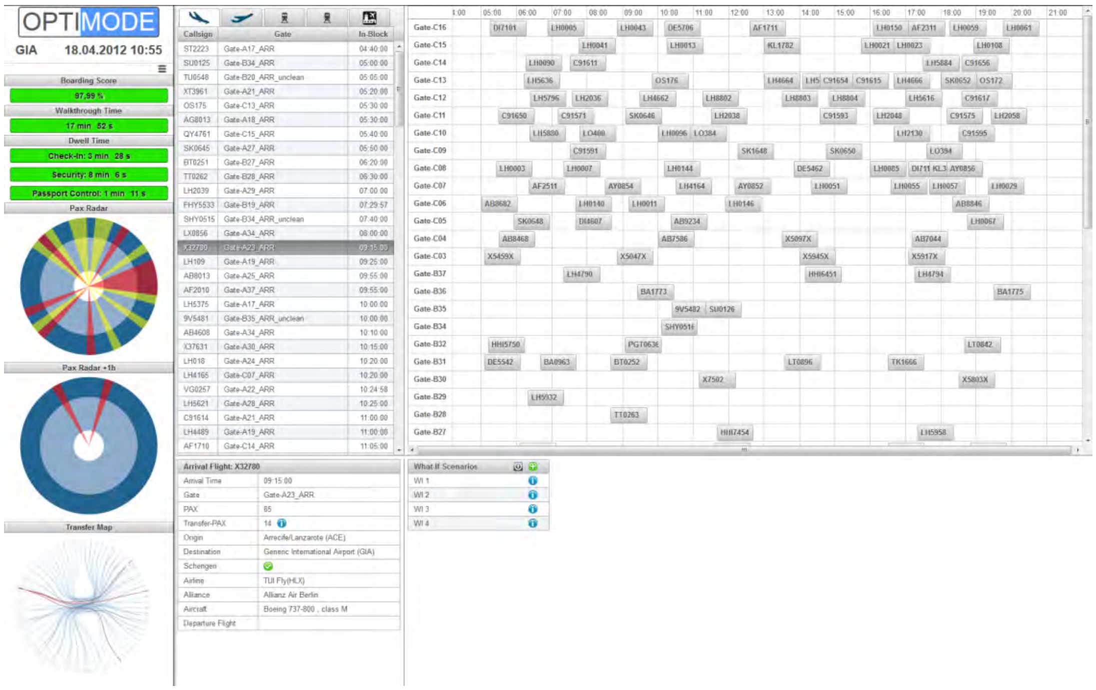

Figure 4: Graphical user interface for PAirMan

2.3 Airport Simulation Airside

The main focus of the Optimode.net project are the airport landside with terminal processes and the public transport feeder traffic. For that reason the airport airside aspects in this environment are a simple simulation representing a realizable sequence of take-offs and landings. Depending on the flights wanting to start or land a sequencer periodically creates a sequence subject to the operational capacity of the runway system on a first-come-first-serve basis. Insufficient ground capacities at the runway or apron, e.g. available parking positions, or for turn around processes could lead to delays on airside. Due to the focus of the planned scenario, the airside capacities were set to a non-limiting but realistic amount having a temporal progress over the day considering the expected demand. Thus, the traffic on the airside is plannable over the whole scenario timeframe. This sequencer is part of DLR's Total Operations Planner (TOP). Furthermore, the TOP includes functionalities to perform What-If-Probing, to create performance indicators for a better situational awareness, and supports an airport stakeholder negotiation to find the best solution to cope with severe traffic situations.

Depending on the time in the scenario, different reliable timestamps exist on the airside: scheduled, estimated and actual times with increasing accuracy to calculate the expected demand. The schedules are defined in the flight plan of the scenario. The other timestamps need to be created within each simulation run to represent the actual traffic and planning situation, respectively. In our combined airside-landside-simulation we defined the following timestamps:

- estimated in-block time (EIBT): the flight is expected to be at the parking position and landside activities can start, e.g. de-boarding of passengers
- target off-block time (TOBT): the flight should be ready to go off-block; all turnaround processes are finished, including boarding.

These times are created from the sequencer and send to landside as constraints from airside.

