Airport Operations Modelling: Agent Based Modelling of Ground Crews

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Airport Operations Modelling: Agent Based Modelling of Ground Crews

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Abstract Contribution presents the results of design research project aimed at the development of a simulation model for regional airports ground crew operations using a novel hybrid DES-ABM approach. We have used DES methodology to model the aspects of airport operations that are static or outside the main scope of our model, e.g. flight traffic, and ABM methodology to model the operation of ground crews, where the scheduling and work processes are variable. Use of ABM allows us to model the dynamic aspects of ground crew operations, such as dynamic scheduling and assignment of crews to flights, making the model more realistic and more flexible than when using DES alone. The hybrid DES-ABM simulation model is to be used in a ground crew scheduling system development for validation and optimization of heuristic scheduling algorithms. The resulting model contributes to the knowledge of domain experts with measurable improvements of ground crew scheduling solutions.

Keywords: • airport operations • ground crew • simulation and modelling • agent based modelling •

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1 Introduction

International airports are operating in a competitive environment. The requirements of low cost airlines and prevalence of cost-cutting measures in aviation is forcing airports to optimise their operations and reduce costs while still offering efficient and high quality airline and passenger services. Efficiency, quality and costs are conflicting criteria, presenting airports with a difficult optimisation problem.

To improve efficiency and reduce costs, an airport can optimize the availability, i.e. schedule, of resources used for passenger and airplane services. However, airports are complex logistics systems, and the analysis and optimization of processes can be a tedious and time-consuming task. Airport processes have their own specifics since they can be interleaved and can therefore not be analysed separately. Since they are also subject to frequent changes, they cannot be modelled with an exact mathematical approach.

A wide range of scheduling problems can be found in the airports and elsewhere in the airline industry. Scheduling problems in these environments do not have straightforward solutions. Their complexity varies according to the number of constraints addressed. Typical scheduling problems in the airport domain are: aircraft scheduling (Bian, Burke, Jain & Kendall, 2005; El Moudani & Mora-Camino, 2000; Gurtner, Bongiorno, Ducci & Miccichè, 2016; Yan & Chen, 2008), ground crew scheduling (Clausen, 2011), disruption management (Pereira, Fadigas, Senna & Moret, 2011)(Love, Sørensen, Larsen & Clausen, 2002), aircraft landing sequence scheduling (García Ansola, García Higuera, Pastor & Otamendi, 2011; Tavakkoli-Moghaddam, Yaghoubi-Panah & Radmehr, 2012) or personnel training scheduling (Brucker, Qu & Burke, 2011). Particularly in the domain of personnel scheduling, the most popular type of scheduling problem is the aircraft crew scheduling, while the problem of ground crew has mainly been neglected. Nevertheless, if an airline wishes to produce a high quality service for their passengers, the ground crew is as important as the aircraft crew.

The aim of our research was to produce a viable approach to solve ground crew scheduling problem at the airport. The contribution of our research is an IT artefact used to automate workforce scheduling and shift generation at a small international airport. The system produces floating shifts adjusted to variation of workforce requirements throughout the day in a fraction of the time needed for manual schedule preparation, and allows dynamic rescheduling in case of unforeseen events or disruptions. In order to achieve optimal workforce deployment, we needed to minimize the criteria of personnel costs and aircraft delay costs. Prevalent methodology for this purpose is discrete event simulation (DES) methodology, which is well suited for well-defined processes. The dynamics of airport operations however requires a certain level of adaptability, and the modelling of adaptable business process requires a flexible methodology, such as ABM. In this research, we addressed the problem of ground crew scheduling in a more efficient and innovative way. A similar solution for a small airport in need of an adaptable system
with accurate feedback and the possibility of ad-hoc changes does not exist according to our literature research.

This paper presents the development of a novel hybrid DES-ABM simulation model of regional airports ground crew operations, which will be used for schedule verification and optimization, specifically for the optimization of workforce quantity present in work groups covering specific types of tasks during the working day at the airport. The simulation model can be used to support the scheduling process in international airport of similar size.

