Feasibility of traffic prognosis for an Airport Operation Centre

Initial results of a field study

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Abstract—**Airport Operation Centres are one conceptual solution to optimize airport performance. This paper presents initial results on the feasibility of this concept. The focus is on an automated prognosis of the traffic situation. An approach for the evaluation of such a concept is presented. Whilst the analysis of a sample of real airport data revealed a need for input data with a higher quality, operators rated the concept of traffic prognosis as feasible. The results indicate the potential of this concept. Nevertheless, future research should focus on empirical evidence, that a reliable, accurate and useful traffic prognosis can be created in order to allow for performance based airport management.**

Keywords: airport operations, collaborative decision making, performance prognosis, concept validation, human factors

I. Introduction

Within the air traffic management (ATM) system, airports are a major bottleneck. Key performance indicators, like punctuality, efficiency as well as passenger comfort are directly influenced by the operational processes of an airport. In the future ATM system, airports will be measured against these key performance indicators (KPI), for instance punctuality. Therefore, several concepts aim at improving the operations at an airport from a holistic point of view. This paper reports research on the operational feasibility of a concept, which uses the prognosis of the airports traffic situation as a basis for decision making processes at an airport. Beside all commonalities of the ATM systems worldwide, each has unique properties that shape those holistic concepts. Therefore, the concept described within this paper was developed to meet the properties of the European ATM systems. For instance, within this system lower airspace responsibility in air traffic control is divided between the national ANSPs. For the upper airspace Eurocontrol assumes partly responsibility. Furthermore, the airport as a stakeholder is often responsible for processes within the terminal and on the apron.

A. Concepts for improving airport performance

Airport collaborative decision making (A-CDM) was developed and promoted as an operational concept by Eurocontrol [1]. This concept aims at providing more accurate and reliable data concerning the target departure times of aircraft to utilize slots more efficiently and also enable a better planning and allocation of capacities in the air space. The concept of system wide information management (SWIM) is one important technical enabler for this approach [2]. Goal of SWIM is to ease the sharing of high quality information between ATM operators by developing a more flexible communication infrastructure. At an airport, this information is distributed and stored within the airport operation database (AODB).

To expand the approach of collaboration at the airport further, the operational concept of Total Airport Management (TAM) was developed [3]. Through optimization programs the capacity and efficient use of the European airspace increased in the past (e.g. Single European Sky) shifting the focus to new bottlenecks on the ground, the airports. Therefore, TAM focusses on optimizing the airport processes for a pre-tactical time frame. The scope of TAM is the entire airport, monitoring and guiding airside and landside operations. It describes an environment where airport stakeholders like ANSP, airport, airline and groundhandling, will create and maintain a mutual plan focusing on the prediction of flight events at least three up to 24 hours in advance. That plan incorporates occurrences affecting the planning of the flight events. The goal is to optimize the operational processes at the airport according to the expected traffic situation. Operational decisions taken by the airport operator or air traffic control (ATC) should be made in the full knowledge of airline operational constraints and/or priorities, coherent with the principles of CDM. Vice versa, operational decisions of the airline should take into account the constraints of ATC, airport and groundhandling. Those decision making processes could take place as negotiations. The central tool of TAM is the Airport Operation Centre (APOC) where representatives of all relevant stakeholders develop such an airport operations plan.

TAM bases on a traffic prognosis which predicts the upcoming traffic situation upon which KPIs are calculated. The representatives of the stakeholders are able to develop pre-tactical plans and to evaluate their plans on basis of that prognosis and the impact on the airports KPI. So, the decision-making process incorporates these KPIs so that a performance-based airport management is enabled. First simulation trials of the TAM concept, focusing on coordination and a-priori provision of time stamps of the turn-around processes from

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arrival to departure indicated that airport performance regarding punctuality and delay could be increased [4].

Within the project “Airport 2030”, where this study was conducted, an experimental prototype of an APOC workplace was installed at a European midsize airport (without A-CDM in place). Within this project, the APOC was defined as a control centre where the representative of the airport’s central traffic management office can holistically supervise and control the operations [5]. Up to now, there is no legal instance somewhere at the airport, which has the task and responsibility to supervise all operations with a focus on the overall airport performance, as described above. The working position, which is most likely to take over such a task from the view of the airport company, is anyone out of that central traffic management office.

