AUGMENTED REALITY TECHNOLOGY FOR CONTROL TOWER ANALYSIS OF APPLICABILITY BASED ON THE FIELD STUDY

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ABSTRACT - The paper proposes the concept and analyses possible application of augmented reality technologies in an airport control tower. Augmented reality overlays computer generated graphics over real objects in the surrounding environment. To explore the applicability of Augmented Reality technology into the airport tower environment we have performed the field study using the video camera mounted on the glasses worn by the controller to investigate what information are acquired by the towers controllers, if the scanning pattern depends on visual conditions and what are the working methods regarding various information sources. The results indicate that controllers' performance described as head-up and head-down activities depend on traffic load and visibility conditions. Additionally we analysed the information acquisition pattern. In addition, we found statistical difference for different working methods using head-up or head-down information sources.
Keywords: Airport tower, Air Traffic Control (ATC), Augmented Reality (AR), Augmented Vision, Head-up, Head-down Time

1 AUGMENTED REALITY APPLIED TO AIRPORT TOWER

Augmented reality technology allows to present the graphical and textual information overlaid with real environment. Superimposed information can be displayed by head mounted display (HMD) worn by the controller or transparent display placed on the tower windows. The displayed information can include flight data, runways and taxiways occupancy, velocity and acceleration of aircraft, positions of vehicles on the airport surfaces or their trajectories, etc.

The tower controllers often face the problem of low visibility due to meteorological conditions or have to manage the aircraft placed on areas that are not visible from the tower, (e.g. occluded by buildings). Augmented reality by highlighting significant information can improve the performance of visual dependent tasks.

In addition, B. Hilburn [5] reported head-down time in the tower environment as a major contributor to the risk of missing critical events. Additionally, head-down activities shift the controllers' depth focus between the far distance outside the tower windows and the tools and devices inside the tower. Graphical information presented on a transparent head-up or head-mounted display (HMD) can eliminate these problems.

2 RELATED WORK

Although there are some studies concerning head-up time in the tower environment, none of them specifically focused on what kind of information the controller obtains through the window. The previous studies on head-up/head-down time aimed to investigate the usage of various devices or tools and none of them directly concerned direct observation through the tower's windows. Grossberg's study on local (runways) controllers' activity showed that they spent 70% of their time either looking out of the window or at the radar image, and 21% time was addressed to strips [4]. Bruce [1, 4] reported 38% of time spent looking out of the window for local controllers and 47% for ground controllers. The study conducted by D. Pavet [9] using the same technique (camera glasses) as the current study, demonstrated 20% of time focussed on the window for local controllers and ground controllers alike. The recent studies by B. Hilburn [5] show 43% - 49% of head-up time, depending on position (ground and tower position). In his study tower position, represent the local control. However, the head-up time observed during real-time simulation for tower position [6] was only 12%, possibly on account of the introduction of a tool that required head-down manipulation, or simply an effect of simulation. The pilot study we conducted [8] showed that controllers spend 30%-40% of their time looking out of the window, which is consistent with the results of other researchers.

In summary, the results from previous studies report from 12% to 49% of head-up time, depending on the position and the tools used by the controllers. However, none of them investigated what was happening during the head-up time.

The present study aims to investigate what kind of information the controllers gain by looking out of the window and at which moments direct observation is significant. We assume that controller performance will vary depending on traffic density and visibility conditions. The controller's performance, dependent on the variables, will be broken down into:
• Head-up activities - defined as time spent looking out of the tower's windows.
• Head-down activities - defined as time used for other sources of information e.g. strips, radar or meteorological information.

The independent variables are:

Traffic level
- High-traffic hours
- Low-traffic hours

Visibility conditions
- Day
- Night

The study concerns ground control positions.

