Modeling and Evaluating Intermodal Traffic Management Structures involving Airports and Railways

Olaf Milbredt,* Florian Rudolph,† Erik Grunewald,‡
and Thomas Christ§
German Aerospace Center (DLR)
Institute of Air Transport and Airport Research
Lilienthalplatz 7, 38108 Braunschweig, Germany

Seamless door-to-door travel requires comprehensive traffic management. We have developed a software system to model and evaluate intermodal traffic management including a microscopic simulation of a generic airport model. Key ingredient is the passenger trajectory consisting of passed stations and the time stamp of passing. In this study the system is tested with the simulation of one day including the train and flight schedule. The system was required to determine the "state" of the airport comprising of Key Performance Indicators and Key Control Parameters. In a second step the manage ability was tested including a forecast model, adaption of train and flight schedule, and modification of process times. After testing, the system was then able to evaluate various management strategies with respect to the change of the state of the airport and operational impact.

Keywords: Intelligent Intermodal Transport Management, Performance Based Airport Management, Microscopic Simulation, Active Intermodal Traffic Management, Passenger Trajectory

Nomenclature

KPI	Key Performance Indicator
KCP	Key Control Parameter
A-CDM	Airport Collaborative Decision Making
TAM	Total Airport Management

I. Introduction

Within its report Flightpath 2050 the High-Level Group on Aviation Research envisioned seamless door-to-door travel.[1] To develop a transport system which achieves such a goal, a conjunction of different modes in form of physical connections, encompassing management structures, and appropriate business models is necessary.

In this paper the technical feasibility of integrated traffic management incorporating airport management and railway management is considered. The goal of such a system is to evaluate the possibility not only to exchange information, but to adjust operational parameters on the basis of the overall situation. The question is what information exchange is needed and how large is the operational impact of an overall traffic management.

Key ingredient of our approach is a customer-centered view addressed by the so-called passenger trajectory. It consists of pairs of points in space and time, where the passenger passes a certain milestone of the journey. This data can be used to compute the remaining time to the airport or even to a specific gate determining whether a passenger can be at the gate in time. If a critical mass is reached, operations at the airport can be adjusted.

The broad use of mobile devices and mobile internet make it feasible for stakeholders of transport to pass information about schedule and delays to passengers. The provision of status information is extended by real-time information

*Ph. D., Research Assistant, olaf.milbredt(at)dlr.de
†Research Assistant, florian.rudolph(at)dlr.de
‡Research Assistant, erik.grunewald(at)dlr.de
§Research Assistant, thomas.christ(at)dlr.de

about arrivals and real-time computation of remaining time. The feasibility is tackled by a software system including a microscopic simulation environment mimicking a broad range of quantities from which the KPIs introduced by A-CDM and TAM can be derived.[2–4] On the other hand, values of parameters influencing the KPIs — called Key Control Parameters (KCPs) — are also recorded to make the state of the airport available.

The microscopic simulation is combined with a flight plan and information from a Railway Management System. In the next step this combination (exclusively on an information exchange basis) is extended by a Management System. This system enables an airport operator to change the settings of the KCPs and thus the values of the KPIs to meet the required needs. The connection to the Railway Management System makes it possible to manage settings at the airport on the basis of changes at the railway system and vice versa. In this work the focus is on the connection of landside airport management and railway management. Based on the model of a generic airport providing a wide spectrum of operationally important situations, the system is tested at various levels, from providing information through airport management to combined traffic management.[5]

In the Optimode project, traffic management research went beyond the borders between stakeholders and looked at an exemplary intermodal networked airport. A generic airport model was considered (Generic International Airport GIA) which was connected by individual transport and rail transport to a metropolitan region. The idea is to extend the A-CDM which is already established on the airport airside to the airport landside and to ground transportation generally. The core of the A-CDM is the mutual information exchange to achieve a common situational overview to support decision-making involving collaborative operative interaction. The A-CDM serves to increase efficiency among the stakeholders involved at an airport, as shared decision-making agreements can offer the potential to find comprehensive solutions which optimize system performance better than individual optimization attempts within the resources of individual stakeholders.[6] Spies *et al*. complemented the A-CDM approach by adding the ability to provide process-oriented landside airport information.[7] The methods of involving passenger process information at an airport control center and the selection of relevant processes were first described by Helm *et al*.[8] The possibilities to control traffic in passenger flows within a terminal with the aid of priority rules, as previously only used for product differentiation (economy, business class etc.), were examined by Grunewald *et al*. using a generic model.[9] In the Optimode project, which follows up on those results, a management method is examined which focusses on individual passengers and their entire travel chain.

