An analysis of a ground traffic control decision support system based on the 3-step principle of heuristic decision making

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Abstract

Aim The aim of this paper is to demonstrate that the 3-step principle of heuristic decision making (Gigerenzer et al., 1999) can be used to analyze how the design of a decision support system can influence operators' decision making behavior. The 3-step principle distinguishes an information search (1st step), terminating the information search (2nd step), and finally making a decision (3rd step), based on the acquired information. *Background* Ground traffic controllers manage the ground movements of departing and arriving traffic. Therefore they must pursue multiple goals in parallel, such as releasing aircraft to depart on time, minimizing the number of stops to save fuel, handling arrivals, and providing high throughput at the airport. Decision support systems are developed to support controllers to manage these tasks efficiently. *Method* A petri net model was developed for a ground controller at Dallas Fort-Worth Airport to simulate different controller heuristics. In addition, two design variants of ground control decision support system were realized in a medium-fidelity simulation and tested in HITL simulations. *Results* The application of the 3-step principle, within the airport-controller petri net model, is able to describe how the design variants of a decision support system can strongly guide participants' information search and therefore their decision making behavior. *Discussion* The application of the 3-step principle for the design of assistance systems is discussed.

Introduction

Airports are complex environments where many movements must be coordinated to assure an optimal workflow. Therefore ground traffic controllers need to be aware of the current traffic, the scheduled departure and arrival times as well as the required taxi-times depending on the individual stand of the aircraft.

For a ground controller the complexity usually leads to a conflict regarding the attainability of concurrent goals. Possible goals to optimize ground movements are:

- Minimizing taxi delay: move aircraft from their stand to the runway without stops and standing in line for a long time.

In D. de Waard, K. Brookhuis, F. Dehais, C. Weikert, S. Röttger, D. Manzey, S. Biede, F. Reuzeau, and P. Terrier (Eds.) (2012). Human Factors: a view from an integrative perspective. Proceedings HFES Europe Chapter Conference Toulouse. ISBN 978-0-945289-44-9. Available from http://hfes-europe.org

- Minimizing departure delay: release outbound aircraft so that they depart close to their scheduled take of time.
- Handle arrivals: Fit incoming aircraft in the sequence without interference of the movements.
- Provide for a high throughput: Allow for optimal times between a departing aircraft and another.

While the controller wants to enhance the throughput for example, he/she may create lines on the taxiway in front of the runway, disregarding the waste of fuel by greater taxi delays.

Due to the amount and complexity of the information about all parameters combined, the controller cannot acquire the entire situation as humans' cognitive capacity is limited (Simon, 1990). Also a lack of time can favor a quick decision. Under those conditions it is reasonable to use only sparse information and decide by simple rules of thumb instead of taking all given information into account (Gigerenzer & Goldstein, 1996). By deploying such simple rules, so called heuristics, cognitive effort is reduced to remain capable of handling the traffic effectively. Well elaborated decisions may be ideal but decision making on the basis of sparse information may be a satisficing strategy that can be even more efficient because decisions can be made quickly (Simon, 1955).

Gigerenzer et al. (1999) characterize heuristics by three rules which must be applied step by step to come to a decision: In the first step the information necessary to come to a decision is sought. Secondly the search is stopped due to a given time constraint or when sufficient information is acquired. The last step is the decision making itself and results from the two former steps.

In order to support the controller to search for and interpret information more easily, assistance systems are developed that focus on certain aspects of the world. Information is gathered and combined so the controller can read the concentrated information and thereby pursue one specific goal very easily (Endsley, 2001). In one study by Riddle et al., 2012 two different assisting systems - represented in a display - were developed and tested to support the ground controller's task: Temporal Constraint Visualisation Aid (TCV) and the Optimal Release Timeline Visualisation Aid (ORT) (see figure 1).

The Temporal Constraint Visualisation Aid system provided the controller with a spatial representation of temporal distances between aircraft, visualizing the constraints for the required take-off separation of 72 seconds. Therefore bars of different colors were displayed along the taxiway to indicate the ideal position and moment to release an aircraft.

A different assistance system was the Optimal Release Timeline Visualisation Aid. It drew lines at the flight strips of departing aircraft indicating the ideal points in time to release the aircraft from the gates. The lines moved with time and allowed a scheduling of the next movements. The Optimal Release Time provided information for an optimized trade-off between little taxi delay and a high throughput.

