Verification and Validation of Automated Airfield Ground Lighting Based Visual Guidance

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ABSTRACT

The potential of improved routing and visual guidance plays an important role in establishing the Advanced Surface Movement Guidance & Control System (A-SMGCS) concept as an integrated air-ground system. DLR's Air Traffic Management (ATM) simulation facilities were used for verification and validation of the individual visual "Follow the Greens" guidance and routing concept, where routes were generated with the help of a controller assistance surface management system which was integrated in the simulation environment. Real world controllers as well as pilots were the participants in these distributed real-time human-in-the-loop simulations under full airport traffic scenario conditions. The Apron- and Tower Simulator and two cockpit simulators were chosen as a networked environment for the experiment.

1. INTRODUCTION

The different implementation levels of A-SMGCS are characterized by an increasing overall system capability, ranging from surveillance only (Level 1) up to automated guidance and planning functionality (Level 3 and 4). Assisting the pilot by switching of the taxiway centre lines according to an assigned route corresponds to a guidance possibility. Switching only the cleared segment of a route for each individual aircraft forms the core of the "Follow the Greens" concept, replacing the conventional "Taxi via..." voice communication command of the controller by a "Follow the Greens" instruction.

In this paper, the verification of different segment light versions as well as the concept's validation results referring the pilots' workload are presented.

2. REAL TIME SIMULATION

The validation facilities of DLR's Institute of Flight Guidance are used in line with the EUROPEAN Operational Concept Validation Methodology (E-OCVM)[1]. Regarding the need of getting pilot feedback under human-in-the-loop conditions, the selection of a real time simulation environment was essential.

2.1 Systems

By addressing the need for flexibility and scalability [2] in a well-balanced approach of "in-the-large" and "in-the-small" [3], the following third party system modules were integrated in the simulation environment (see Figure 1):

- Surface Manager (SMAN)
- Airfield Ground Lighting (AGL) Server
- Two Controller Working Positions (CWP)
- Two Cockpit Display Units

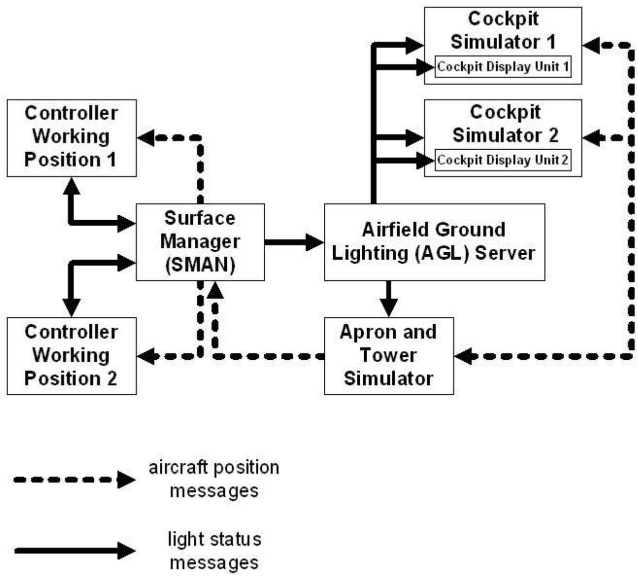

Figure 1. Simulation environment

Two cockpit simulators and the Apron- and Tower Simulator generated the aircraft movements for the experiments under full traffic conditions. Two kinds of messages were distributed in the simulation ensemble:

- Aircraft position messages
- Light status messages

Aircraft position messages were sent out and received by the movement generating components, whereas light status messages were only received. Aircraft position messages as well as light status messages were sent out and received by the SMAN module. The AGL server acted as a message forwarder for light status messages only, sending them in a segment oriented format to the cockpit display units and converting them to an individual light switching format for the out of the window display systems of the cockpit simulators and the Apron- and Tower Simulator.