Within the airport terminal and at the start and end points of the railway line, there are special sensors which are assumed to be able to record passenger events and provide the data to the management layer. Passenger events could be the arrival at or departure from a task station. The sensors record these passenger events for each individual passenger and link each event to a personal primary key. Even though such sensor systems are not in use everywhere and the technical standards are not laid out for the future, the technology itself is already available. Taking radio-frequency identification (RFID) technologies as an example, passenger tracking can be performed successfully provided the users carry the RFID chips e.g. in their hand luggage and the sensors are installed throughout the transportation system. Other radio standards could also be used, one example being cellular radio.[10]

Travelers on their way through the simulated infrastructure network can therefore be detected as they pass defined points. Such path-time sequences are recorded to form the so-called passenger trajectory corresponding to the knowledge available to the management layer at the given time. Independently of the expected overall tr-to-tr trajectory, the passenger trajectories describe the path between entering a train to the airport or, for non-rail travelers, arriving at the airport plus the systems handover to air transportation, which has been defined as boarding the plane. This trajectory-based approach presents its own variation of the milestone approach, in which milestones are available to travelers as decision points.[11]

While the referenced project examined the subject of disruptive events, the passenger trajectory is intended to facilitate intelligent management for all operational states. With the introduction of trajectory approaches for subjects (passengers, freight) and for system components (traffic infrastructure and vehicle), collaborative decision making on the airport airside (Airport CDM) is complemented by the interaction with the traveler. With the aid of a forecasting model, the infrastructure capacity utilization of the remaining day is repeatedly simulated so that the passenger trajectories are continuously updated using the sum of individual passenger demand and the infrastructure usage time required for this.

The overseeing management now has a powerful tool to assist in its controlling role and is now able to optimize the entire system above and beyond the borders between responsible parties, besides the optimization of individual parts of the system. The passengers are the connecting element between the stakeholders. Each stakeholders ability to perform his actions is now measured by the ability to meet the demands placed upon them in the KPIs. Management solutions to optimize a traffic situation can now take place across various stakeholders and can be assessed as to their benefit to the system. Individuals, however, can utilize their involvement in the information flow and independently apply their knowledge of the available options to interactively organize the path of their own trajectory, instead of just reacting to events.

II. Methodology

II.A. KPIs and KCPs

Within the test phase the following KPIs and KCPs are used. The KPI "Boarding Score" is defined in such a way

Table 1. KPIs considered

Symbol	KPI	Description
S_B	Boarding score	Denotes the fraction of all passengers who reached the gate in time to all passengers who wanted to take the flight.
T_C	Process time at check-in	Since there may be more than one open checkpoint, the waiting time is proportional to the queue length although we assume the processing speed to be constant.
T_S	Process time at security check	as above
T	Overall process time	Denotes the time for a passenger from entering the airport to reaching the gate of his/her flight.

that it can have a meaning for a specific flight, a specific airline, or a specific range of time. In the sequel we use the definition

$$S_B(t) = \mathrm{Pax}_{\mathrm{OK}}(t)/\mathrm{Pax}_{\mathrm{All}}(t) \tag{1}$$

$$\text{with} \quad \mathrm{Pax}_{\mathrm{OK}}(t) = \text{sum of passengers for flight with off-block time} \leq t \text{ who reached the gate}$$

$$\mathrm{Pax}_{\mathrm{All}}(t) = \text{sum of passengers for flight with off-block time} \leq t \text{ who wanted to take the flight.}$$

We state explicitly if the term is used with a different meaning. The KPIs T_C, T_S, and T are time-dependent and defined by

$$T_C(t) = \text{process time at check-in of the latest passenger being processed at time } \leq t. \tag{2}$$

The other process times T_S and T are defined in an analogous manner. The KCPs c_C and c_S are defined for any time t in

Table 2. KCPs considered

Symbol	KCP	Description
c_C	Open checkpoints at check-in	Adjustable parameter directly influencing the KPI Process time
c_S	Open checkpoints at security check	as above
Δt_F	Flight schedule	The off-block time of a flight can be adjusted to wait for late passengers.
Δt_T	Train schedule	The train schedule can be adjusted to pick up passengers who would otherwise fail to reach their flight.

the simulation interval. The quantities Δt_F and Δt_T denote the change of the respective schedule of a specific flight or train, i. e. the departure time of a train named "S1" is equal to the scheduled departure time $+\Delta t_T(\mathrm{S1})$. The schedule change Δt_T attains values ≤ 0 or > 0.