EOBT (estimated off-block time) is a third timestamp and is provided by landside process management and sent to airside as the earliest time the flight will be ready. The TOP takes this time and on that basis suggests a new TOBT which is as close as possible to the EOBT.
To create the actual timestamps of the traffic process like in-block and off-block times, an additional functionality simply sets the latest planned times to actuals. Other airside operational constraints, e.g. runway closure or delay of traffic can also be defined in the scenario data.
The sequencer described above could efficiently be implemented by utilizing MS Excel-Sheet formulas connected to the Optimode.net database. This was the most efficient way to extract the necessary functionality and keep the airside system slim and flexible. For the airside simulation in this context it is not needed to simulate in depth real traffic behavior as timestamps are sufficient.
For our simulation environment the sequencer is needed for two airports (A-Castle and B-Field). The Excel-file was therefore parametrized individually with the specific runway capacities. To support scenarios with traffic diversions, flights can be cancelled at one airport and will be added to the demand of the alternative airport with new estimated times.

2.4 Public Transport Simulation

The public transportation simulation component covers the simulation of ground level public transportation to model incoming and outgoing passengers by buses and trains to and from the airports. Furthermore, as a regional area is considered in the simulation scenario, a train could be considered to replace a feeder flight between the local airports under certain circumstances to analyze the impacts. For communication with the Optimode.net environment the Optimode.net database contains all the scheduled public transport connections. Besides the scheduled time for the connection, the estimated, targeted and actual times are foreseen and provided when available.
For simulation of the buses and trains the SUMO (Simulation of Urban Mobility) (Krajzewicz 2012) environment is used. SUMO is a microscopic, space-continuous and time-discrete traffic flow simulation, which is distributed as free software licensed under the GPL.
SUMO can be run purely from the command line. For convenience and visual feedback a Graphical user interface (GUI) has been implemented to visualize the current scenario as shown in Figure 5. In the bottom part of the figure a bus stop with an approaching bus (big yellow rectangle) can be observed.

Figure 5: GUI of SUMO showing a bus stop with an approaching bus

SUMO is purely configured by a set of XML files and also generates the output as XML files. This allows for running SUMO in a completely automated environment. For Optimode.net a dedicated component “Optimode.net-SUMO-Adapter” was implemented to run SUMO as required by the entire simulation as well as to feed SUMO with the right input and write results back into the Optimode.net database. The input files for SUMO include i.a. the traffic network and the vehicles with their routes and scheduled stops. Besides several other information the simulation generates the actual performed stops of the vehicles as output. Moreover, the traffic simulation can be halted at any time to dump the current simulation state into a file and continue later again. The adapter uses this feature intensely to calculate forecasts and then jump back to the current simulation time. In a later stage of the project this feature will be also used to calculate different What-If scenarios to analyze the impacts of decisions of the virtual airport management.

In case of a request by the virtual airport management to adapt the target time of a public transport connection, this can be applied easily by the adapter. Should the vehicle not yet have started, just the scheduled stops are adapted and the simulation is continued. If the vehicle has already joined the simulation, the dump file of the current state is adapted accordingly. Finally, synchronizing the actually performed stops from the SUMO files with the database is done by the adapter after each simulation cycle.

3 FOSTER INDIVIDUAL DOOR-TO-DOOR TRAVEL IN PROACTIVE AIRPORT MANAGEMENT

Modern airport management requires a more holistic approach to the whole travel chain and aims at a better situational awareness of airport landside processes and an improved resource management. Main keys to this are a proactive passenger management (Classen and Rudolph 2015), capitalizing on the Total Airport Management (TAM) approach. Unlike common passenger management’s reactive approach, a proactive passenger management utilizes an early knowledge about the passengers’ status and the expected situation in the terminal along with resulting system loads and resource deployment. An appropriate and modern management compatible with the TAM approach will also be considering dependencies of airside and landside operations as well as costs and performance.

Proactive passenger management means an operational approach where the management and control of airport terminal infrastructures, services and passenger processes are conducted based on knowledge about the dynamic system status more in advance. Today passenger management at airports is rendered on an ad hoc basis (Helm et al. 2014). Apart from planning ahead based on experienced data during the weeks before the actual day of operations and some last adjustments the day before there is only little knowledge about the actual situation to be expected. Therefore, current passenger management can only react. Proactive Passenger Management, however, will act rather than react.

3.1 Passenger-Trajectory

To incorporate the door-to-door travel chain of the individual passengers into the operational airport management, a concept was developed by DLR, introducing the “Passenger-Trajectory” (Milbredt, Grunewald and Rudolph 2016). The Passenger-Trajectory takes up the principles of the trajectory based operations concept developed in the SESAR initiative (SESAR 2007) and puts the individual passenger at the center by monitoring and supporting the individual door-to-door journey. The introduction of the Passenger-Trajectory concept optimizes the movement of passengers in time and space by taking into account the constraints imposed by ground transport and airport schedules (i.e. rail arrival times, aircraft departure and arrival times) and the desirable departure and arrival times of the passengers from/to their origin/destination.