2.2 Operators

Real life controllers as well as professional pilots were the main actors of the experiments (see Table 1). Each simulation run requested two controllers on two apron frequencies (one on each frequency) and three pilots, a two man crew in the cockpit simulator 1 and one pilot in the cockpit simulator 2. In order to perform the exercises under Frankfurt Airport typical full traffic conditions, so called pseudo pilots acted as additional supplement operators, steering the other aircrafts according to the voice communication instructions of the controllers during the baseline runs (without "Follow-the-Greens" guidance). Simulation runs with "Follow-the-Greens" guidance contained the activation of a special two dimensional map based cleared route indication on the pseudo pilot stations, enabling them to act nearly the same as a pilot in a cockpit simulator, thus reducing the overall voice communication under these conditions.

Table 1. Real time simulation main operators

Operators	Number	Male / Female
Controllers	4	2 / 2
Pilots	14	13 / 1

3. VERIFICATION

Based on provided input data for the Frankfurt Airport, different light distances were realized in the viewing systems of the simulation environment, 15 m on straight lines and 7.5 m in curves (see Figure 2).

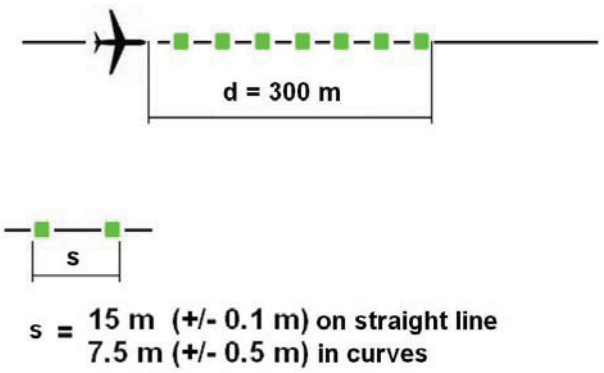

Figure 2. Follow-the-Greens characteristics

Two different versions of end segment lines were verified in a three day period with 10 simulation runs (1 hour each) and the participation of 7 pilots and two controllers, addressing the verification question "Are we building the system right ?"[4]. The traffic scenario was derived from a typical Frankfurt Airport flight plan. Five of seven pilots preferred the end segment line version B, one preferred version A and one was without any preference (see Figure 3, Figure 4 and Figure 5).

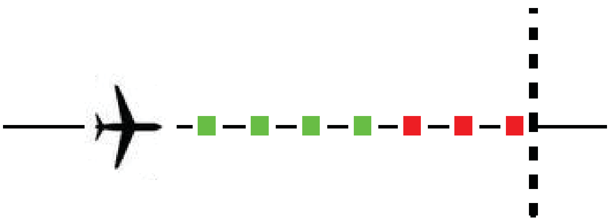

Figure 3. End segment lights version A

Figure 4. End segment lights version B

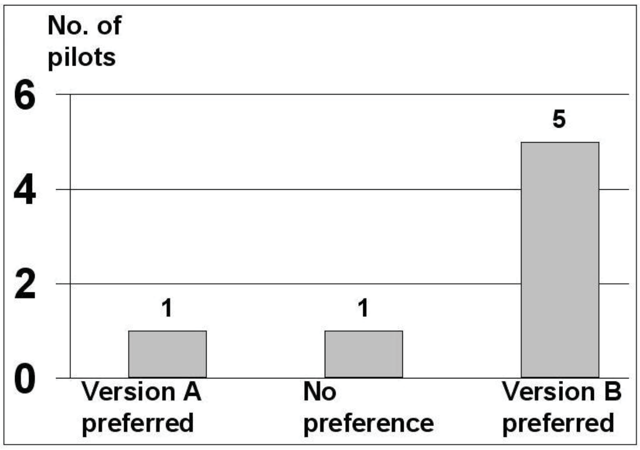

Figure 5. Version preference distribution of the pilots

Although this distribution was not significant (p > 0.05, see Figure 6), end segment lights version B was chosen for the validation runs based on the fact that a p value of 0.7 (see Figure 6) can be regarded as a trend to significance.