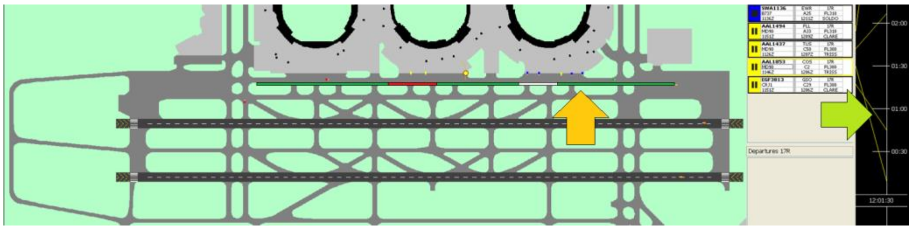

Figure 1: Assistance functions on the display. The orange arrow marks the TCV-Aid, the green arrow the ORT-Aid.

Performance data of that study (Riddle et al. 2012) revealed that participants in the TCV-Aid condition were more focused in minimizing taxi-delay, while participants within the ORT-condition, followed a trade-off between little taxi delay and high throughput. Also these data indicate that information which is easy to access is preferably employed. Thereby it can be inferred that a ground traffic controller would also rather pursue the goal which is easy to access from the assistance system, applying heuristic decision making.

The search for information on a display can be measured via eye tracking. Therefore the areas at the controller's working position which contain the relevant information of the airport processes can be defined as areas of interest (AOIs) where the frequency of attending can be observed for each of them. By the frequency the relevance of the different sources of information can be derived.

Computer models for visual attention have been developed which can explain participants' visual attention over time. The SEEV model (Wickens & McCarley, 2008), which postulates salience, effort, expectancy and value as the four main factors of the visual attention, has been proven suitable for explaining participants' visual attention (Gore, Hooey, Wickens & Scott-Nash, 2009). However, it has not been addressed in what way decision making heuristics can determine the visual search for information.

Like in former studies by (Moehlenbrink, 2011; Werther 2006), in this paper a petri net human-machine-model was developed to simulate an airport and also to simulate the controller, using CPN-tools (Jensen & Kristensen, 2009). Thereby the controller's search and decision making behavior by means of different heuristics are implemented with respect to the information provided by the different assistance systems.

In this paper, it is addressed how the 3-step principle of heuristic decision making can be applied for explaining participants' visual attention over time. So it is claimed here, that participants' information depends on the heuristics applied. Different design variants of an assistance system influences controllers' attention on certain information to come to a decision. In this paper it should be demonstrated, that an implemenation of the 3-step principle of heuristic decision making offers a valuable basis to predict particpants' visual attention while completing a complex task. Thereby the definition of the first step (information search heuristic), defining which information a controller takes into consideration includes important assumptions about his/her visual search. This paper gives attention to the question how the formalization of controllers' heuristic decision making can explain their information search behavior as the first step of the decision process. It is illustrated how an understanding of heuristic decision making behavior can be derived from assumptions about attendance to specific information. An implementation of these assumptions into a human-machine-model allows a comparison of model data to empirical gaze data from human-in-the loop simulations.

Method

In this paper eye-data files of three male pilots are analysed, demonstrating the major idea for modelling and predicting participants' information search, based on a heuristic decision making petri net model. All three commercial airline pilots, considered as a convenient sample to complete the ground traffic control task, sat in front of a ground traffic display. In addition there was a 150° projection of an artificial outside view behind this screen. During the task a remote eye tracking system recorded the participants' gaze data. The screen and the projection showed a simulation of Dallas Fort-Worth Airport.

The task was to release aircraft efficiently. To do so an easy control panel was realized on the display. To reduce the difficulty of the simulation only the ground movement of the in- and outbound traffic needed to be coordinated by the participants, which implied only the clearances to taxi to the gate or towards the runway.

The study was conducted with three assistance conditions and varied between subjects. So for demonstrating the idea, we look at three case studies: In case one, a pilot was assisted by the TCV-Aid which was displayed on the screen, in case two a second pilot used the ORT-Aid, while in case three, a third pilot had no additional assistance on the ground traffic display. At the same time gaze data was recorded to analyze the distribution of visual attention at the areas of interest (AOIs; see figure 2). Those AOIs were geared to the correspondent areas on the display. So they were distinguished in space but also regarding their relevance to the tasks (Wickens & McCarley, 2008) to deliver a clearance for inbound traffic for example the arrival section of the display would be expected more important than the departure list. Not shown in the figure but also considered as an essential source of information was the outside view on the projection in front.