3 METHOD

The observations were conducted between 6th and 10th of March 2006. We collected four hours of video recorded by a camera mounted on the glasses worn by the ground controller. The recordings include the audio of the controllers. Additional flight plan data, such as call sign and time of departing and landing were collected. The observations were made during both day and night conditions. The time of every recording was approximately 50 minutes.
The camera used in the experiment does not provide the focus to depth but offers central view of 60-degrees in front of a controller's head. The camera mounted on the glasses did not capture the eyes' gaze. According to Land [7], the head movements accompany eye movements when the angular displacement is larger than 20-degrees. Therefore, the camera that is adjusted to record the centre of field of view should capture the central vision that is +/- 15 degrees from the line of sight.

The recording technique was not disruptive to normal work behaviour. All equipment was portable and the controller was free to move around the tower room. The recording concerned exclusively the field of view in the front of the controller's head, the face and body posture were not captured.

3.1 Tower environment

Various airport towers characterise with different configuration and sharing of the duties between the control positions. The study was conducted at one tower and therefore represents the local procedures in this particular environment.

In our study, the control tower is composed of the following positions:

- Tower control position (TWR), which is in charge of separating the aircraft and vehicles on the runways and taxiways.
- Ground control position (GND), which is in charge of separating the aircraft and vehicles at the stands and taxiways. Ground controller allows push-back and start-up manoeuvres.
- Clearance delivery controller, who is responsible for the ATC clearance for departure flights and co-ordination with the ground controller.
- Flight plan assistant, who is responsible for printing the strips, providing them to the controllers and coordinating the airport service with the tower controllers.
- Supervisor, who is responsible for coordinating the work of the team, reporting any disruption of performance, incidents and accidents on the airport surface, provides controllers with traffic forecasts and distributes the appropriate information to airports, airlines operators or CFMU (Central Flow Management Unit).

Four controllers (2 males, 2 females) participated in the study. They had between 2 month and 15 years of experience.

3.2 Analysis of recordings

To analyse the videos we distinguished three categories of activities:
- Voice Communication
- Head-up Activity
- Head-down Activity

3.2.1 <u>Voice Communication</u>

The voice communication includes instruction and clearances issued to the pilots, coordination with airport service, approach control and every kind of exchange of the operational data with the tower team.
The communication events were marked as an occurrence without duration of the activity being given (we counted the number of issued clearances, the time of each occurrence but not how long the controller was speaking).

Clearances related to ground control position
1) Push-back and Start-up
2) Taxiing instruction
3) Contact TWR

Cooperation within the tower:
1. Coordinating sequence of starting aircraft at the stands etc.
2. Coordinating of airport services

3.2.2 Head-up Activities

Head-up activities involve scanning the view outside of the tower's windows. We divided the airport surface into two sectors:

a) Runways
b) Apron

3.2.3 Head-down Activities

The head-down activities include all actions performed inside the tower: reading and writing on the strips, forwarding them to colleagues, scanning the approach control radar, Ground Movement Radar (GMR), reading the meteorological data from ATIS (Automatic Terminal Information Service) and using a key-board to contact the airport service and approach control. Due to the limited precision of the video equipment, we simplified the analysis and divided the head-down activity into four areas of focus (central, left, right and far-left):

Strips (central) involve scanning and writing on the strips and using the keyboard. The strips bay and the keyboard are directly in front of the controller position. Strips are placed horizontally on the desk and the keyboard is vertically sits in the stand.

Radar (left) – scanning the approach control radar that is placed vertically on the left hand. The controller uses a mouse to zoom in and out the picture and to calculate the distances between different aircrafts

ATIS (right) - scanning the meteorological data on the ATIS display or wind direction indicator. Both devices are placed vertically to the right of the stand.

Ground Movement Radar GMR (far left) - scanning the GMR that is placed vertically on far left of the radar.

The time while the controllers were not occupied with control activity due to low traffic density, was not considered in the analysis. The analysis captures only the time when controllers were performing control tasks.

4 RESULTS

The data were analyzed in terms of:

– Duration
– Frequency

The frequency was determined for all the activities. Frequency represents the number of an occurrence of single event.

The duration was calculated only for head-up and head-down activities, excluding communication. The duration represents the time of lasting of one occurrence.