The Passenger-Trajectory defines the 4-dimensional points in space and time during the passengers’ travel chain for each individual traveler. This will require disclosure of travel plans by the traveler. In return he or she could receive more precise and reliable information about changes in schedules or interruptions. Moreover, the passenger can even be provided with a real-time connection management via an automated interface, e.g. via a mobile device. However, disclosure of private travel data might still be a concern to travelers. Therefore duly handled privacy schemes are crucial along with an edit value for the passenger in order to achieve such voluntary disclosure.

Figure 6 shows a schematic illustration of the Passenger-Trajectory. The Passenger-Trajectory is initialized with scheduled times within the process chain and provides and monitors target, estimated and actual times accordingly. This is in analogy of the Milestones Approach defined in the A-CDM Implementation Manual (Eurocontrol 2012). The system uses real time integrated information and short term prediction regarding the actual airport flight schedule, the travel time of the various modes and the terminal processing time (i.e. time spent at the terminal to go through check-in, passport control, security check etc.). The scheduled times are available e.g. from reservation details and historical observed patterns (Gelhausen 2009), whilst the updates of actual times can be collected from geolocation data of passengers' mobile devices combined with real time data from transport operators (for example passing the check-in desk or entering the security area), thus allowing the calculation of accurate actualizing estimated times. The real time data from the transport operators can also be used for passengers who don't want to share their data for an indirect tracking. Such information services are voluntarily for the passenger but will be of added value both for the passenger, who will be able to optimize the journey in terms of time and travel experience, and for air transport stakeholders and transport operators, who will be able to optimize the use of resources and offer improved services to the passenger.

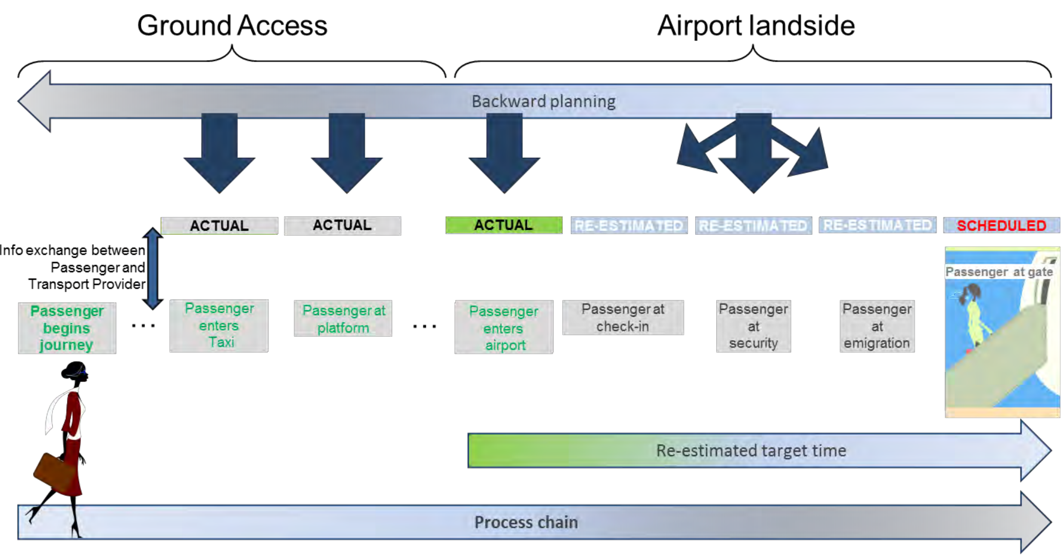

Figure 6: Principle of the Passenger-Trajectory

3.2 Proactive Passenger Management – Forecast

Proactive Passenger Management is a concept where planning and control of the terminal processes are facilitated by a decision support system that provides a situational awareness not just of the actual moment but also about the expectable future of the actual day of operations (Claßen and Rudolph 2015). For this purpose DLR developed a forecast system that provides the operations management staff with information about

- actual and future status of the passenger flow
- passengers' waiting times
- passengers' timeliness at the gate
- calculated passenger trajectory milestones.