II.B. Simulation environment

By using the RealSimConnector tool in combination with appropriate simulation software (e.g. TOMICS), which offers a highly extensive, detailed depiction of all the relevant processes, it is possible to create a test and simulation environment which can recreate fictive scenarios detached from reality. For the processes, the focus is on passenger clearance at the airport. During the simulation run it is possible to activate pre-defined realistic update events at any time to intervene in the procedure. This can, for example, be used to analyze the effects of management decisions or experimental support tools. All the relevant simulation values can (and must) by passed on following filtering by the RealSimConnector . This makes it possible to depict the information infrastructure which is to be analyzed in a realistic manner. Particular attention is placed on the use of detection sensors, the control of which takes place via the SensorSimulation of the RealSimConnector. Operating this requires a connection to the Optimode database and an up-to-date version of TOMICS, which has to be installed on the same computer. Direct dependencies to other applications are not required apart from the connection to TOMICS with integrated SensorSimulation. Once the scenario has been loaded (containing the model of the subject airport) the simulation can be started. First, various initialization steps are performed and recorded in the LOG. The SensorSimulation starts at the same time. While running, sensor data and the passes through pre-defined checkpoints are continuously forwarded to the Optimode database. Update commands which can change the simulation are read from the Optimode database following each completed period (30 seconds or 60 seconds), translated, then added to the simulation. Feedback is provided on their success or on any errors which may have occurred.

In order for the trajectories calculator tool (PETRA) to run properly, results, data and calculations from other applications with the Optimode system are necessary.The tool is also designed so that the best (most up-to-date) data is always used. This ensures that even when one or more components fail, PETRA can still be used. Within the system, it only communicates directly with the database like all the other applications. PETRA accesses tables which are maintained by other applications and also makes its own table available, which is then accessible to other applications. No direct communication link is provided to other applications. The Passenger and Airport Data Exchange Unit (PAXU) provides the external information such as the current flight and rail timetables to the Optimode system. The RealsimConnector supplies passenger data from the simulated reality and the forecast calculates the expected infrastructure times.

The following illustrates how the PETRA application is integrated into the overall Optimode system, and how the communication with the other relevant components is achieved for the departing passengers. When PETRA is started, it establishes a connection to the Optimode database. If the connection successful, the stored flight timetable is initially read in in order to ascertain the expected number of departing passengers. Then the updated external data and the passenger trajectories are read in. This connects with the updates from the flight and train timetables and the corresponding transfer connections. This information is then made available in the tables `global_flights`, `global_trains`, and `global_transfer` by the Passenger and Airport Data Exchange Unit (PAXU). The PAXU itself uses the data generated from the Management for vehicle-based airside updates (TOP) and from the Management Tool for landside Train updates.

Passenger data is provided in the table `rs_pax_outbound`. The contents of this table is read directly from the reality simulation via the RealsimConnector. A database procedure prepares the data for reading by PETRA.

The waiting times at the individual infrastructure points (such as check-in, security checkpoints) are also necessary to calculate the passenger trajectory. The times anticipated for these places are calculated by the forecast and provided in the table `petra_outbound_infrastructure_e`. The times are saved at five-minute intervals. These waiting times are used for example by PETRA to calculate the completion times for each passenger at each processing point. With the aid of PETRA, this allows a situational overview to be created for each passenger and thus determine whether and with which quality (fail, late, on-time) the final arrival time at the gate can be achieved. The calculated data is filed together with the current actual values from the reality simulation in the database in the table `petra_outbound`. The content of this table corresponds to the root datasheet of the PETRA. The updated external data and the passenger trajectory are then read in again and the cycle begins again. The contents petra outbound serve the forecast again as input in order to generate new infrastructure and waiting times in the cycle.