4.1 The analysis of the performance

We started the analysis with calculating the mean values of scan for all visual activities. The duration of average scan for different activities varies between 2.3 sec for Atis and 6.5 for Runways. According to the figure we can see that the average scan for Runways and Apron were higher than for other activities.

The analysis of occurrences of activities shows that the most frequent activities were Strips (29.6%), Runways (24.3%) and Apron (16.2%).

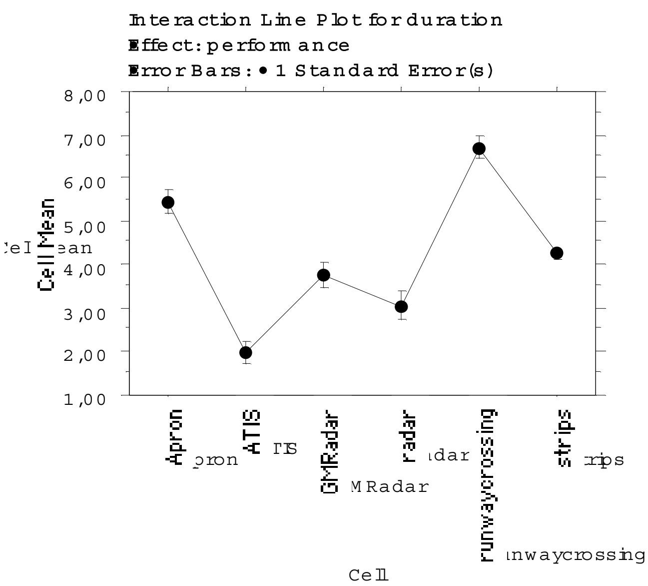

FIG. 1 Time of average scans for the activities

The results indicate different working methods for the various sources of information. Scanning Runways, Apron and Strips are very frequent activities, but scanning Strips required less time whereas monitoring the outside view is more time consuming.

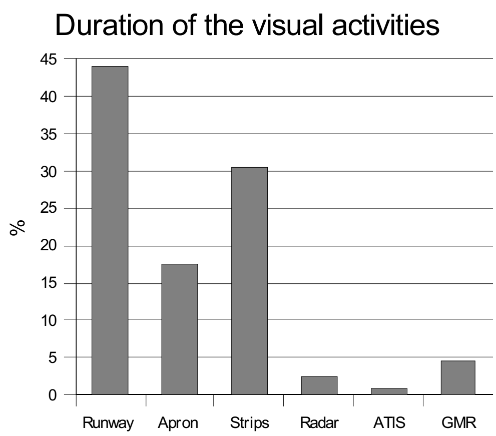

FIG 2. Total duration of the activities.

Additionally we calculated the total time that controllers are giving to different activities. According to figure 2 the main occupancy of the controller was given to monitoring the Runways 44%, scanning Strips 30.6 % and Apron 17.5% .Considering those results we can conclude that the controller spent 60% of the time monitoring the airport surface.

4.1.1 Head-up and head down activities

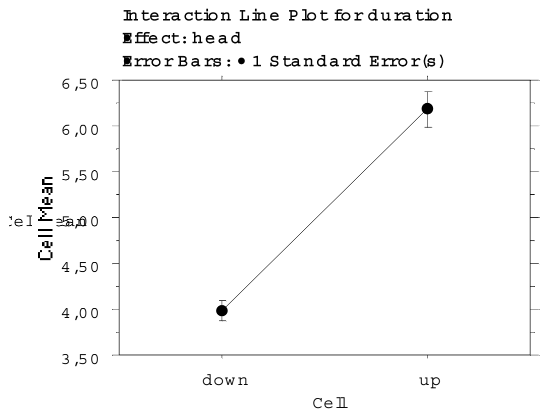

FIG. 3 Comparison of the average scan for head up and head down sources of information.