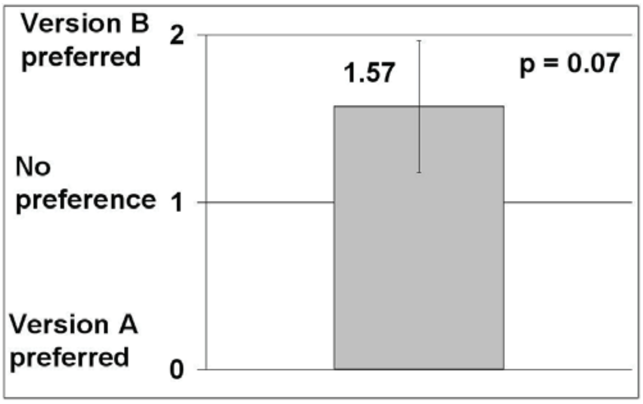

Figure 6. Average preference of the light versions

In case of a holding position overrun, red blink mode of the following five lights was implemented (see Figure 7).

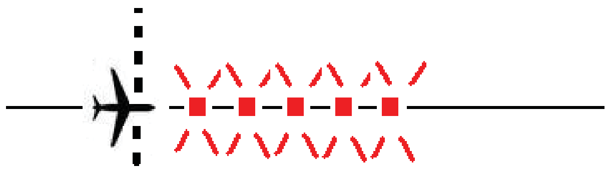

Figure 7. Holding Position Overrun

The last light segment in front of a stop bar was switched according to Figure 8.

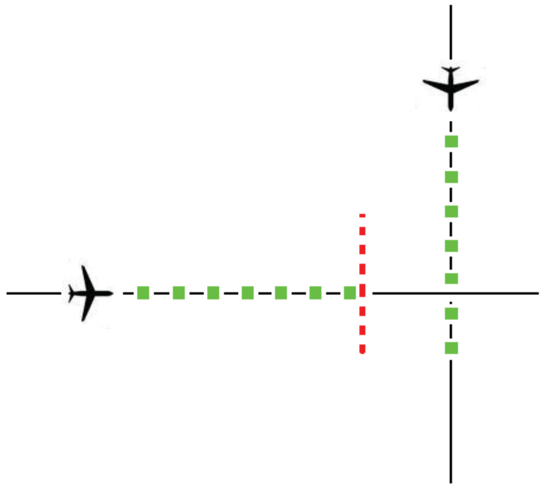

Figure 8. Switching mechanism for nearing stop bar

For runway incursion events, the remaining lights to the runway and the elevation lights were switched to red blink mode (Figure 9).

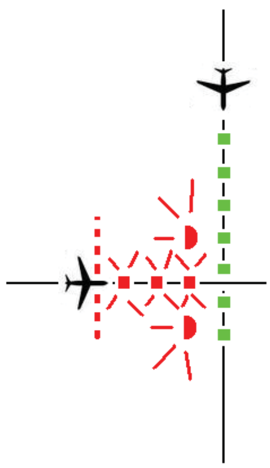

Figure 9. Runway incursion

Route deviations were indicated by switching the next five lights of the wrong route to red blink mode, in front of the aircraft as well as behind it (Figure 10).

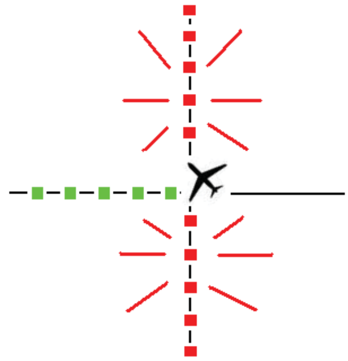

Figure 10. Route deviation

4. VALIDATION

The "Follow the Greens" guidance and routing concept validation simulation consisted of 20 full traffic condition runs (1 hour each) , 10 conflict event testing runs (1/2 hour each) and the participation of 7 pilots and two controllers, addressing the validation question "Are we building the right system?"[4]. During the runs, different kinds of data were logged, covering the following areas:

- Subjective data via questionnaires (mid-run and after-run) and debriefing feedback sessions
- Objective data via simulation run time recording

These data referred to the following indicators:

- Workload
- Situation awareness
- Usability
- Traffic throughput
- Taxi times
- Punctuality

The experiments under full traffic conditions were equally distributed referring the type of guidance (with / without "Follow-the-Greens") as well as considering good and bad visibility conditions (see Table 2).