This forecast calculates an estimate of the number of passengers who reach the gate at a certain time. Ideally, this time should be set x minutes prior to the off-block time of the flight. In addition, the forecast calculates a time where all passengers reach the selected flight subject to the actual and expected situation at the airport (e.g. actual number of passengers on flights and in building, delayed incoming flights, resource availability, gate changes etc.). This time was introduced by (Helm et al. 2014) as a new milestone called "Estimated Passenger at Gate Time (EPGT)" and helps determining a reliable off-block time (EOBT) at an early point in time prior to a flight's departure.
The forecast functionality described above can be enriched with the sampling points of the Passenger-Trajectory (e.g. via mobile devices or stationary sensors) resulting in more accurate feedback about the actual status of each passenger. In addition this real time information can be used for an improved short term prediction of the airports' future situation (see Figure 7). This in turn enables an airport management system to control processes and resources more appropriate.
The forecast is modeled with the network simulation of Anylogic. The Anylogic's network Library is tailored and extended for specific needs of the simulated forecast and to gain higher computational performance. The forecast is designed as modular construction system for recurring elements and runs in an endless loop in a fast-as-possible execution. The forecast needs about one minute to complete a simulation run over one day of operation.

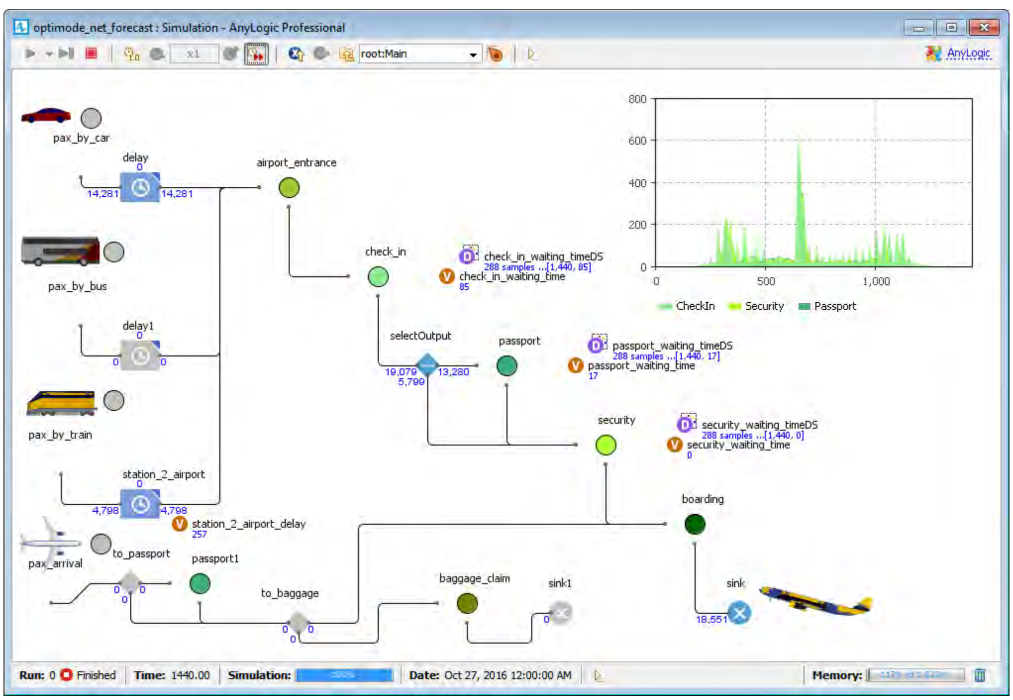

Figure 7: Part of the forecast simulation including a diagram of waiting passengers

3.3 What-if

An airport is a multimodal transport hub and as such a complex system with various stakeholders. It is hard to estimate the impact of any action performed by one of the stakeholders on the whole system. An action with positive effects for one field of responsibility can at the same time deteriorate the overall system performance. For that reason a common data basis has already been introduced to provide comprehensive situational awareness to all stakeholders involved. The system provides an advanced capability of so called what-if calculations to predict possible effects of a decision before implementing it in reality. By this means all stakeholders can estimate the impact of that decision on their own field of responsibility and on the overall airport in advance – thus consequently implementing the TAM concept. This calculated information is a profound basis for decision support. But according to empirical cognition airport practitioners as potential users of this software shall always have the last power of decision (see Milbredt, Grunewald and Rudolph 2017).

Technically a procedure had to be implemented by coordinating several steps of calculations of different tools. In addition a comfortable user interface has been designed which is depicted in Figure 8. First a user has to create a new what-if scenario by defining a scenario name and description and by adding it to the list of scenarios. Alternatively the user can select an existing scenario thus switching the complete user interface into the what-if mode. Unlike the default mode in which actions are directly implemented in the system, the what-if mode at first only stores all proposed actions as events in the selected what-if scenario. A scenario can consist of one or more actions such as a gate change or intentionally delaying a flight.