B. Concept for an airport operations centre

Today, keeping track of the daily changes of the scheduled flight plan and predicting the impact on the airport processes requires a lot of manual work and the integration of various information sources. Furthermore, not all relevant information, like weather forecast or the actual traffic situation, is available to all operators involved in decision making process. This lack of information hinders effective communication. Within an APOC, all relevant information of the airport like air and land traffic, ground operations, and weather conditions, should be collected, monitored, and analyzed. All stakeholders involved are supposed to share their information and to have the ability to make harmonized decisions by the help of planning and simulation tools for pre-tactical planning.

Every stakeholder within APOC receives a workplace with online access to its operation centre to share information and to ensure upcoming decisions. It is assumed, that operators decision making within an APOC should be supported by automated assistance tools. For instance, the TAM concept includes an assistance tool called “Total Operations Planner” (TOP). TOP creates a forecast of the traffic situation on basis of flight plan data and capacity values for airport resources. The resource capacity values are set by the operators via a graphical user-interface. Within the concept, certain roles with specific rights are defined. For instance, the airport can close or open a runway by setting the capacity of a runway to zero, the ATC can set the arrival and departure capacities, and the airline can cancel flights.

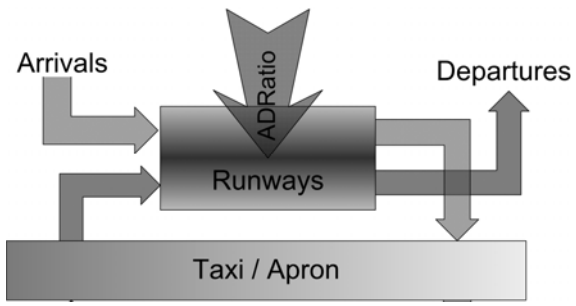

Figure 1. The generic-macroscopic airport model used for traffic prognosis

These capacities, as well as the most actual flight data are fed into an airport model, shown in Fig.1 which predicts time stamps for flights in the future. As an extent, TOP can furthermore use optimization algorithms to calculate optimized arrival and departure sequences considering inter alia single airport capacities. On basis of this traffic prognosis, the KPI are calculated in another module of TOP.

These results are presented to the operators by a set of human-machine interfaces. The TAM concept includes a centralized information screen, called video-wall, where aggregated information of airport processes is displayed. This incorporates the KPI (as a result of the TOP prognosis), status of resources and capacities, weather information or tasks to be solved. It can also contain any further information necessary to comprehend a situation. Furthermore, the KPIs are also presented onto the individual workplaces of the operators.

II. RESEARCH QUESTION

The prognosis of the traffic situation for the whole day of operations is the basis for the decision-making processes of the stakeholders within the APOC. In case the traffic prognosis is reliable, accurate and useful, feasibility of one part of the APOC concept is ensured. The decision making process itself is not addressed in this paper; related research is reported in [6][7].

The study therefor aims at exploring four research questions addressing the prognosis of the upcoming traffic situation. The first two research questions are assessed within a preliminary study, by analyzing flight data from the airports operational data base:

1. What quality of the prognosis of airport performance can be achieved with the experimental APOC set-up on the basis of real airport data?
2. Are the chosen parameters and metrics appropriate to predict the airport’s performance?

The results are used for a further study with airport operators, in order to assess research question three and four in an operational context:

3. Is the prognosis of airport performance comprehensible for operators? Do operators have adequate situation awareness and trust in the automated system?
4. Are the visualizations of parameters and metrics appropriate for operators?

III. PRELIMINARY ASSESSMENT OF PROGNOSIS QUALITY

A. Sample

The AODB data from the mid-size airport were recorded. The sample for the analysis consisted of N = 167 days from November 2012 to July 2013; equally distributed over the months and weekdays. For each day and flight the scheduled, estimated and actual timestamps of each flight for the runway and the block were available, as well as aircraft type, route and stands. Furthermore, the history of all updates for each day and flight was recorded.

B. *Data Analysis*

The flight plan data from the AODB were analyzed regarding the availability of updated flight event data (estimated time of arrival ETA, estimated time of departure ETD). Mean value and standard deviation are calculated. Furthermore, a qualitative analysis of a traffic prognosis in a situation with a capacity breakdown was conducted. Therefore, the KPI delay calculated from the AODB data was compared to the delay calculated on basis of the traffic prognosis of the assistance tool TOP for the same day.