Additionally we have performed calculation for the head-down and head-up activity. Figure 3 presents the mean time of average scan. The mean for Strips, Atis, GMR and Radar activity was 3.9s whereas the mean for Runways and Apron is 6.2s. These results can be explained as the effect of various form of the information that controllers search. The window view provides diffused information in various part of the airport. The controllers monitor the surface supervising aircraft and vehicles positions, possible routes deviations, follows the progress of the taxiing. The monitoring process allows to detect unexpected events happening on the surface. Information provided on the strips is precise and predefined. The information such a callsign, aircraft type, or parking position is allocated to specific field on the strip. The information printed in capital letters and as an abbreviation are easy readable for the controller.

Additionally, the strip organisation on the bay is performed by the controllers themselves, what help to mind the placement of particular strip and save the time for search. Depending on the source of the information, the controller use different working methods. Scanning the airport surface is the activity that is more attentive and consequently more time consuming, whereas scanning head-down sources such as strips and radar are more brief activities.

4.1.2 Visibility conditions

The recordings were taken during day and night under good visibility conditions. The day conditions were considered as full day light whereas the nigh conditions were considered as complete nightfall. Recordings include two hours for every condition.

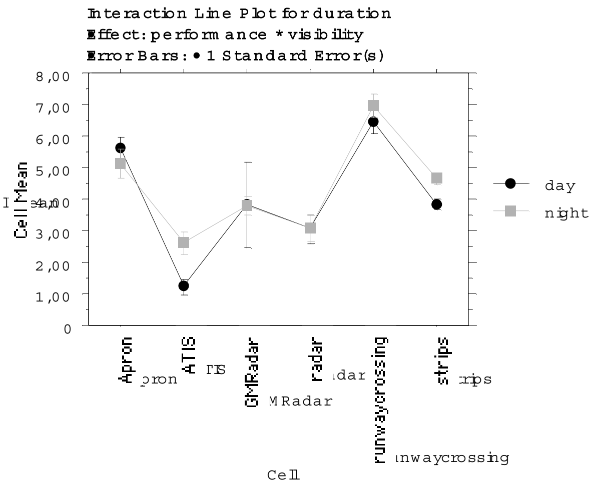

FIG 4. Comparison of average scans depending on visibility conditions

Figure 4 represents the mean value of the activities. According to the figure, the difference can be found for the average scan of Atis, Runways and Strips.

During the night, the controller spent longer time reading the ATIS including wind direction indicator, looking at the Strips than during the day. However, we also found that time for scanning the Runways was higher by the night than for the day, what might be explained that in the night information provided by the window are more difficult to obtain. However, the results for Apron do not confirm it. This case can be explained by the difference in the lightening for Apron and Runways. During the night, Apron areas are visible due to artificial light up. The controllers visually can identify the aircrafts and vehicles. However runways, that do not have sufficient light up. The controllers to maintain the metal picture derive the information from the light of the aircraft and vehicles.

4.1.3 Traffic load

According to the regulations, this airport can allow 20 landings per hour in good visibility conditions. The traffic load during the recorded time varied between 18, 22, 30 and 33 operations. We divided the data with 18 and 22 movements as low traffic hours and 30 and 33 as high traffic hours.

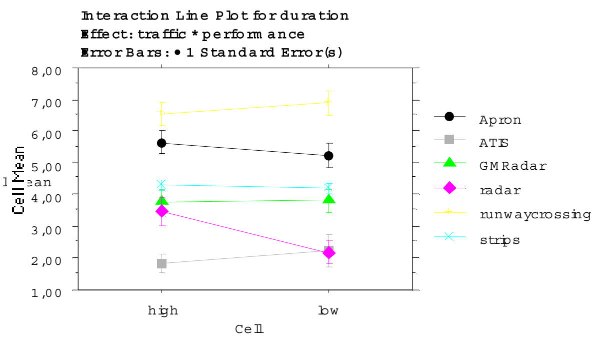

FIG 5 Comparison of average scans depending on the traffic density.

Figure 5 presents a comparison of the average duration of activities depending on the traffic density. Regarding the head-up activities, scanning the Apron was maintained at comparable level for both conditions, whereas scanning Runways decreased in the high traffic condition.