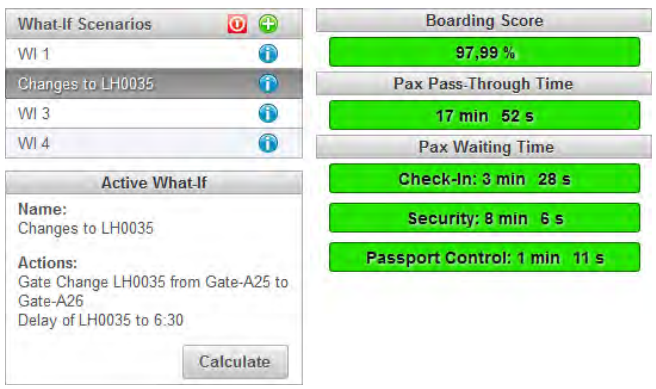

Figure 8: Definition and evaluation of what-if scenarios

As soon as a what-if scenario has completely been defined with one or more virtual actions the user can start background calculations. The first step of this procedure is the creation of a data snapshot. As a lot of data tables are static and thus not affected by what-if functionality only relevant dynamic data is cloned in order to avoid interference of the operational system. Some examples of such dynamic data are the scenario flight plan, the train schedule, the operational plan for airport process points and details of the involved Passenger-Trajectories. To finalize the first step the proposed actions have to be applied to the set of data, together forming the definition of the what-if snapshot.

In a next step two forecast calculations are processed. The first forecast is an agent and network based simulation model. It takes the current airport situation as basis and adds all actual changes of the flight and train schedules and of the operational plan for the different process points. The first output of the simulation is a timestamp for each flight estimating the arrival time at the gate (EPGT) of at least 95% of the booked flight passengers. The second output is a matrix containing the estimated average time in minutes needed to reach nodes in the Passenger-Trajectory over the day. For example the time needed to walk from a check-in counter to the security check is stored in this matrix for each five minute steps over the whole day. Longer waiting queues will thus result in longer point-to-point transit times.

The second forecast is a scheduling software focusing on the Passenger-Trajectory. For each passenger it stores a list of scheduled and actual timestamps und calculates estimated times for further nodes in the trajectory. A new forward calculation is required if there are any changes either in the actual passenger process, e.g. by passing a process point or other node, or in the operational airport environment, e.g. increased or decreased waiting times, gate changes etc.

In the final step the what-if scenario must be evaluated. All KPIs displayed in the real time management system are also determined for the what-if scenario. An alerting mechanism evaluates the indicators and prepares the display for a comparison between the real system and the what-if scenario. Therefore any indicators' improvements or deteriorations are highlighted to all stakeholders. This aggregated and common view of a possible future scenario can then be used for a joint evaluation and decision making between the stakeholders.

The system is designed with modular expandability and can be used together with knowledge-based systems. Such knowledge-based systems can be used for system recommendations and refinements. Nevertheless, the user shall have the last power of decision.

4 CONCLUSION

In the underlying paper the simulation environment that builds up the virtual multi airport region and modern concepts of proactive airport management are described. Key elements are the inclusion of ground transport systems and the introduction of the Passenger-Trajectory to foster individual door-to-door travel along with forecast functionalities. For this purpose a simulation environment was built that is the base for researching the possibilities of proactive airport management. Also an integrative management tool is being developed, designed to foster common decision making of the different stakeholders at the airport. By its features the system is expected to support airport operational managers in gaining a common situational awareness supported by multifaceted alerting mechanisms and an appropriate degree of information details. Additionally the management tool provides possibilities to proactively control the airport and to pre-evaluate potential actions by simulating what-if scenarios.

Building upon this, the management tool and the simulation environment offers a profound basis for future validation research in order to substantiate the system's benefit. As mentioned above, there are further ideas to improve and extend the management tool. These improvements include for example a detailed view for Passenger-Trajectory data.

With these improvements in place, an in-depth investigation of the system benefits is envisaged. This will i.a. be performed by comparing the results of specific validation scenarios with and without the Optimode.net management system. This shall be conducted with real life airport practitioners from different stakeholders, thus bringing in their perspective, expertise and judgement. First test runs with DLR personnel in the roles of the different stakeholders involved in reality already showed positive potentials and further opportunities for improvement in detail (Milbredt, Grunewald and Rudolph 2017).

One very thrilling question is whether and at what point a stakeholder will be able to proactively control a given situation together with other stakeholders with Optimode.net. As introduced with the Total Airport Management concept, this paper advances the idea of data sharing and real collaborative decision making between different stakeholders. The early situational awareness of the status throughout the whole transport hub allows all stakeholders to act in advance instead of react. Thus, applying modern airport management and fostering individual door-to-door travel.

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