Table 2. Distribution of the validation runs

without "Follow-the-Greens" guidance (= BASELINE)		**with "Follow-the-Greens" guidance**	
10 simulation runs		10 simulation runs	
800 m visibility	10000 m visibility	800 m visibility	10000 m visibility

All conflict event testing runs were conducted with “Follow-the-Greens” guidance.

4.1 Hypotheses

According to the validation objective[4], hypotheses for each indicator were defined (see Table 3 to Table 7). Each hypothesis consists of two sub-hypotheses with H0 characterizing an indicator's operational improvement or that there is no change in comparison to baseline conditions. Sub-hypothesis H1 is associated with a degradation of the regarded indicator under conditions with "Follow the Greens" guidance.

Table 3. Workload hypotheses

No.	Hypothesis
HY1-H0	The pilots’ workload with "Follow the Greens" guidance is lower or equal than without "Follow the Greens" guidance.
HY1-H1	The pilots’ workload with "Follow the Greens" guidance is higher than without "Follow the Greens" guidance.

Table 4. Situation awareness hypotheses

No.	Hypothesis
HY2-H0	The pilots’ situation awareness with "Follow the Greens" guidance is higher or equal than without "Follow the Greens" guidance.
HY2-H1	The pilots’ situation awareness with "Follow the Greens" guidance is lower than without "Follow the Greens" guidance.

Table 5. Traffic throughput hypotheses

No.	Hypothesis
HY3-H0	The traffic throughput with "Follow the Greens" guidance is higher or equal than without "Follow the Greens" guidance.
HY3-H1	The traffic throughput with "Follow the Greens" guidance is lower than without "Follow the Greens" guidance.

Table 6. Taxi times hypotheses

No.	Hypothesis
HY4-H0	The taxi times with "Follow the Greens" guidance are lower or equal than without "Follow the Greens" guidance.
HY4-H1	The taxi times with "Follow the Greens" guidance are higher than without "Follow the Greens" guidance.

Table 7. Punctuality hypotheses

No.	Hypothesis
HY5-H0	The punctuality with "Follow the Greens" guidance is higher or equal than without "Follow the Greens" guidance.
HY5-H1	The punctuality with "Follow the Greens" guidance is lower than without "Follow the Greens" guidance.

4.2 Results

Only workload related results were of significant character ($p < 0.05$), thus the hypothesis decision for sub-hypothesis H0 confirmation or rejection was only possible for this parameter. It must be emphasized that apart from any significance analysis, traffic throughput, taxi times and punctuality data have to be treated keeping in mind that most of the traffic was handled by the pseudo pilots. Although they were able to act nearly the same as the pilots in the cockpit simulators (see 2.2), the experiment conditions affected their behaviour because of the following facts:

- A pseudo pilot was responsible for the handling of several aircrafts, not only one like a pilot in a cockpit simulator.
- The pseudo pilot stations were map based and not equipped with an out of the window display point of view display.

The workload was analyzed according to the following indicators:

- After-run pilot feedback to a source of information preference question ("Follow-the-Greens" guidance versus guidance via the Cockpit Display Unit)
- NASA Task Load Index (TLX)[5][6]
- Voice communication channel occupancy times

Because of a higher reliability and better differences, the un-weighted values of the six NASA TLX sub-scales were used[7].

The after-run pilot feed back to the source of information preference question shows a significant average of 72.7 percent with respect to the "Follow-the-Greens" guidance (see Figure 11). General pilot comments in after-run debriefing sessions address a complementary usage of "Follow-the-Greens" guidance and the CDU, concentrating on the "Follow-the-Greens" guidance for the current local taxi situation and benefiting from the CDU map display for an airport overview orientation.