C. *Results*

1) Availability of updates: On average, an ETA is available for 95% of all arrivals (*sd* = 2.5; *min* = 84%, *max* = 99 %). The ETA allows for a traffic prognosis on the basis of updated flight data. Regarding the ETD, this time was in average only set for 8% of all flights (*sd* = 4.4, *min* = 1%, *max* = 26%). It has to be mentioned that only the ETD published to passengers was used for this analysis. These results describe the actual state-of-art regarding the quality of the input data for the traffic prognosis. Whilst there are sufficiently updated data for the arrivals, an update of the departure flights is available only for a small margin of flights.

This result implies that an accurate, automated traffic prognosis for a day without disturbances caused by capacity bottlenecks is not possible. As there are no sufficiently updated data of the departure flights, the prognosis can't predict delays etc. for this traffic. Therefore, it is assumed that with the actual input data and the actual implementation of the tool TOP, a traffic prognosis is more accurate and therefor useful for a day with a rather long-term breakdown of one capacity.

2) Performance during a strike day: In preparation of the field study, from the real airport data sample a day with a major capacity breakdown of one of the capacities used in the generic-macroscopic airport model (compare Fig. 1) was selected. Goal was to predict, by using the assistance tool "TOP", the curve representing the development of the delay over the day of operations. That curve should be compared to the measured delay gained by analyzing the AODB data (compare Fig. 2). For completeness, the KPI punctuality will be reported, as well.

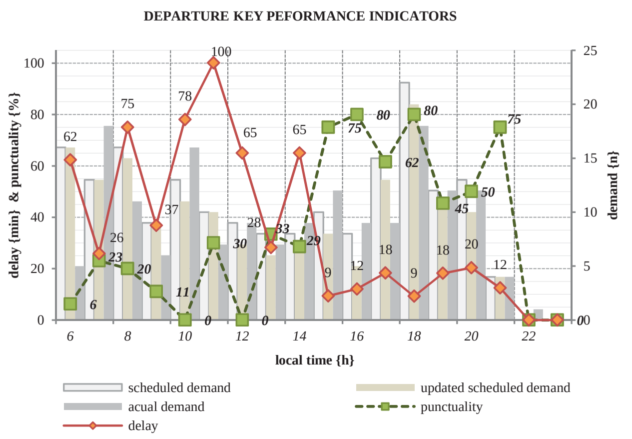

Figure 2. key performance indicator delay for strike day

Within the sample there was one day with an unannounced strike of the passenger security. At 03:45 am, the trade union declared that security personal would be on strike for the whole day. Over the whole day, on average only three security gates were open. As one security gate can accommodate 80 persons per hour, during the day on average only 240 passengers per hour could pass security for aircraft boarding. During that day, the two major airlines declared that they would operate flights as punctual as possible and that passengers should not come to the airport. Nevertheless, passengers went to the airport, because they heard that some flights were operated and there was no a priori information about cancellations. The airport terminals outside of the security area were congested with passengers waiting to get through security. This caused safety problems and problems with the statics of the terminals.

KPI were calculated from the AODB data. For the whole day, only 54% of all flights were punctual and the average delay per aircraft was 28 minutes. The capacity bottleneck mainly inflicted the departures. Only 37% of all departures were operated punctual; with an average delay of 35 minutes. The time series for the calculated KPI are visualized in Fig. 2. From 3 pm on, the two major airlines declared to start massive cancellations of flights. At the end of the day 41 of 372 scheduled flights were cancelled. These flights were not relevant for any delay calculations. Further 49 flights were operated as "empty flight", i.e. those flights did not wait for passengers but departed punctually from the airport. In fact, the time response of punctuality and delay performance indicate that from 3 pm on punctuality of departures went up from averagely 17% between 6 am to 2 pm to 67% (3 to 11 pm). This effect can be seen in Fig. 2, too. In the morning, the average delay per hour increased up to a maximum of 100 minutes delay at 11 am and decreased significantly after 3 pm.

3) Traffic Prognosis for the strike day: In order to recreate this traffic situation and thus calculate similar KPIs, major decisions and capacity settings for this day had to be identified and fed into the TOP airport model.

TABLE I. THEORETICAL IMPACT OF AICRAFT FILLING ON DEPARTURE CAPACITY

Sec. gates open	*Passengers available*	*Filling of aircraft [%]*	*Passengers / aircraft*	*Departure capacity (n)*
3	240	100	120	2
3	240	50	60	4
3	240	25	30	8
3	240	10	12	20

Within the traffic prognosis, the departure capacity was used as the parameter, to map the real bottleneck of the security gates onto the generic airport model of TOP. Different theoretical departure capacities and a responding filling of aircraft with passengers are calculated (compare table 1). In all cases, 240 passengers are available per hour that can be distributed over departing aircrafts. Assuming there is an average number of 120 passengers booked on each flight, if airlines decide to fill every aircraft to 100% it would allow for a maximum of two departures per hour. A departure of eight aircraft per hour resembles that aircraft will be filled up to 25%. On average, the actual departure demand during the day was 10 flights / hour. The exact values per hour are shown in Fig. 2 (gray bars depicting “actual demand”).