II.C. Test description

II.C.1. Airport Model

The test of the simulation environment described in Sec. II.B was carried out on an airport model called Generic International Airport (GIA) developed in the institute. Fig. 1 shows the terminal building of GIA. GIA has a passenger volume of approximately 13.5 million passengers per year distributed over some 160,000 flight movements. These figures make this airport one of the 30 largest airports in Europe.[12]

II.C.2. Management tasks

Besides providing information the system is also required to perform management tasks reflecting basic functionality of an intermodal traffic management system. Based on the values of the KPIs described in Sec. II.A the following tasks are considered.

Task I Change of train schedule (corresponding KCP: Δt_T),

Task II Change of flight schedule (corresponding KCP: Δt_F), and

Task III Change of open checkpoints (corresponding KCPs: c_C and c_S).

Each task comprises of identifying the need for change and its amount and to perform the required task with appropriate measure. E. g. within Task III it is necessary to trace a low boarding score back to a lack of open checkpoints.

II.C.3. Scenarios

All scenarios cover a situation with a requirement for change, i. e. boarding score $S_B < 1$.

Scenario I In this scenario we consider the generic airport described in II.C.1 with high process times at check-in and security check. Only a fraction of passengers are expected to use the check-in counter. Others are assumed to check-in via Internet. Therefore, a high process time at check-in only affects a fraction of all passengers, whereas a high process time at the security check affects them all.

Scenario II This scenario is devoted to a situation at the generic airport leading to a lower boarding score because of a late train. Only a fraction of the passengers considered use the train for transfer to the airport, but the delay propagates through the railway system. Here, two possible actions are possible. Firstly, it is possible to provide an additional train scheduled earlier or, secondly, to delay the off-block time of the affected flights.

All scenarios are considered with varying times (process time or delay), so that we are able to model the impact on the boarding score S_B. By varying the strength of the action taken, we are furthermore able to determine the functional relationship of the corresponding KCPs (see Task I, Task II, and Task III) and the boarding score.

II.C.4. Test phases

The system was tested in two phases.

Phase I Based on the definition of KPIs in Tab. 1 and KCPs in Tab. 2 the system is required to record all values for the generic airport described in Sec. II.C.1 providing an overall "state" of the airport. The goal is to show that the system is able to identify the low boarding score and the reason for it, namely the small number of open checkpoints in Scenario I and delay of train in Scenario II. The requirements of this phase are seen as basis and are part of all other phases.

Phase II Whereas in the first phase the goal was to show whether the required information is provided, the second phase involves testing the system's active management ability. After identifying the reason for a low boarding score, the system is required to take appropriate action by performing one of the management tasks described in Task I, Task II, and Task III.

III. Calculation/Results

The simulation is performed using a time range of 12 hours with 50 outbound flights and ca. 8000 passengers passing the terminal building. The time discretization for all quantities is chosen to be 15 minutes leading to a total of 48 values for each quantity.

III.A. Scenario I

In Scenario I we consider two simulation runs which are different in their open checkpoints at the security check. At the top of Fig. 2 different schedules of open checkpoints are depicted together with the resulting boarding score. On the left, the simulation run is executed with a schedule comprising of more open checkpoints, whereas on the right we see fewer security checkpoints to be open. The boarding score on the left approaches 0.99, whereas the boarding score on the right does not exceed 0.8.

In Fig. 3 the passengers were expanded according to their status. The statuses used are defined in the following way.

Passed Passengers who are labeled as "Passed" were at the gate in due time and the off-block time for their flight is in the past.

OK The label “OK” describes passengers whose off-block time for their flight is in the future, but who are/will be at the gate in time

Late Passengers who will be at the gate less than 30 min before the off-block time for their flight have the status “Late”.

Fail This label is reserved for passengers who failed to reach the gate in time.

On the top left of Fig. 3 we see that the number of “Late” and “Failed” passengers are roughly the same at about 300. On the top right, the scale for the number of passengers is doubled, so that around 3000 passengers are “Fail” and 500 are “Late”. The same trend for the labels “Passed” and “OK” is shown in the pictures at the bottom.

In Fig. 4 the overall process time of the simulation runs according to the left and right of Fig. 2 is depicted. The legend of the x-axis shows the simulation time in minutes and the y-axis shows the overall process time in minutes. The top figures shows that the process time is highly oscillating in the range of a few minutes to approx. 75 min. The picture at the bottom shows less oscillation and process times up to about 250 min.