For head-down activities, a difference could be found only for scanning Radar, which increases during high traffic load. Scanning Strips was maintained at the comparable levels for both traffic load conditions.
The results indicate that controllers more often used the head-down sources of information during high traffic; nevertheless, head-up scanning was still their primary preoccupation.

4.2 Analysis of pattern

4.2.1 First order transition probability

We performed an analysis of patterns for every hour of recordings. We created four patterns, presenting first-order simple transitions probabilities. We simplified the analysis by decreasing the number of activities in order to make transitions more evident. The new categories and the description used for the analysis are listed below.

Scanning Sources of information:

- Runways and Apron – one category created by combining scanning the runways and aprons; this category corresponds to total head-up time.
- Strips - corresponding to scanning strips or using a keyboard, head-down source of information.
- Radar corresponding to scanning the radar, head-down source of information.
- GMR and ATIS - one category created from the GMR and ATIS, the least frequent activities, head down sources of information.

Actions:

- Push-back considered as the important task authorising aircraft to leave the stand. Push-back contributes to the fluidity and sequence of the traffic.
- AC taxiing - Medium importance clearances and instructions concerning taxiing process
- Coordination - Less importance clearances: contact tower/ground; continue approach and every kind of coordination with airport services or tower team.

The first part "scanning various sources of information" refers to visual sources available in the tower, while the second part, "actions" covers voice communication. Voice communication was divided into three groups, depending on the importance of the commands.

We produced the patterns, presenting seven categories connected by arrows indicating first-order transitions. The direction of the arrows represents the direction of the transitions. The colour and thickness of the arrow indicates the simple transition probability.

We have distinguished four probability ranges:

1 Red, wide arrow – very strong transition probability, higher than 0.15

2 Orange arrow – strong transition probability, between 0.05-0.15

3 Yellow arrow – medium transition probability, between 0.01-0.05

4 Black line arrow – weak transition probability, less than 0.01

The figure 6 and 7 represent the day's patterns, figure 8 and 9 night pattern, and again, figure 6 and 8 represent low traffic to compare to the figure 7 and figure 9 with high traffic.

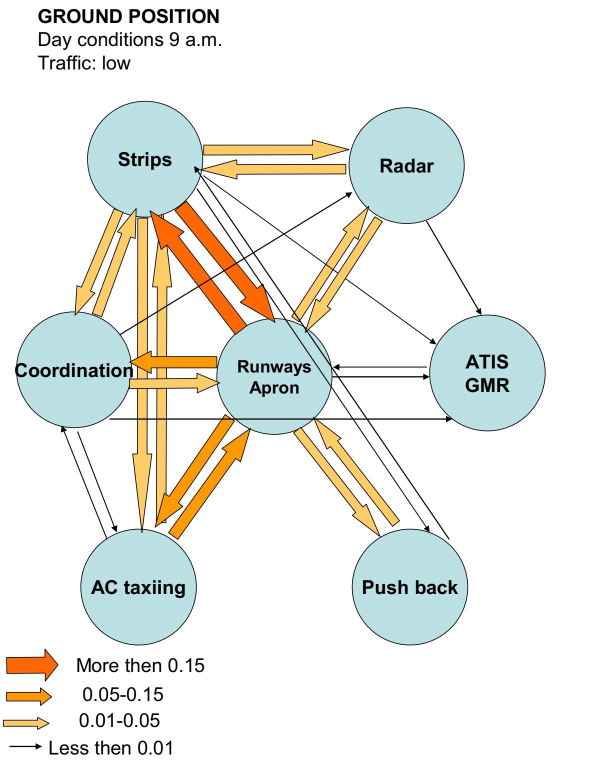

FIG 6. Simple transition patterns for day conditions, low traffic.