TABLE II. OPERATIONAL DECISIONS AND PROGNOSED KPIS

	Prognosis	
Decision	***Punctuality [%]***	***Delay [min]***
1) seasonal plan	100	0
2) capcity 2 AC/h	50	297
3) capacity 8 AC/h	51	97
4) cancelations	60	47
real data	*54*	*28*

In order to compare the traffic prognosis of TOP with the real data, four major operational decisions made during that day were implemented and translated as input to the TOP airport model. First, the initial scheduled flight plan data from 04:00 am was loaded and the predicted KPI curves were visualized at the TOP HMI (compare Fig.3). This first step resembles the seasonal flight plan without any updates (step 1 in table 2). The calculated KPIs indicated 100% punctuality and zero minute delay. Afterwards, the strike and the closure of all but three security gates were announced (simulation time was still 04:00 am). According to table 1, a departure capacity of two flights per hour for the whole day of operations was set which resembles a “do-nothing” scenario for the whole day (step 2, compare upper left picture in Fig. 3). Accordingly, the KPIs were calculated (compare Table 2, row “capacity 2 AC/h”. Whilst the overall punctuality of all flights decreased to 50%, the average delay for the whole day went up to 297 minutes.

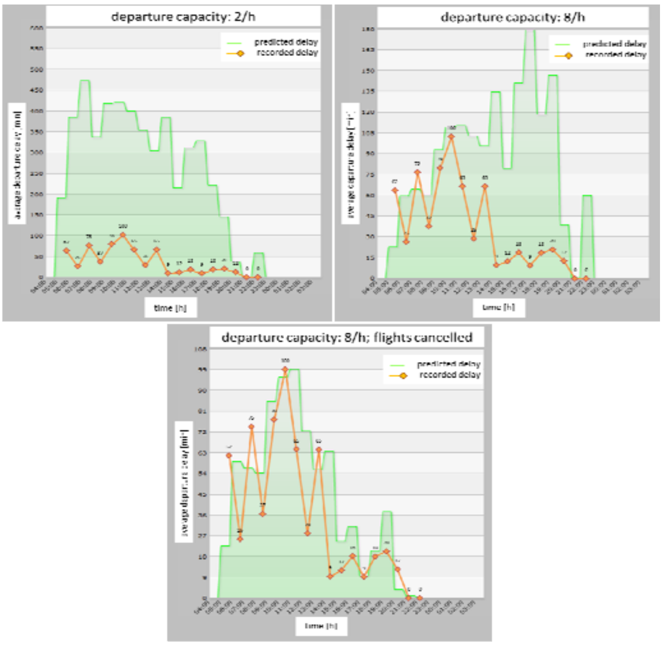

Figure 3. development of KPI delay for strike day depending on setting of departure capacity parameters (y-scale dimensions differ)

In the next step, the decision of the airlines was simulated to operate certain flights as punctual as possible (step 3), even if not all passengers would reach the aircraft in time, which resulted in only part wise filled aircraft (25% in average) and a departure capacity of 8 flights per hour. With these input parameters, the predicted punctuality slightly changed to 51%. Still, almost all departures were delayed but average delay was reduced to 97 minutes per flight. The fourth step was the cancelation of the flights declared as cancelled by the airlines. Basically, this was achieved by deleting these aircraft from the departure demand. Accordingly, the predicted average delay was further minimized to 47 minutes per flight, the punctuality rose to 60%.

The graphs that were produced by the TOP HMI (Fig. 3) show the approximation of the predicted delay curve to the recorded delay curve over the day of ops from step 2 to 4. The y-scale changes between the plots. At a departure capacity of 8 flights per hour and a reduced demand (lower picture), the delay curves and the location of the delay peaks look quite similar even if they do not match completely. Also, compared to the real data, the average delay in the traffic prognosis was higher than in reality with 28 minutes but within the same range. So, this traffic prognosis was evaluated as sufficiently accurate and therefor potentially useful for operators.