2 Literature review

Since 19% of delays in air traffic are caused by airport operations (Burke et al., 2010), these operations cannot be neglected. Diverse approaches and simulation studies have been presented in the literature. As discussed in Bazargan (2004), to efficiently cover the aircraft maintenance operations, aircraft were classified according to the stopover time. Based on the length of stopover, the entire maintenance program with exact numbers of technicians and daily shifts are proposed. Kleinman, Hill & Ilenda (1998) have used stochastic methods to calculate the delay costs in air traffic. Attempts were even made to influence the schedule of aircraft landings in order to balance the workload of ground staff. Boysen & Fliedner (2011) have tried to adapt the landing schedule in order to efficiently schedule the ground crew.

In general, most of the research in the area of airport operations is focused on optimization of airport surface operations (Weiszer, Chen & Stewart, 2015), in some cases divided into passenger-related tasks and aircraft-related tasks (Clausen, 2011). Most of the solutions for ground crew scheduling are focused on only one work group (Chu, 2007; Lin, Xin & Huang, 2015; Weiszer et al., 2015). Herbers (2005) covers some aspects of ground staff planning with proposed procedures for requirement planning. Some of the solutions are limited to fixed shifts and static demands (Lin et al., 2015), while others use mathematical models not appropriate for complex systems (Bazargan, 2004; Qi, Yang & Yu, 2004). In general, the approaches to shift planning and crew assembly often use assumptions with strongly limited validity, or deal with simplified problems, thus limiting wider practical applicability.

3 Methodology

3.1 Design science research

Design science research is a process of creating new knowledge through design of novel and innovative artefacts and analysis of their performance with reflection to enable improvement and understand the behaviour of aspects of Information Systems (IS) (Vaishnavi & Kuechler, 2015). According to Hevner, March, Park & Ram (2004), design science research in IS addresses the so called “wicked” problem, characterized by
unstable requirements and constraints, complex interaction between subcomponents, inherent flexibility to change design processes, dependence on human cognitive and social abilities. Considering all these characteristics, we concluded that the problem of ground crew scheduling matches the description given. Similar to other design science research our objective is to develop a technology-based solution to a relevant problem of personnel scheduling (Vaishnavi & Kuechler, 2007).

Hevner (2007) introduces the three design science research cycles in a design research project: the relevance cycle, the rigor cycle and the design cycle. The research process model as presented in Vaishnavi & Kuechler (2008) consists of awareness of the problem, suggestion, development, evaluation and conclusion. These steps and cycles, together with the design science research checklist (Vaishnavi & Kuechler, 2007) were used as a guideline to develop the artefact.

Our main research question, that we have sought to answer, was:

- how can the addition of ABM components to a DES airport ground crew model be used to improve the model in terms of adaptability and comprehensibility?

### 3.2 Modelling and Simulation

A part of the IT artefact development phase was the development of a simulation model for validation and optimization of heuristic scheduling algorithms. According to Borshchev (2013), three different types of simulation methods can be applied to a given problem, based on the abstraction level of the model. System dynamics (SD) (Forrester, 1961; Sterman, 2000), discrete event simulation (DES) (Stewart, 2004), or Agent based modelling (ABM) (Gilbert, 2007) can be used to map the real world problem to the model.

Most of the simulation solutions for ground crew scheduling at the airport are based on DES method. Although this approach has historically had a significant success in scheduling process optimization, the addition of ABM based components can add more flexibility to a simulation model. Using ABM, we can model the movement of individual crewmembers (as agents) who can make their own decisions about the performance of the tasks assigned to them according to a predefined set of rules. Most of real events are much easier to model using agents; therefore, the model is more realistic and flexible than the DES model. Nevertheless, both models enable monitoring of resource utilization and other important statistics. According to Siebers, Macal, Garnett, Buxton & Pidd (2010), ABM is a better choice for dynamic process modelling since descriptive models of decision making processes can be included in the model, whereas DES models are more appropriate for the normative approach. Although ABM can be considerably more difficult to develop than SD and DES models, it allows the spatial or geospatial aspect to be included in the behaviour of an individual agent.
3.3 Proposed research design

In our research, we combined the design science research project with the simulation modelling approach. At the beginning of the research, the identification of opportunities and problems in the actual ground crew scheduling environment took place. Afterwards, the criteria were set to enable evaluation of the efficiency of the proposed artefact. Semi structured interviews were conducted with scheduling experts for each service group with the goal of identifying the tasks and scheduling criteria.