Besides the study a petri net based human-machine-model was developed. The model contained the layout of the simulated airport as well as a rudimental simulation of a human decider. That decider was realized in different ways corresponding to the assistance systems and designed to come to a heuristic decision by means of sparse information. Figure 3 illustrates the principle of the decision making process in the petri net model. When an aircraft requested taxiing it was put into a loop of waiting aircraft. One after another then was checked and due to the heuristic rule either released or postponed to the loop to be re-evaluated later. The mentioned checking was in accordance with the 3-step principle.

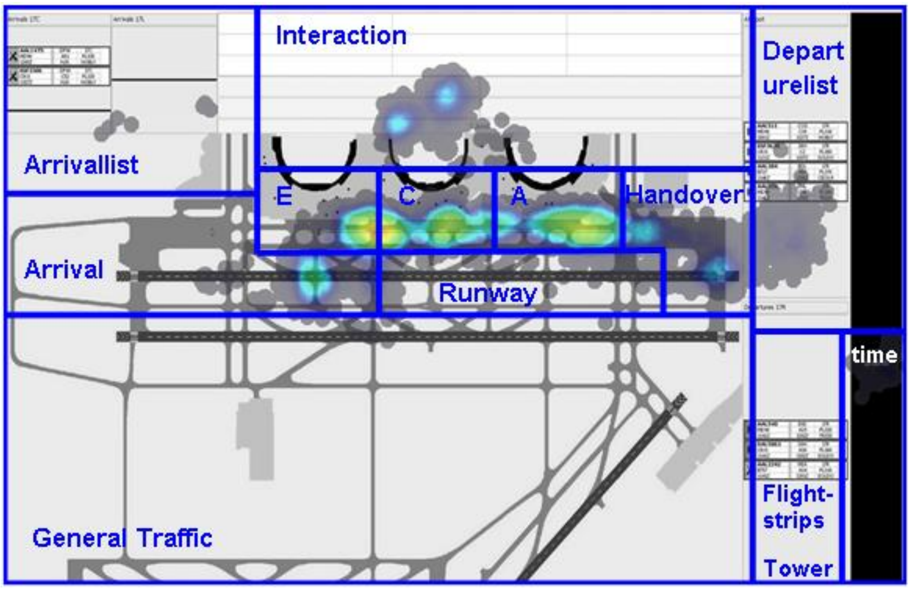

Figure 2: Airport layout with an AOI-overlay.

The heuristic assumed for the pilot in the TCV aid that he followed the information about empty and blocked spaces on the taxiway, whereas the model related to the ORT aid released aircraft at the recommendation of the calculated optimal time. For the control condition there is no strong indicator for heuristic decision making. In the model it is assumed that the pilot of the control condition looked for the scheduled take off times, distances between aircraft on the taxiway and estimated taxi times, how long it takes to get to the runway, in order to decide when to release an aircraft.

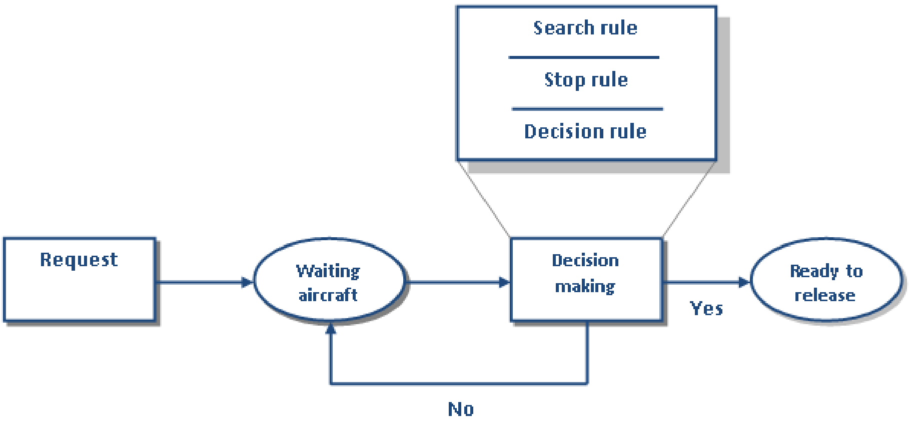

Figure 3: Schematic depiction of the controller's decision making implemented in the human-machine-model.

Table 1: Principle of counting the values in the decision making process (example of a request for departure from terminal E).