IV. MAIN STUDY ON FEASIBILITY OF TRAFFIC PROGNOSIS

A. *Sample*

The sample for the field trial consisted of $N = 9$ operators from the mid-size airport, 8 of the airport itself and one of the air navigation service provider, located at the airport. The sample consisted of experienced operators, with a mean age of 47 years ($sd = 7$ years, 66% male), five of them working in managerial positions. The professional background included tower supervisor, airport operations manager on duty, security, passenger services and planning operations.

B. *Methodology*

For this study, the method of “simulation interview” was adopted to serve as an evaluation method within the field study. Simulation interviews are a method used for cognitive task analysis [8]. Challenging scenarios are presented to subject matters expert by means of low-fidelity paper-pencil simulations or computer-supported simulations. Afterwards, subject matters experts are asked to identify major events, judgments and decisions regarding their specific position or task. The strike day analyzed in the preliminary study was used as the validation scenario. The calculated traffic prognoses were discussed with the operators. The assistance system TOP and the visualizations were used to conduct the prognosis and to discuss the influences on the airport traffic situation. So, the simulation interview did not aim at reconstructing the decision making process in real-time. The goal was to reconstruct the major decisions to allow operators to get an impression of the overall operational concept and to evaluate the usefulness and acceptance of traffic prognosis as core functionality. Furthermore, by using the same scenario for all operators, experimental control was achieved and feedback and data of operators could be used for descriptive statistical analysis.

C. *Experimental Set-Up*

The experimental APOC consisted of three workplaces with a HMI to the assistance tool TOP, as shown in Fig. 4. A video wall was set up, consisting of two Quad-HD displays. Furthermore, the APOC accommodated a fourth workplace for the technical supervisor with interfaces to the technical backbone of the APOC database. This backbone is explained further in the following section. The exercise leader guided through the simulation interview, explaining the HMI interactions and the results of the traffic prognosis which were visualized upon the TOP HMIs and the video wall. He was supported by a second person.

The technical set-up had to fulfil a couple of requirements. First, operational data and operations must not be inflicted by the experimental system. So, a filtered copy of the AODB was stored in a research database (upper part of Fig. 4). Second, the system must be able to work in replay and in a "live" mode, where data were transmitted directly from the research database onto the TOP database for a traffic prognosis. This was achieved by using a second tool (TAPAS). There, the date and according time of the day could be set by the technical supervisor. Then, via the service this data was copied from the research data base, including all update messages. So, the real flight data from the strike day and the development of the data by incorporating estimates of flights could be replayed.

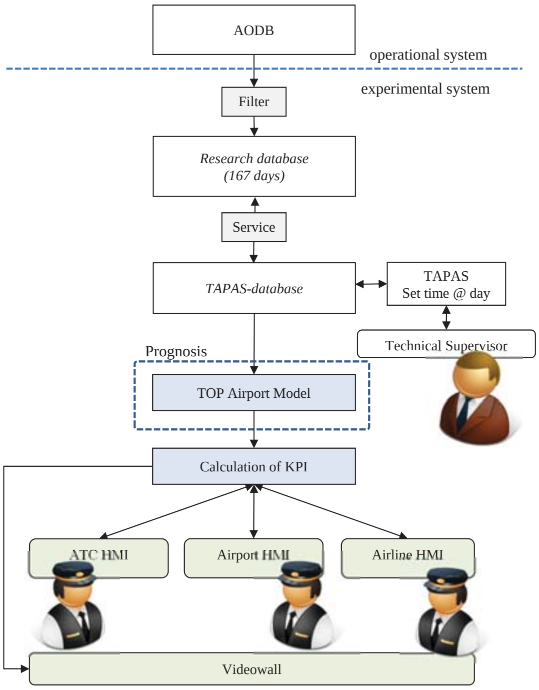

Figure 4. technical set-up of the experimental APOC workplace

D. *Procedure*

Between one and three operators took part in the simulation interviews at a time. The whole trial took two hours (compare Fig. 2). First, they were introduced to the concept of the APOC, the automatic traffic prognosis and the events of the strike day scenario. Afterwards, they answered a biographic questionnaire. Then, the simulation interviews started with operators being seated at the three TOP HMI positions. Operators were assigned to the position most suitable to their real tasks. The whole scenario took about 20 minutes, including the four decision making steps explained in section 3. Afterwards, operators answered a second questionnaire regarding the quality of prognosis and information visualization. Following this, the system was switched into the live mode. So, operators got an impression of the actual day of ops and its visualizations at the experimental APOC workplace. A third questionnaire regarding situation awareness and trust in automation was answered. During the simulation interview and the live modus, communication between operators and the experimenters was recorded.