III.B. Scenario II

The next scenario considers the case of a train being 50 min behind its scheduled time. This leads to a considerable amount of passengers who are expected to be on that train failing to reach their flight in time. The tables in 3 show

Table 3. Train at scheduled time and 50 min late

Passenger status	Number
OK	133
Late	19
Fail	0
Total	152

Passenger status	Number
OK	38
Late	27
Fail	87
Total	152

passengers who are expected to take the delayed train. On the left the situation without delay is shown. There is an amount of passengers being “Late”, but no passenger fails to reach the gate in time. The right table shows the situation with delay. A considerable amount of 87 passengers fail to reach the gate in time.

Two possible reactions are assessed:

1. Installation of a “fast-lane” at the security check with a process time of 5 min instead of the 30 min used in the calculation and
2. Delay of affected flights.

In Tab. 4 the result of the installation of a “fast-lane” is shown. Many passengers (87) are labeled as “Late”, but no passenger is being labeled as “Fail”, so that this intervention eliminates the occurrence of failed passengers.

Table 4. Installation of “fast-lane” at security check

Passenger status	Number
OK	65
Late	87
Fail	0

Two possibilities are considered for delaying the affected flights. The first is to delay the affected flights by constant $\Delta t_F = 20$ min. This leads to a cumulative delay of all flights of 6 h. We gather from Tab. 5 that this interference is not able to erase the occurrence of failed passengers. 22% of failed passengers remain to be labeled as “Fail” in this situation.

The second possibility considered is to set the TOBT for each flight to 08:50. In Tab. 6 the delayed flights are shown. The sum of the delays for all flights is 6 h and 29 min. The result of this intervention is shown in Tab. 7. No passenger is labeled as “Fail”, so that the individual delay shown in Tab. 7 provides the desired effect. Here, we considered a limited amount of possibilities to demonstrate the assessment capability of the software system. It can be used to perform an optimization of various strategies to react to delay scenarios.

Table 5. Uniform delay of SOBT of 20 min

Passenger status	Number
OK	38
Late	95
Fail	19

Table 6. Affected flights and individual delay

Flight ID	SOBT	Δt_T / min	Number of pax
124633	18.04.2012 08:10	40	23
124635	18.04.2012 08:30	20	27
124638	18.04.2012 08:30	20	27
124647	18.04.2012 08:10	40	130
124648	18.04.2012 08:39	11	99
124666	18.04.2012 08:34	16	53
124675	18.04.2012 08:19	31	152
124688	18.04.2012 08:39	11	152
124701	18.04.2012 08:05	45	92
124703	18.04.2012 08:34	16	92
124711	18.04.2012 08:25	25	92
124721	18.04.2012 08:05	45	92
124729	18.04.2012 08:34	16	51
124740	18.04.2012 08:19	31	92
124769	18.04.2012 08:39	11	37
124808	18.04.2012 08:39	11	22
124812	18.04.2012 08:50	0	115
124823	18.04.2012 08:50	0	27

Table 7. Results for an individual delay of affected flights

Passenger status	Number
OK	38
Late	114
Fail	0

IV. Conclusions

A paradigm shift from an isolated air transport system to one embedded in the overall transport system is required for realizing door-to-door travel proposed by Flightpath 2050. The usage of more than one transport mode needs to be possible not only by accident but by design. This includes not only physical connections of different modes but also encompassing management structures and information systems.

We developed a software system comprising of a microscopic simulation serving as a reality substitute, nowcast and forecast for the KPIs, and a system connecting forecast and microscopic simulation. Although in a microscopic simulation all data are known by design, data exchange is modelled by sensors with a given uncertainty similar to those possible in real world application . The queue length at the security check is e. g. provided by assuming the existence of a camera system producing anonymous data or by tracking Bluetooth or Wlan signals. The latter produces individual data for each passenger. Each sensor can be adjusted by an inaccuracy. This parameter characterizes the information gain from the specific sensor. Tracking information of passengers are modelled by the so-called passenger trajectory consisting of milestones and respective time of the journey. Entering a train and entering the airport may be such milestones. Together with a forecast respecting the times of the infrastructure, these data can be used to compute the remaining time for a specific passenger. The microscopic simulation of a terminal of a generic airport model is connected to a management tool for aircraft schedules and movements and a management tool for train schedules.