In this paper, the second major iteration of the relevance cycle is presented. Outputs from the experimental and field-testing were used to improve the artefact. In the rigor cycle an exhaustive literature and related work study in the knowledge base was conducted to ensure the presented solution is not only a routine design based on the application of known design process and artefacts. Since the combination of DES and ABM has not been previously used to solve the ground crew scheduling problem, our contribution can be seen as an improvement. In the final phase, our artefact came in a form of an instantiation.

In the following section, we present the development of our artefact. Following the steps proposed by Vaishnavi & Kuechler (2008), the problem is defined and the model suggestions are given. The model is then developed and evaluated with proper conclusions given. In the phase of development, simulation modelling techniques were used to achieve the given goals.

4 The problem definition

The aim of this step is to generate problem awareness. The modelled airport is a regional hub located in the southeast Europe with over 30,000 flights and over 1,400,000 passengers per year. The airport has a single 3300 m long runway equipped with CAT III/B Instrument Landing System, a 23 m wide taxiway, and 25 independent parking positions. Airport’s Aerodrome Reference Code (International Civil Aviation Organization) is 4E. The terminal capacity is 500 passengers per hour, with 13 check-in counters and 2 baggage claim conveyors. The total area of the airport is 320 hectares. The airport was selected for the design research project due to similar size and organization to other regional airports (e.g. Salzburg WA Mozart airport) and the established R&D relationship with the faculty.

Ground crew scheduling problem at the considered airport and therefore also the operation of the simulation model is confined with the arrival and departure of the aircraft, i.e. tasks can only be performed on aircraft, present at the airport. The tasks are performed in a predefined time sequence according to several criteria (aircraft size, carrier, etc.). The execution times specified by the airport scheduling experts are deterministic, i.e. fixed, making the model deterministic as well. The execution times are determined from experience and represent the maximum expected task duration.
Until the proposed IT artefact based solution was introduced, management at the airport used spreadsheets to manually generate schedules based on their knowledge and prior experiences. Ad-hoc solutions and schedule changes due to frequent disruptions of the aircraft timetable (arrivals and departures) required a lot of effort and were too slow to allow a timely but optimal response. In addition, the workforce requirements in peak and off-peak times were not properly addressed and have been only partially solved with the employment of part-time workers (students).

Interviews with manual scheduling experts, e.g. crew managers, were conducted to extract the decision criteria and heuristic rules for scheduling. All the criteria identified were stored in the Flight Information System (FIS), enabling a smooth transition to the algorithm-based scheduling. The identified scheduling criteria were as follows:

- Type of stopover (arrival or departure),
- Flight type (charter, scheduled or transfer),
- Aircraft type (320, CRJ, SH3 etc.),
- Carrier (9 carriers are currently using the airport),
- Destination.

### 4.1 Ground crew operations

The scheduling criteria presented in previous sections were used to define tasks which have to be performed for the arriving and departing aircraft. The tasks of the ground crew are performed by crewmembers with appropriate skills. An individual crewmember can have one or more skill groups defined. Each skill group incorporates several different tasks; therefore, crewmembers in this skill group are able to perform all the given tasks in their skill group. Some tasks are simple and can be performed by almost any skill group (e.g. luggage handling), while others require specific knowledge or other skills and can therefore be performed only by certain skill groups. With the workforce requirements calculated, shifts have to be defined. Several rules are given to define a start time and the duration of the shift: maximum and minimum duration, allowed start times, number of shifts an employee can be scheduled to during one workday. The availability and schedule of resources used also have to be defined. During one shift, each skill group performs only one type of a task. In general, tasks are divided into three main groups: a) aircraft supply, b) passenger service and c) technical service.

Figures 1 and 2 describe the process of passenger service (fixed tasks are not included) for the arrival and departure of a scheduled passenger flight (aircraft of type S, e.g. Canadair CRJ 200 LR). The passenger service department included six different operational tasks, which were mapped to skill groups with the same name, listed in Figure 1. Most of the skill groups required two persons to be assigned to the skill group. The two exceptions are the skill groups lost luggage referee at the arrival and Sales desk referee at the departure, where according to the requirements; two workers should be assigned to the task. The required number of individual workers in specific task group is
not shown in the graphical presentation. As it can be seen from Figure 1 and 2, most of the tasks overlap and must be performed simultaneously. The tasks that require a strict sequence are the tasks of guidance and transfer in Figure 2, which cannot be stared before the check-in task is finished. The sales desk in this particular case is opened three hours prior to the departure of the aircraft and stays opened one hour after the departure.