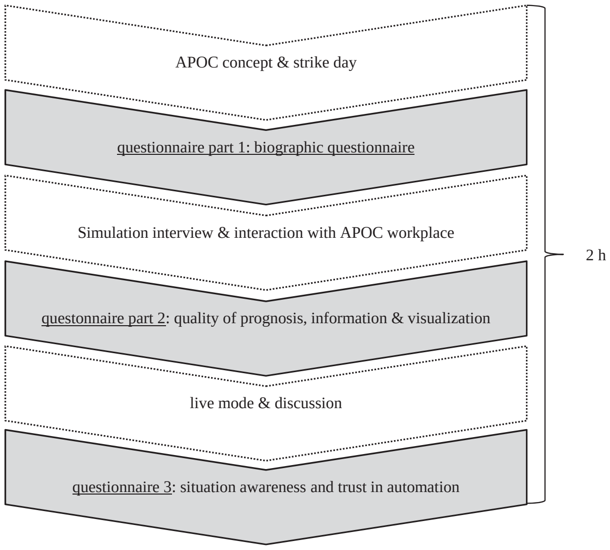

Figure 5. procedure of the field study

E. *Variables*

1) Quality of Prognosis & Information and Visualization: Tailormade questionnaires were developed for the topics quality of prognosis and information & visualization in order to capture the specific aspects of the APOC concept. First, it was of interest, in how far operators could understand the prognosis and the logics behind it. Successful human-machine interaction depends on a good mapping of the operators "mental model" of the airport and the logics of the automated system [9]. Furthermore, operators should be able to use the prognosis in order to develop mitigating actions in case of a performance breakdown. This ability highly depends on the information that is generated by the prognosis. Therefor, it was assessed whether the information was sufficient, comprehensible and whether the visualziation of the HMI was suitable. One aspect of the APOC workplace is the collaboration of different decision makers in order to develop a pre-tactical plan. Thus, it was assessed in how far the workplace supports collaborative decision making. A 7-point-Likert scale was used to measure operators agreement with the above described statements. The value "3" is a neutral position; values over 3 indicate, that operators agree with the statement, values lower than 3 indicate, that operators disagree with the statement.

2) Situation Awareness: To assess the situation awareness of the operators, the 3D-SART scale was used [10]. This scale was chosen, because the items are generic and the scale is easily applicable. Furthermore, it breaks the construct of situation awareness down into the three dimensions “supply of attentional ressources” (S), “demand of attentional ressources” (D) and “understanding of the situation” (U). The situation awareness score is calculated by applying (1)

$$\text{situation awareness} = U - (S+D) \qquad (1)$$

3) Trust in Automation: The trust of operators into the automation of the experimental APOC workplace is assessed with the SATI scale [11]. This scale was developed within the project “Solutions for Human Automation Partnership in European ATM” (SHAPE), financed by Eurocontrol. This scale consists of 6 items, covering aspects of trust in automation. SATI is measured on a 7-point-Likert scale, as well. Values over three indicate that operators trust the system.

F. Data Analysis

The questionnaire data from the field tests were used to calculate mean value and standard deviation for the scores of situation awareness, trust in automation, quality of prognosis and information & visualization, as well as for each single item.

V. RESULTS

A. Quality of traffic prognosis

Within the field study, operators rated the quality of prognosis for the strike day scenario. An overview of the results is given in Table 3. Each row shows one statement regarding one aspect of prognosis quality from an operational point of view. In average, operators tended to agree with the statements regarding the quality of the prognosis (*mean* = 4.4, *sd* = 0.7). Operators specifically agreed that the prognosis for the strike day was comprehensible and that they were able to decide, whether they should plan preventive actions. Operators had neutral opinion whether the prognosis included a) enough information for the implementation of preventive actions and b) the relevant mechanisms and dependencies of airport operational processes.