In this paper we use the above mentioned software system to show technical feasibility of evaluating intermodal traffic management including airports and railways. The system was tested in two phases with two scenarios in each phase. In the first phase the system is required to provide all necessary data consisting of KPIs and KCPs defined prior. The goal is to identify a low boarding score and possible reasons for this development. In the second phase these data are used to test the system's active management ability by assessing the performance of management tasks such as change of open checkpoints, train schedule, and flight schedule. In this paper we considered two simulation runs of the terminal simulation within 12 h. In the second run the number of open checkpoints at the security check is smaller than in the first run resulting in a considerable amount of passengers who fail to reach the gate in time. Within the first run we considered a delay of a train and reactions on the airport infrastructure. As one reaction the installation of a "fast-lane" is assessed and as a second reaction the delay of affected flights is evaluated. The installation of a "fast-lane" eliminated the existence of failed passengers and so did the second by choosing the right amount of delay.

The software system can be enhanced by a measure for the operational impact of management decisions. Together with an economic model we can therefore build a decision support system for intermodal management. A further extension consists of an optimization approach for various management strategies using the assessment of the outcome of decision by our software system.

References

[1]High Level Group on Aviation Research, "Flightpath 2050 — Europes Vision for Aviation," http://ec.europa.eu/transport/modes/air/doc/flightpath2050.pdf, 2011.

[2]EUROCONTROL, "Airport CDM Operational Concept," http://www.euro-cdm.org/library/cdm_ocd.pdf, September 2006.

[3]EUROCONTROL, "Airport CDM Implementation — The Manual, v. 4," http://www.eurocontrol.int/sites/default/files/publication/files/2012-airport-cdm-manual-v4.pdf, April 2012.

[4]EUROCONTROL and German Aerospace Center (DLR), "Total Airport Management Operational Concept," http://www.bs.dlr.de/tam/Dokuments/TAM-OCD-public.pdf, October 2006.

[5]Ezzedine, H., Bonte, T., Kolski, C., and Tahon, C., "Intermodal transportation system management : towards integration of traffic management system and users information system." *Computational Engineering in Systems Applications, IMACS Multiconference on*, Vol. 1, Oct 2006, pp. 972–979.

[6]Modrego, E. G., Igaru, M., Dalichampt, M., and Lane, R., "Airport CDM Network Impact assessment," *Proceedings of the Eighth USA/Europe Air Traffic Management Research and Development Seminar*, 2009.

[7]Spies, G., Piekert, F., Marsden, A., Suikat, R., Meier, C., and Eriksen, P., "Operational Concept for an Airport Operations Center to Enable Total Airport Management," *Proceedings of ICAS*, 2008.

[8]Helm, S. M., Claßen, A. B., Rudolph, F., Werner, C., and Urban, B., "Integration of Landside Processes into the Concept of Total Airport Management," *Journal of Air Transport Studies*, Vol. 5, No. 1, 2014, pp. 55–73.

[9]Grunewald, E. and Popa, A., "Passenger Management by Prioritization," *AUN2014: Airports in Urban Networks*, April 2014.

[10]Oberli, C., Torres-Torriti, M., and Landau, D., "Performance evaluation of UHF RFID technologies for real-time passenger recognition in intelligent public transportation systems," *Intelligent Transportation Systems, IEEE Transactions on*, Vol. 11, No. 3, 2010, pp. 748–753.

[11]Laplace, I., Marzuoli, A., and Féron, É., "META-CDM: Multimodal, Efficient Transportation in Airports and Collaborative Decision Making," *AUN 2014, Airports in Urban Networks*, 2014.

[12]Rudolph, F., Grunewald, E., Günther, Y., and Piekert, F., "Intermodal Augmented Scheduling," *AUN-2014 'Airports in Urban Networks'*, April 2014.