Task	Step	Heuristic/ Assistance	Relevance of AOIs: Terminal_E	Terminal_C	Terminal_A	Departure-list	...
Departure Release Terminal E	Request	No	0	0	0	0	...
		TCV	0	0	0	0	
		ORT	0	0	0	0	
	Search	No	+1			+1	
		TCV	+1	+1	+1	+1	
		ORT	+1			+2	
	Stop	No				-1	
		TCV		-1	-1	-1	
		ORT				-2	
	Positive decision	No	-1				
		TCV	-1				
		ORT	-1				
	Reevaluation decision	No	-1				
		TCV	-1				
		ORT	-1				
	Waiting aircraft	all	0	0	0	0	
	...	...					
	Search	...					
	...	...					
	?	No	55	61	81	98	
	?	TCV	111	160	188	99	
	?	ORT	89	132	129	426	

The controller-airport-petri net model was run independently in a simulation. For every step of the decision making process, values were counted within the model related to the AOIs, which had been defined relevant for the particular tasks. For example, if an aircraft was checked whether it could effectively be released, the model counted plus one to the value of the departure list AOI during the information search.

This value lasted till the decision - whether to release or not - was made and then subtracted again. In the output a value for every AOI and second was extracted and later summed up. The increase and decrease of the AOIs' values were not set to match the data but based on simple considerations about which information would be necessary to assess and where to find it. The approach is associated to the implementation of the SEEV model by Gore, Hooey, Wickens and Scott-Nash (2009) for instance. However, within the approach introduced here, different values are defined for different heuristics. For the values (relevance*importance), only the relevance of the values is considered, as a first simplified version. Table 1 shows an exemplary counting of the values for the consecutive subtasks to release an outbound aircraft on terminal E.

The implementation of the 3-step principle for the determination of visual attention corresponds to the implementation of the decision making itself; the longer it took to search for the appropriate information the higher the value counted in total.

Results

The data for every AOI derived from the human-machine-model as well as the actual gaze data from the case studies are compared for two different traffic scenarios. Figure 4 and 5 show the comparison between model and empirical data.

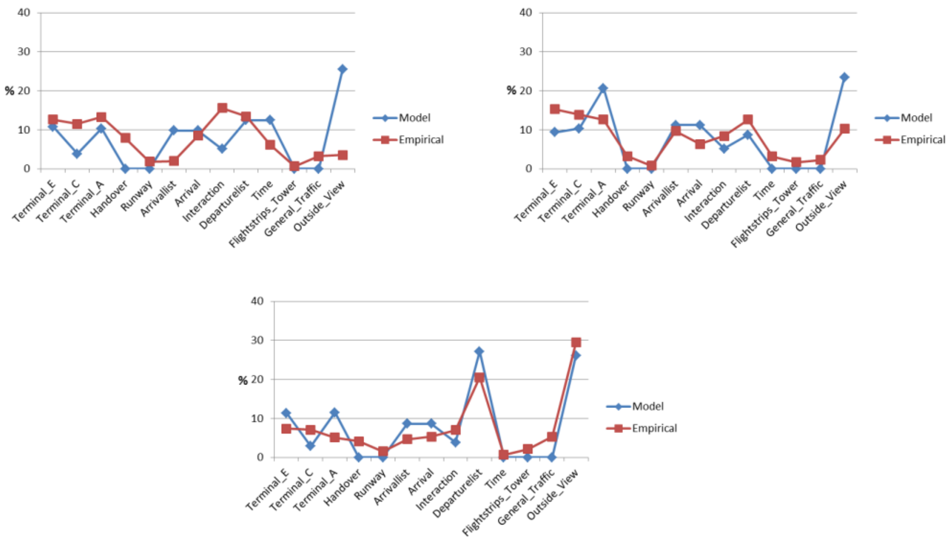

Figure 4: Comparison of the empirical percentage dwell time data to the determined probabilities of attending derived from the model in the condition without aiding system (upper left), the TCV-Aid condition (upper right) and theORT condition.