The arrival services are mostly completed long before the departure of an aircraft, however they affect the availability of ground crew groups and equipment.

![Figure 1: The process of passenger service for the arrival of type S aircraft](image)
Figure 2: The process of passenger service for the departure of type S aircraft

Our work in the relevance cycle has so far resulted in two versions of heuristic workforce requirement scheduling algorithms and a shift construction algorithm. The algorithm for generation of floating shifts and assignment of individuals to shifts is described in (authors, source anonymized). The shifts are generated according to the generated workforce requirements and shift length demands. In order to automate the validation of algorithm-generated schedules and shorten the algorithm tuning-verification cycle we have developed a simulation model of airport operations used, which combines DES and ABM. The model development is described in the following chapters.

5 Selection of modelling methodology

Different simulation methodologies can be used in airport scheduling. While the most frequently used (especially in the case of passenger flow) discrete event simulation (DES) has been used to simulate airport situations for decades, agent based modelling (ABM) has only recently gained attention of the researches in the area of airport scheduling. According to Piera Eroles, Ramos & Fernandez Robayna (2009), DES has proved to be efficient in the case of airport ground crew scheduling problem. ABM has been used in various cases, from optimization of the air transportation system (Bouarfa, Blom & Curran, 2016), to airport capacity prediction (Peng, Wei, Junqing & Bin, 2014). Due to efficient usage of DES and ABM combination in other personnel scheduling domains, we can expect that the combination of both methods can also add significant value in the case of airport ground crew scheduling. While the DES methodology is efficient to represent the flow of agents and diverse resources in the case of airport ground crew scheduling, ABM components allow us to model the activities and the communications
between crew groups, their supervisors and aircraft management in detail. Using this methodology, we can lower the level of abstraction and enable a comprehensive insight on the ground crew problem, making it clear and presentation friendly when presenting it to the airport management. In addition to the advantages of the DES, where the resource utilization and time agent spends for individual activities can be addressed and optimized, the ABM allows the spatial insight on agents with detailed ground movements and estimation of time needed for the movements from one site to another.

According to Clausen (2011), ground crew tasks can be divided into passenger-related tasks and aircraft-related tasks, where the latter include maintenance, cargo, baggage, loading, cleaning, catering, towing and operations. While some personnel scheduling problems are not constrained with the availability of equipment, ground crew uses several different types of equipment within their tasks. In addition, skills of personnel have to be considered. Only few tasks performed by ground scheduling crew are plain, with no sequences and dependencies defined. Several overlapping tasks have been identified, while other tasks are interconnected. Due to these attributes, the ground crew scheduling problem gains complexity, number of constraints and variations of schedules. Mathematical models used to resolve the personnel scheduling problem in advanced scheduling tools could be used at the level of individual work group, but due to interconnectivity of tasks and resources in a case of ground crew, other techniques need to be employed (Qi et al., 2004). Since high level scheduling solutions can be too costly for small airports, many of them still use solutions which combine manual scheduling with basic spreadsheets or similar basic tools.

6 Model development

Since most general-purpose modelling tools are limited to a single methodology (SD, ABM, DES), the combination of DES and ABM methodologies within a system model generally required the utilization and integration of several general-purpose modelling tools or the development of proprietary code for the implementation of the ABM model. However, the AnyLogic tool (http://www.anylogic.com) allows the use of all three simulation methods, and from version 7 it also enables the usage of agents in DES and ABM model, allowing easier combinations of both methods to be implemented in one simulation model.

Borshchev (2013) emphasizes the possibility of a DES servers and entities to be implemented as agents and use of agents to introduce inter-component messaging into the model. The latter approach is used in the presented case. DES and ABM models are linked via passing a message between aircraft and work group agents, where aircraft traffic model is presented as a DES model and ground crew work model is presented as ABM model.
6.1 Model data

The simulation model generates arrivals and departures of aircraft based on the flight schedule data transferred from the FIS (Flight Information System of the airport) into internal Anylogic database. Table 1 shows an example of parameters stored in the database, assembled from the FIS. DD1 defines the date of the flight, FLTNO_A and FLTNO_D describe the aircraft’s arrival and departure code. The type of traffic (e.g. C – charter passenger only, F – scheduled cargo/mail, S – scheduled passenger) is defined in column TRFTYP, ST_A and ST_D show the time of arrival or departure, and ROUTE_A and ROUTE_D designate the arrival or departure airport, and ACTYP defines the type of aircraft.