TABLE III. QUALITY OF PROGNOSIS

item	mean	sd
prognosis comprehensible	4,78	1,09
able to decide whether to take preventive actions	4,78	0,97
able to decide when to act	4,67	1,00
event very likely	4,67	1,00
able to decide whether own responsibility is affected	4,63	1,30
assumptions and logics are applicable	4,38	0,92
able to decide which preventive actions	4,33	1,00
assumptions and logics are comprehensible	4,22	1,39
prognosis reliable for preventive actions	3,89	0,78
enough information to implement preventive actions	3,75	0,71
relevant mechanisms and dependencies included	3,50	1,20
quality of prognosis - score	4,35	0,67

B. Information and Visualization

The results of the information and their visualization questionnaire are presented in table 4. The average rating for information available within the traffic prognosis and their visualization indicate a slight agreement of the operators (*mean* = 4.0, *sd* = 0.4). Best ratings achieved the statements that information was comprehensible (*mean* = 4.9, *sd* = 0.6) and useful for discussing collaborative preventive actions within a group of decision makers (*mean* = 4.8, *sd* = 0.8). Operators had a neutral opinion whether information were not too numerous and the visualization fostered a quick understanding.

TABLE IV. INFORMATION AND VISUALIZATION

item	mean	sd
information comprehensible	4,89	0,60
useful for group discussion on collaborative preventive actions.	4,78	0,83
visualization useful for overview on airport situation	4,56	1,13
enough information to understand traffic situation	4,33	1,12
visualization useful for common understanding of airort situation	4,33	1,12
relevant information for own decisions	4,25	1,04
information not too numerous	3,33	1,50
quick understanding of visualized information	3,11	1,76
Information and visualization - score	3,97	0,43

C. Situation Awareness

The situation awareness score is below the middle of the scale (min = -12, max = 6, 50% = -3) with a mean value of -4.4 (*sd* = 2.6). As Fig. 6 shows, the score consists of the three dimensions demand, understanding and supply. The understanding of the situation is relatively good ($mean_{U}$ = 4,0; sd_{U} = 1.0). but at costs of a rather high demand and supply of attentional resources of the operators ($mean_{D}$ = 3.9; sd_{D} = 1.1; $mean_{S}$ = 4.6, sd_{S} = 1.1).

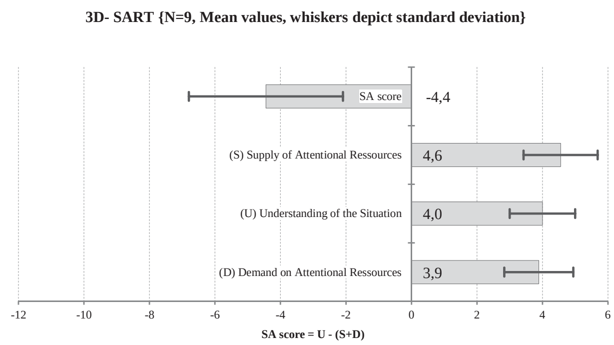

Figure 6. Results of the situation awareness rating

D. Trust in Automation

Operators indicated that they trusted the system (*mean* = 4.5, *sd* = 0.6). They felt very often that the system was usable (*mean* = 5.0, *sd* = 0.7) and understandable (*mean* = 5.0, *sd* = 0.9). Operators gave lower, but still positive ratings to the statements that the system worked robust (*mean* = 4.4, *sd* = 1.1) and that they were confident working with the system (*mean* = 4.1, *sd* = 1.6). It has to be kept in mind that operators rated the system after conduction the simulation interviews.

Compared to other simulation methods, operators therefor had rather little direct interaction with the system.

TABLE V. SHAPE AUTOMATION TRUST INDEX

	mean	sd
system was useful	5,00	0,71
system was understandable	5,00	0,87
system worked reliable	4,75	0,89
system worked accurately	4,71	1,38
system worked robust	4,43	1,13
confident working with system	4,13	1,55
Trust in automation -score	4,50	0,60

VI. DISCUSSION

A. *Methods for assessing prognosis quality*

The goal of the study was to understand the quality of an automatic traffic prognosis. This traffic prognosis should be used within an airport operations centre (APOC) to enable collaborative, pre-tactical decision making of stakeholders at a European mid-size airport. Within a preliminary study, data from the AODB was analyzed regarding the feasibility for traffic prognosis. Furthermore, a validation scenario for the field study was created by using the real operational data from a strike day. Nine operators of a mid-size airport took part in the field study. They conducted a simulation interview where they reproduced the decision making process during that strike day. The impact of a breakdown of the departure capacity on the airport key performance indicators and airport resources was predicted. Operators could implement alternative capacity settings, representing the decision to operate more punctual by not waiting for passengers to pass the security gates and flying empty, in order to mitigate the performance breakdown. The simulation interview enabled operators to develop an understanding of the concept of a traffic prognosis to predict the airport performance. Furthermore, the specific setting of the strike day helped operators to assess, whether this prognosis would be useful for their individual decision making process. The collaborative decision-making process was not focus of this study. Therefor it was possible to gather sound empirical results on the feasibility of traffic prognosis, as well as the concept of Total Airport Management from an operational point of view.