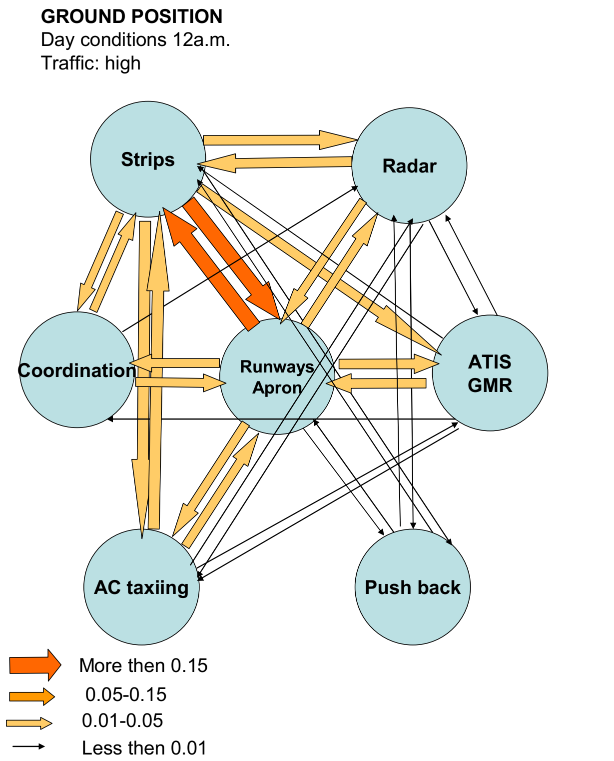

FIG 7. Simple transition patterns day conditions, high traffic.

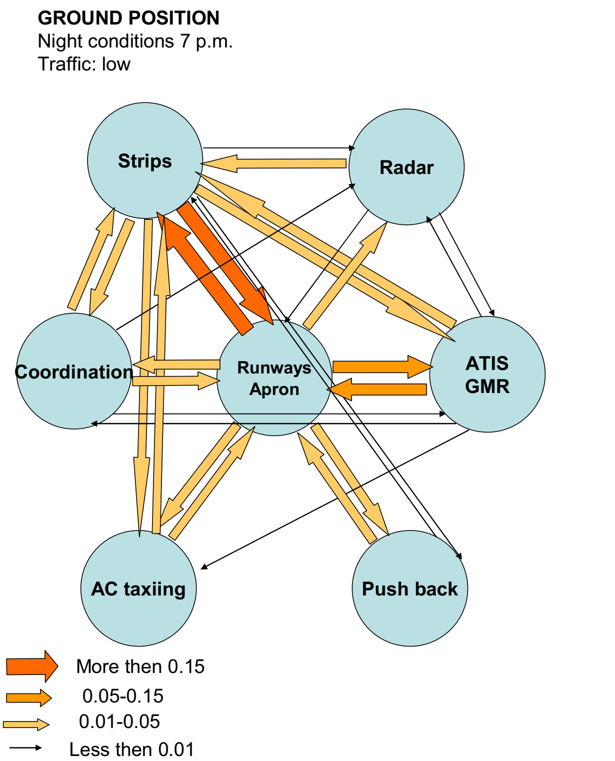

FIG 8 Simple transition patterns for night conditions, low traffic.