<table>
<thead>
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<th>DD1</th>
<th>FLTNO_ A</th>
<th>FLTNO_ D</th>
<th>TRFTYP</th>
<th>ST_A</th>
<th>ST_D</th>
<th>ROUTE_A</th>
<th>ROUTE_D</th>
<th>ACTYP</th>
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<tr>
<td>01.05.2016</td>
<td>JP648</td>
<td>S</td>
<td>00:20:00</td>
<td>IST</td>
<td>735</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>S</td>
<td>02:40:00</td>
<td>CPH-BCN</td>
<td>320</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>F</td>
<td>06:25:00</td>
<td>VIE</td>
<td>F27</td>
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<td>CRJ</td>
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<tr>
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</tbody>
</table>

6.2 Aircraft traffic simulation model

The level of abstraction and autonomy has to be identified prior to the development of the simulation model. According to available data, we have identified the DES as the most appropriate method to model the aircraft traffic simulation model. For the purpose of personnel scheduling, only arrivals and departures of the flights are important in our simulation model. Further on, the model was upgraded to the ABM elements where the movement of an element on the surface is easier to implement.

The arrivals and departures constitute of several discrete tasks that involve ground crew members. Delay elements are used to model a simple delay in the process. In our case, the delay elements include the state of arrival or departure services depending on the
ABM of ground services. Services for an individual flight are completed when all the tasks performed by the ground crew are finished. To make the model more transparent, a physical layout of the airport was used and paths of the aircrafts were added to the model. Due to focus on workgroup tasks and client specifications, taxiing and parking logistics were not modelled and are excluded from the model statistics.

The aircraft traffic model consists of two submodels: the Arrivals submodel, and the Departures submodel. The separation was a logical sequence of the airport business rules and inability to track individual aircraft in FIS after the arrival. The arrivals submodel uses the arrival schedule from the FIS to generate the aircrafts. Aircraft taxi to the gates (moveToParkA and queueArr) already waits on the apron for an assignment. The submodel of arrivals ends with an element of parking or exit point from the system. While the model of departures assumes the aircraft is present at the airport and available to start the tasks when needed.

The departure tasks start times are based on the departure times given in the FIS schedule. The modelled departure times depend on the execution of tasks and should not be delayed when scheduling constraints are defined properly. In the Departures submodel an aircraft first has to move to the gates (elements moveToParkD, queueDept and moveToGates), where it is serviced (e.g. boarded by passengers, loaded with baggage, etc.), with the delay modelled with ServiceDept element. Afterwards, the aircraft moves to the runway (moveToD, TakeOff). The queues were modelled to enable the simulation of an aircraft waiting until a taxiway or a gate or a parking area is available. The FIS data is gathered in the elements arrivals and depts., linked to a local database with arrival and departure schedule and service requirements for each flight. The service requirements are assigned to every aircraft at the moment of its entry in the model according to the ideal heuristic requirements, where the availability of workforce is not an issue. The service task parameters are contained in the messages generated by aircraft agents and sent to the relevant ground crew work group agents. Work group agents maintain an internal queue of tasks, which are executed according to the FIFO (first-in first-out) rule and specified service start time. Since AnyLogic models all DES entities as agents, the addition of the message feature to the DES aircraft traffic model was straightforward.
6.3 Ground crew model

Due to relatively rigid process modelling in DES methodology, which hinder the modelling of dynamic aspects of ground crew operation, the decision was made to incorporate ABM to allow dynamic ground crew process modelling, while preserving the required level of abstraction. ABM has allowed us to model the dynamic aspects of ground crew operations with better analogies with the actual processes, making the model more comprehensible. ABM allows us to model the entities and processes in a way that is closer to reality, i.e. the ground service work groups have the role of service stations, however they travel to the aircraft and not vice versa; the sequence of services depends on the availability of service work groups, and the place of an aircraft within a service work groups’ internal queue; and perhaps most important, an aircraft can be serviced by several work groups simultaneously.