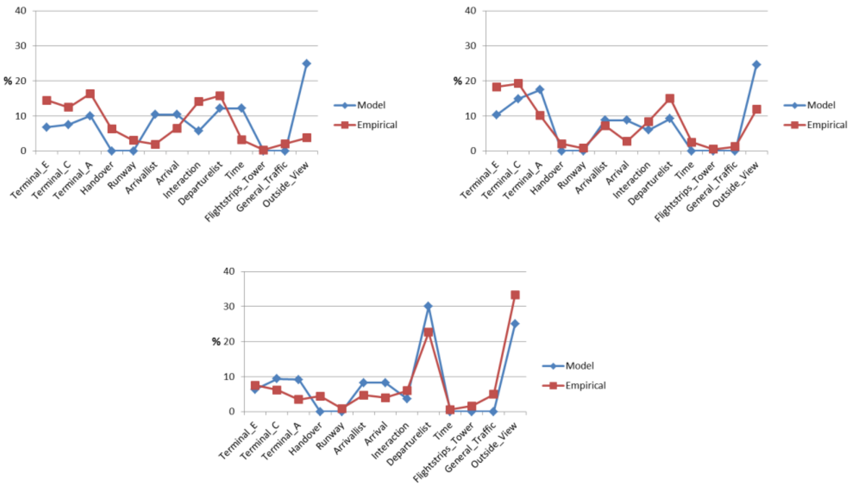

Figure 5: Comparison of the empirical percentage dwell time data to the determined probabilities of attending derived from the model in the condition without aiding system (upper left), the TCV-Aid condition (upper right) and the ORT condition.

The gaze data was measured by the percentage dwell time, the model data was similarly calculated as the probability of attending in two different scenarios. The two curves apparently differ from each other. However, in the TCV-Aid condition the lines match quite accurately and even better in the ORT condition.

Table 2: Correlation between empirical and model data.

			Model		
	Scenario	Aid	No	TCV	ORT
Empirical	2	No	**.135**	.523	.745
	3	No	**.154**	.457	.745
	2	TCV	.277	**.720**	.638
	3	TCV	.435	**.706**	.670
	2	ORT	.278	.635	**.894**
	3	ORT	.398	.614	**.887**

To get an indication of how well the determined values fit the empirical data, the correlations were calculated. In the TCV condition the compared data correlated at r = .720 for scenario 2 and r = .706 for the third scenario. The determined values by the model in the ORT condition resembled the empirical data by r = .894 and r = .887 as can be read in table 2. In contrast the condition without an assistance system did not show any correspondence between the model values and the actual gaze data ($r = .135$ and $r = .154$).

Discussion

This paper demonstrated that an implementation of the 3-step principle into a human-machine-model can be a valuable approach to explain actual gaze data. During implementation of the 3-step principle of decision making the focus was on the information search rule.

It was shown how the search and decision rule can be implemented in an airport-controller petri net model. Further it was analysed that the probability of attending can be well explained on the basis of heuristic decision making. Simulation data generated by the human-machine model were compared to empirical eye data from three case studies.

As the correlations indicate an adequate match between the modeled values and the actual gaze data can be obtained. This finding suggests that the assumption of heuristic decision making can provide important information to explain actual gaze data. Nevertheless, if the heuristic rule the controller uses cannot obviously be identified, the visual attention cannot be predicted.

The implementation of the search rule to determine the probability of visual attending turned out well as the value was counted every second. So the longer the search the higher was the value.

The calculations in the model were based on very simple considerations and also calculated as overall values. Nevertheless the results point to a good approximation to real gaze data as heuristic strategies can be inferred from the experimental setting. The more we know how a controller makes a decision the better we understand where his/her attention is allocated.

Conclusion and outlook

It is possible to determine the controllers' probability of attending by a model based on heuristic decision making. Due to controller's goal different aspects need to be considered and thus information is gathered from different areas. The search for information guides the eyes to the relevant areas while irrelevant information is neglected. This search is guided top down by the pursued goal so the probability of attending can be derived as the applied heuristic of information search is identified. The better the understanding of the controllers' decision making strategy the more accurate the assumptions about the distribution of visual attention can be implemented in a human-machine-model.

Thus the advantage of considering the decision making process within the field of visual attention would be an enhanced accuracy in predicting the probability of attending.

As it is based on heuristic decision making processes the developed petri net model meets the requirement to be simple. In the complex controller's working position the considerations about the probability of attending could be much more precise concerning the numerous different tasks and the related complex visual scanning patterns. In future the SEEV-approach by Wickens and McCarley (2008) could therefore be applied with all its components for a more accurate and adequate prediction of the visual attention.

Also further research could aim to a time related comparison within the human-in-the-loop simulation. Although the data was collected every second and could easily be matched to real gaze data afterwards, the model was not designed to react exactly like a human controller so it could not be applied to a simulation working hand in hand with a real controller without greater restrictions.

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