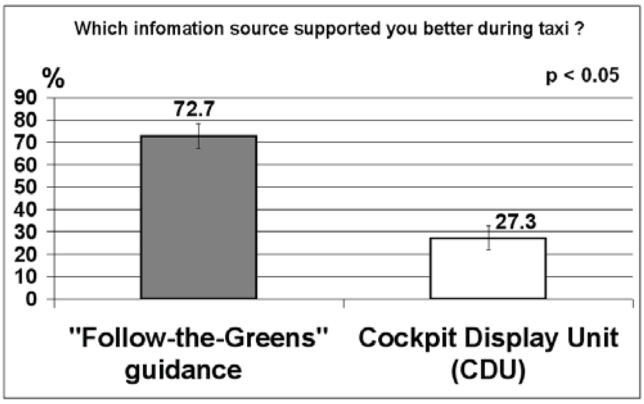

Figure 11. Source of information question

The average NASA TLX score values are significant lower for "Follow-the-Greens" guidance, especially under bad visibility conditions (see Figure 12 and Figure 13).

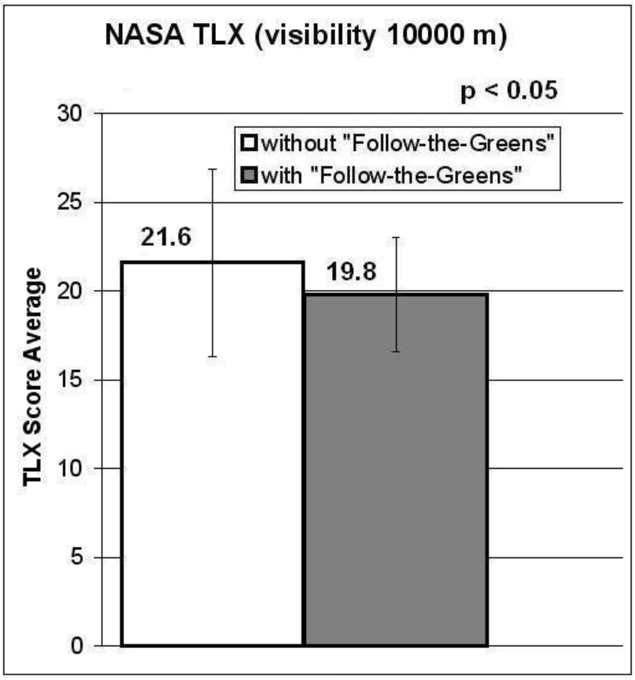

Figure 12. NASA TLX scores for visibility 10000 m

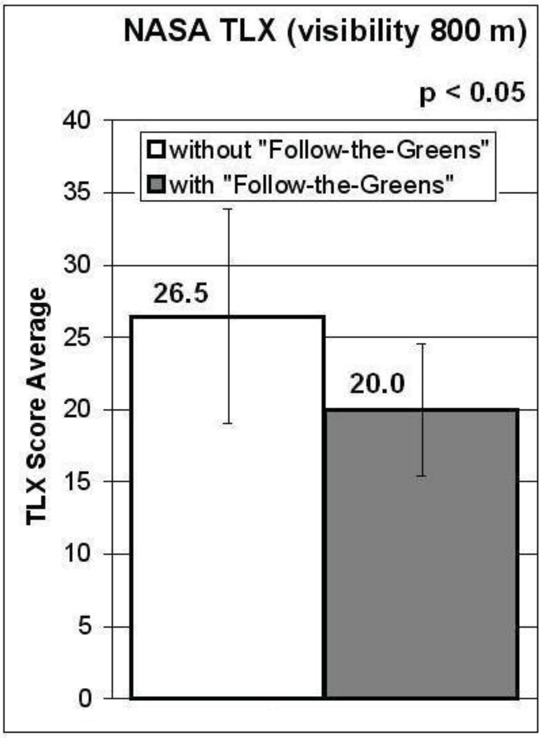

Figure 13. NASA TLX scores for visibility 800 m

The average voice communication channel occupancy times are significant lower for "Follow-the-Greens" guidance, independent from the visibility conditions (see Figure 14 and Figure 15).