B. *Operational Aspects of Prognosis Quality*

Whilst the availability of updated flight data needs improvement, operators evaluated the traffic prognosis, as well as the information and visualization as comprehensible and useful. They had sufficient trust into the highly automated APOC workplace. All questionnaire scales indicated a medium agreement of the operators. As the workplace and visualizations presented to the operators were experimental prototypes these ratings show that the concept is on the right track.

The results also indicate room for improvement of the algorithmic of the traffic prognosis and the design of the human machine interfaces. For instance, operators did not agree with the statement that the prognosis included the relevant mechanisms and dependencies. At the present state, landside processes and information, like passenger boarding, are not included. Especially for the validation scenario strike day this information was relevant for the operators of the security and passenger services, but not included in the system. Furthermore, during the preparation of the validation scenario it was decided to increase the capacity of the apron resource artificially in order to foster the comprehensibility and reliability of the prognosis. One of the operational problems of the strike day was that the airport operations managers run into problems with reassigning gates to arriving aircraft as the gates were still blocked by the unpunctual departing aircrafts. This problem was there for hidden in the traffic prognosis.

The operators' situation awareness ratings are rather low. Within an operational system, higher scores would be preferred. These results can be explained with the novelty of the prognosis of traffic and key performance indicators for the operators. Up to now, there is no operator at an airport experienced with monitoring or steering the overall airport performance. Furthermore, the operators had quite different professional backgrounds and responsibilities. It is assumed that with training and experience, operators require less attentional resources to understand the traffic prognosis. Furthermore, the decision making process within an APOC is not as time critical as decision making within the cockpit or at an ATC workplace. So, APOC operators have much more time to gather information, integrate them into an overall situation and to predict the future states. Nevertheless, participants of the simulation interview were able to figure out the potential impact of the traffic prognosis on their own processes and responsibilities. They furthermore discussed how these processes could change if they would have such a traffic prognosis in advance. Participants from the airport security could identify opportunities to handle the situation better with regards to passenger comfort. For instance, reliable information about cancelled flights at an early stage could be announced to passengers waiting for the security check. Following passengers affected would be guided to an information desk and they could be informed about next steps.

C. *Open questions and future directions*

Beside those positive results regarding the feasibility of the automatic traffic prognosis, the validity for a broader spectrum of traffic scenarios needs to be investigated. The reported effects could be demonstrated for a rather long lasting and massive capacity shortage. It is trivial that a major input effect causes a major outcome effect in terms of the key performance indicators. Furthermore, the need for preventive action is relatively clear for all decision makers involved into the situation. Operator state that in those situations a common understanding between stakeholders exists about the primary goal, to keep the operations running.

Therefore, it needs to be understood, in how far minor input effects, like one delayed aircraft or missing resources of the ground handling agent, influence airport operations and whether the traffic prognosis and the key performance indicators are sensitive to these disturbances. Additionally, the quantity and quality of input data for the automatic traffic prognosis needs to be sufficient. At the moment, the traffic prognosis for departing air traffic would be rather imprecise, as on average less than 10% of departures have an updated off-block time. It is expected that the implementation of A-CDM provides a more reliable and complete data base for traffic prognosis. Nevertheless, a prognosis always contains uncertainty. Lindberg and Zackrisson [12] point out four impact factors for the usefulness of a forecast – the predictability of the system, the quality of the model used for forecast, the quality of the input data and the way, decision makers use the forecast. Regarding the first three arguments the validation scenario of this study provides a good example. The actual measured delay curve of the strike day was recreated as good as possible. At the end, after adjusting the parameters of TOP according to the known decisions made during that day, the predicted curve still did not perfectly match the measured curve but showed similar trends and peaks. It needs to be assessed, what precision of traffic prognosis can be achieved. One assumption is that performance can be predicted on a global level; for instance that within an hour five out of ten scheduled aircraft will have a delay. But there will be a discrepancy between the prediction which aircraft will be delayed and the actual delays. Nevertheless, empirical data are needed to clarify these assumptions. As the results of this study show, the general feasibility of a traffic prognosis for supporting collaborative, pre-tactical decision making of airport stakeholders could be demonstrated. The authors hope that the positive results of this study encourage more empirical research into the evaluation of the APOC concept.

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