Each work group agent has an internal state chart model of its task process, as shown in Figure 4. The initial state is Waiting, and here the agent waits for a service request message from an aircraft, with service requirements specifications (i.e. number of personnel, desired start of service, desired end of service). These requests are added to the internal queue and processed according to the FIFO rule. If an agent is in the Waiting
state (i.e. free), a request is queued, and model time equals the specified service start time, the work group agent moves to the aircraft, and begins the requested service, and performs until specified end time. After the servicing is complete, the work group agent sends a message to the aircraft and proceeds to the next aircraft in its internal queue or returns to the waiting area.

![State chart of the ABM of a ground crew group](image)

7 Evaluation

The FIS serves as a database for the ground crew scheduling, providing an accurate source of data about arrivals and departures at the airport. The start, end and work requirements of tasks, which have to be performed at an aircraft, are determined by the attributes of the aircraft to be serviced. The availability of workers is determined by the workforce requirements schedule. The schedule is generated and optimized by the heuristic algorithm. By combining the schedule of optimized workforce numbers and ideal requirements of a flight, we can verify the effects of a generated workforce requirements schedule in practice and foresee the potential flight delay costs.

Workforce requirements generated by the heuristic method described are used to vary the availability of workers during the simulation run. Workers are modelled as resources and arranged into work groups. Each work group performs only one type of task. A work group is then modelled as an agent.
Flight delays in the simulation results are mainly caused by the occupancy of personnel with other tasks (current priority rules are defined as a FIFO service system). Therefore, the discrepancy between ideal and modelled workforce requirements exists. Delays in the presented model are calculated for departures. Delays are measured by comparing the scheduled departure time as recorded in the FIS, and the departure time as recorded by the simulation model. The modelled delays are however exaggerated because the start times of tasks are not yet optimised and the start of a task is delayed unless all required workers are available. Further development of the model will include the execution of tasks with a reduced number of workers and longer execution time and the execution of tasks at earliest opportunity (i.e. time shifting of tasks) and should model flight delays more accurately.

8 Conclusion

Although managing disruptions of airport ground processes is a complex task (Kuster & Jannach, 2006), suitable personnel and equipment scheduling solutions are vital for efficient operation of an airport as a system. International airports face a constant challenge to coordinate all the departments, efficiently perform all operations needed and provide an excellent service to the passengers. Airport ground crew scheduling system does not have a straightforward or mathematical solution which could easily be implemented. The complexity of the problem and the necessity to solve it is not only an attribute of large airports. In our research, no appropriate solution or algorithm to solve the ground crew scheduling problem in a small international airport was found. Therefore a research was conducted to develop and evaluate an artefact to solve the ground crew scheduling problem in a small international airport.

Two versions of heuristics were developed in this artefact to implement an efficient scheduling algorithm. The algorithm for generation of floating shifts and assignment of individuals to shifts is described in previous publication (Rodič & Baggia, 2013). Further, on, a simulation model was built to verify the proposed algorithm and enable further optimization of the processes. The simulation model presented used two simulation methodologies, DES and ABM. This combination provides us with an efficient and realistic model, which is used to simulate the results of the developed scheduling algorithm. According to the design science research checklist, all questions were answered during the presented phases.

We were able to answer our main research question “How can the addition of ABM components to a DES airport ground crew model be used to improve the model in terms of adaptability and comprehensibility?”: using a suitable tool (i.e. Anylogic), we can combine the ABM and DES methodologies within a single model. Since ABM modelling requires more effort and produces a more complex model, it should be limited to the modelling of system elements, that are by nature dynamic and cannot be suitable modelled using DES methodology. Such an approach improves model comprehensibility
by more accurately modelling the behaviour of system elements with autonomous, dynamic behaviour, such as ground crew groups.

Limitations of our research stem from the specifics of the airport processes, which are mostly dependent on its size. Therefore the developed approach and artefact can be reliably expected to be applicable only to airports of similar size. Furthermore, the execution times specified by the airport experts are deterministic, i.e. fixed, making the model deterministic as well. The development of a stochastic model would require lengthy recording of actual task execution times and matching with appropriate distribution function. The airport management has decided not to implement such a survey as of this time.

Our future work on the research will involve model-based optimization of work-force requirements as outlined in the previous section and the adaptation of the entire scheduling solution to the airport’s development of infrastructure.

References