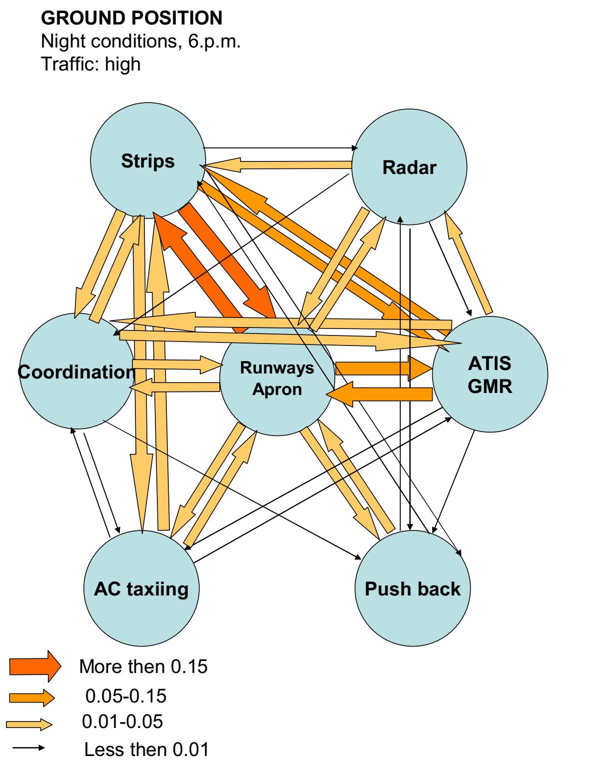

FIG 9 Simple transition patterns for night conditions, high traffic.

During the day, very strong transition probability occurred between Runways/Apron and Strips (0.25-0.27). AC taxiing has strong-medium transition probabilities to runways/apron.

Surprisingly, pushback, considered as important task, obtained medium–weak probabilities with runways/apron, and with strips. This could be explained by the fact that the push-back is approved in the moment when the controller is ready to add aircraft to the current traffic. Therefore, the push-back is less critical than crossing traffic on the taxiways.

Usage of radar or ATIS/GMR characterise medium-weak probability.

The comparison of patterns under day and night conditions demonstrated higher transition probabilities involving GMR during night. During day, GMR obtained weak-medium transition probabilities, whereas during the night the probability was medium–strong. Generally the night patterns appeared to be diffused and more complex.

The analysis of patterns under high and low traffic conditions does not provide clear conclusions. The patterns obtained during low traffic appeared to be of lower complexity than high-traffic patterns.

4.2.2 Three successive activities

In order to analyse information accusation pattern we extract only visual activities and computed all possible triplets occurred in our data. The total number of occurred triplets was 48. The triplets occurred with different frequency varying from one to 109. Based on the histogram of the results we extract the most frequent triples within the bin set at 37 representing 15% of occurrence.

The most frequent triplets were and their occurrences were

1. Runways Strips Runways - 109
2. Runways Strips Apron - 71
3. Apron Runways Apron - 69
4. Apron Strips Runways - 55
5. Strips Runways Apron - 47
6. Strips Apron Strips - 39
7. Runways Apron Runways - 38
8. Strips Apron Runways - 37

Those results are consistent with the analysis of simple transition, showing that the main sources of information for the controller were monitoring the airport surface and strips. The information gain via the window are verified on the strips and again by looking out of the window what is represent by the triplets: Runways, Strips, Runways or Runways, Strips, Apron.

Additionally triplets such as Runways Apron Runways represent the monitoring of the airport surface.

5 CONCLUSION

The ground controllers prioritize outside view over other sources of information. The process of scanning the sources of information accessible head-up and head-down is different. Monitoring the airport's surface is a frequent and long duration activity. By comparison, scanning strips and other tools are frequent but relatively short duration activities.

Regardless of traffic load, the window's view from the tower remains an important source of information. However, during high traffic loads controllers show a tendency to use the head-down tools more than during low traffic.

Concerning day and night conditions, the results confirmed the expected tendency that during the night the importance of the head-down support tools increases. However, monitoring Runways and scanning Apron remain as main source of information.

The analysis of patterns revealed that the strongest transitions were from looking outside of the tower window to strips. It was again confirmed that controllers frequently switch attention from the strips on their desk to the view of the far distance through the window. Those two main transitions represent the identification process required to maintain adequate metal picture of the situation. Aircraft that are visible by the windows are identified using the information provided by the strips such as airline, aircraft type, parking position. Introducing identification information to the window view would eliminate the transitions.

The results of this study confirmed that direct observation is of prime importance to the tower controller. Strips are a second source of information, requiring frequent head-down movements and consequently changing the point of gaze and adjusting the focal depth to short distance for a very short time.

Presenting the information that currently is available on head-down devices on the head-up display should significantly decrease head-down time. Furthermore, it should eliminate the fixation switch between far and near locations which was reported as being a component of the head-down problem by B. Hilburn [5].

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