Figure 1. Scheme of the airport model used within the simulation[12]

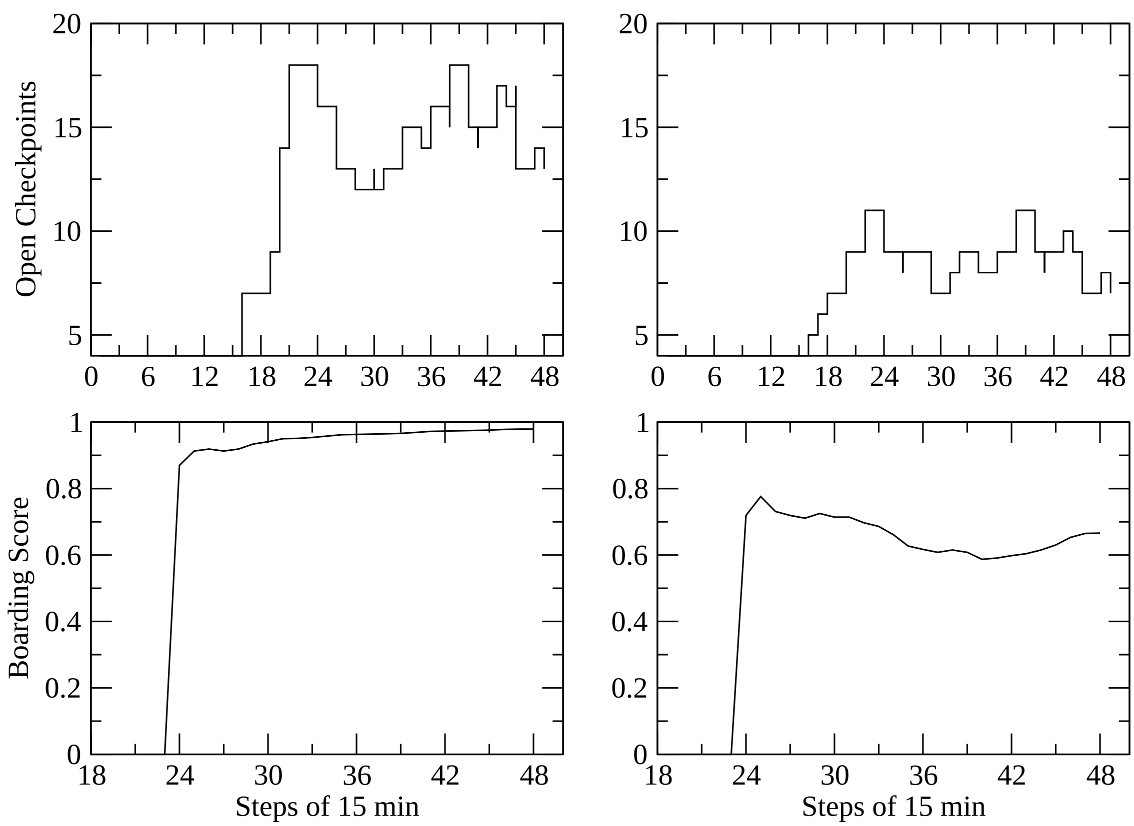

Figure 2. Number of open checkpoints at security check c_S and corresponding boarding score S_B