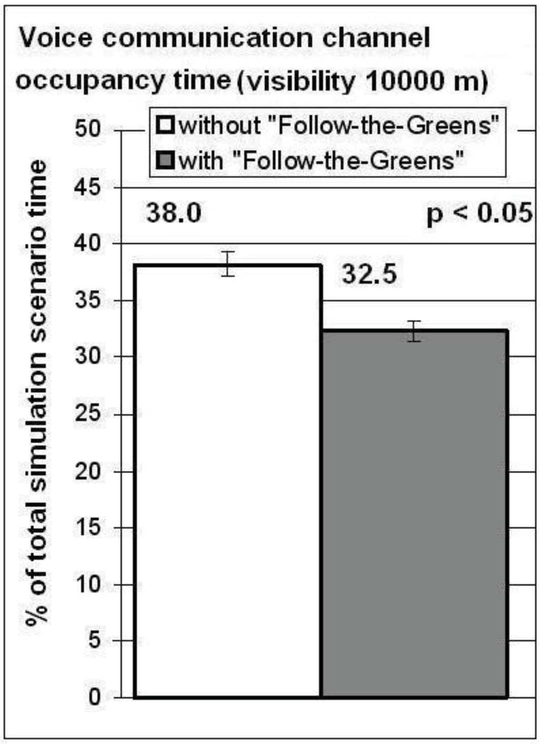

Figure 14. Occupancy times for visibility 10000 m

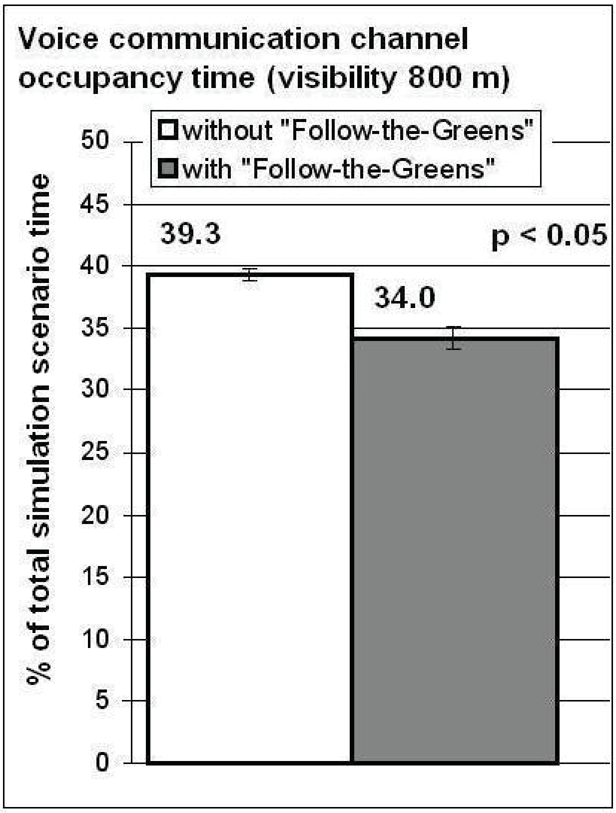

Figure 15. Occupancy times for visibility 800 m

All workload indicators result in an operational improvement, thus the HY1-H0 (see Table 3) postulation is confirmed.

5. SUMMARY

The simulation runs for the verification of two different end segment light versions identified pilots' preference for a version with three red end lights outside the cleared route, indicating the end of this route in front of the first red light (see Figure 4). This implementation is in line with the intuitive association of "do not roll on / over red".

Pilot workload improvement under "Follow-the-Greens" guidance conditions was shown in the simulation runs for operational validation, based on significant results of three indicators (see 4.2).

Future validation trials, especially referring to significant pilot situational awareness, traffic throughput, taxi times and punctuality results, may benefit from an enlarged number of simulation runs, participating pilots and involved cockpit simulators.

6. REFERENCES

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