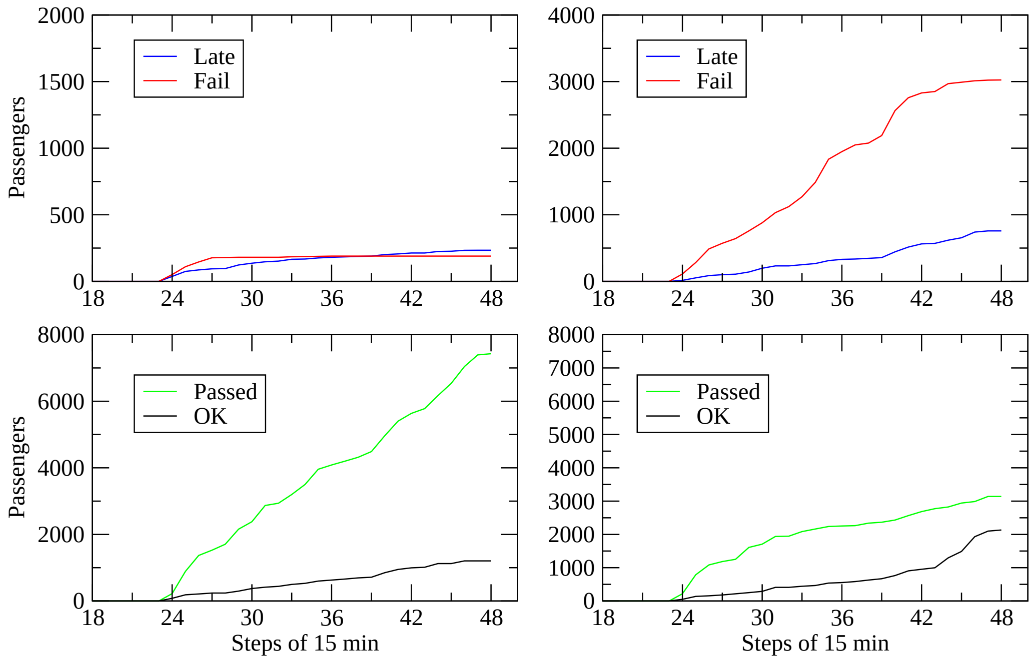

Figure 3. Left: Number of passengers corresponding to checkpoints and boarding score on the left of Fig. 2; Right: Number of passengers corresponding to the right of Fig. 2

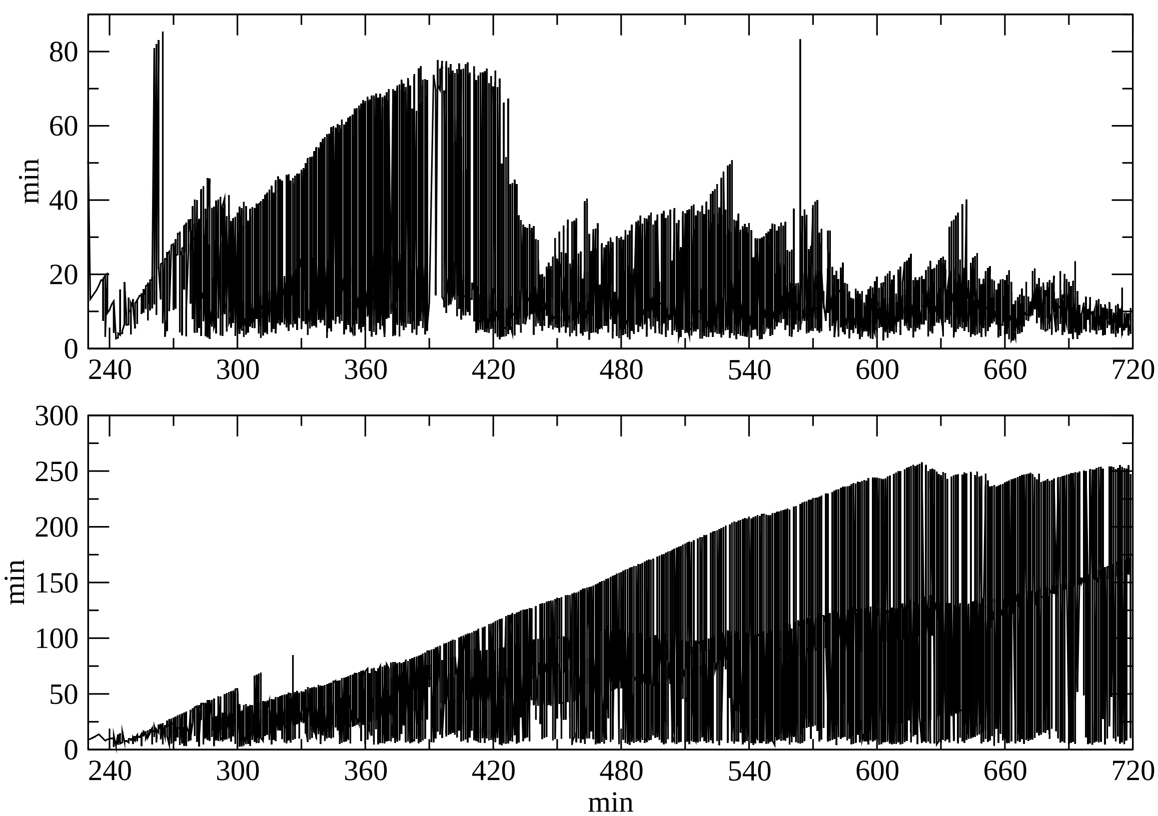

Figure 4. Top: Process time T according to the left of Fig. 2; Bottom: Process time T according to the right of Fig. 2