# An Assessment of Pilots' Concurrent Use of Runway Entrance Lights and Surface Movement Control System Guidance System Stop Bars

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Two Human-in-the-Loop (HITL) simulations were conducted to investigate the concurrent use of Runway Entrance Lights (RELs) and Surface Movement Guidance Control System (SMGCS) stop bars. The first study investigated use by pilots who did receive training on using these lighting systems simultaneously, while the second study investigated use by pilots who did not receive training. A total of 11 commercial pilots were asked to taxi a mid-fidelity simulated aircraft under low visibility conditions. Results suggest that pilots who have not received the proper clearance from ATC are not likely to cross the illuminated stop bar, even when RELs extinguish indicating that the runway is not actively being used. In addition, RELs were found to generate stopping responses on 100% of trials for the trained pilots, and 67.5% of trials for the untrained pilots when they were erroneously cleared onto an active runway. While the lighting systems were effective in reducing the number of runway incursions, pilots ignored or did not respond to the RELs in 32.5% of trials in the untrained group. Though the performance data suggest that these lighting systems can enhance runway safety, some pilots' subjective reports indicate that the concurrent use of the systems could cause some confusion. Results point to the importance of an effective training program, and notification that the systems are concurrently being used in an airport environment to ensure their full effectiveness.

## INTRODUCTION

The Federal Aviation Administration (FAA) has made reducing the number and severity of Runway Incursions (RIs) one of their top priorities in improving safety. These efforts have produced a significant reduction in the number of serious RIs (Category A and B), lowering the number of these incursions from 67 total events in 2000 to only 6 events in Fiscal Year (FY) 2010 (FAA, 2010). While the answer to reducing the number of these errors has been the careful implementation of multiple solutions, one specific strategy has focused on the use of technologies to improve Situation Awareness (SA) for aircrews and airport vehicle drivers. Technologies, such as the Runway Status Lights (RWSL) system and the Surface Movement Guidance Control System (SMGCS), have been shown to enhance operator awareness (McGarry & Moertl, 2006; Moertl, 2005).

### Runway Status Light System – Runway Entrance Lights

Runway Entrance Lights (RELs) represent one capability of the RWSL system, and these specific lights are designed to notify a pilot or vehicle operator that the runway that they are about to enter or cross is in use. RELs are presented as in-pavement red lights that extend from the hold short line to the center of the runway. These lights lie parallel to the taxiway centerline and are shown to the left of the taxiway lead-on lights, which remain illuminated when the RELs are illuminated, as shown in Figure 1.

The direct-to-pilot warnings that RELs provide are driven by surveillance of traffic on or near the surface of the airport, and are based on a projected or current assessment of runway safety. Using this surveillance information, all RELs within the system illuminate simultaneously when a departing aircraft is detected in the operating environment that exceeds 35 knots (kts) on a departure roll, or when an arriving aircraft is on final approach or landing. The algorithms underlying the system are designed such that, when the triggering aircraft is within two seconds of a taxiway and runway intersection, the RELs for that specific intersection extinguish. Though the surveillance system driving the RELs can provide a projected or current assessment of runway safety, the system does not provide clearance to the pilot to taxi on, depart from, or arrive on a runway.

Research in simulated flight environments has shown that RELs effectively reduced the likelihood of a runway safety incident (e.g., an incursion) from 33% when no lights were present to 16% with the use of the lights (McGarry & Moertl, 2006).

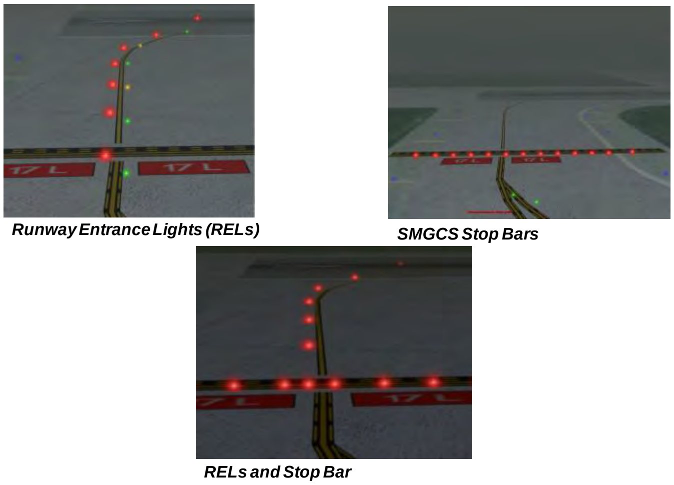


**Figure 1: Runway Entrance Lights, SMGCS Stop Bar and Combined use RELs and Stop Bar**

### Surface Movement Guidance Control System – Stop Bars

The SMGCS also provides lighting system support to pilots and vehicle operators on the airport surface. While SMGCS includes runway guard lights and edge lights, it is also comprised of stop bars. These stop bars, which are generally used only in low visibility conditions, are located at the entrance to a runway and provide a visual confirmation of clearance. Like RELs, stop bars are presented as red, in-pavement lights. However, these lights extend across the length of the hold short line, providing a visual barrier to indicate to the pilot that Air Traffic Control (ATC) clearance has not been issued. When a stop bar is illuminated, the taxiway lead-on lights are extinguished providing additional visual cues to the pilot to hold short. Figure 1 includes a simulated image of the SMGCS stop bars.

While RELs are illuminated and extinguished automatically through surface surveillance, stop bars are operated and controlled by ground controllers. Thus, immediately after a controller issues a verbal clearance to an aircraft to cross the hold short line, he or she extinguishes the stop bar, and the lead-on lights are immediately illuminated.

### Concurrent Use of RELs and Stop Bars

Independently, the RELs and SMGCS stop bars have been used operationally at several airports. Components of the RWSL system have been installed at Dallas-Fort Worth International Airport, San Diego International Airport, and Los Angeles International Airport, and the FAA intends to deploy the system at additional locations. SMGCS stop bars are currently in use at Seattle Tacoma International Airport (SEA), Hartsfield-Jackson Atlanta International Airport, Salt Lake City International Airport, Denver International Airport, and Memphis International Airport.

Though presently no airport has been outfitted with *both* of these lighting systems, some airports are scheduled to receive the RWSL system and will be equipped to support the concurrent use of these lighting systems under low visibility conditions. There has been some concern noted about the concurrent use of these systems, particularly when the lighting systems provide *different* information to the pilot. The lighting systems are prone to presenting different information in two possible cases:

- After the traffic aircraft has cleared the intersection and the RELs extinguish, but the clearance has not been issued and the stop bar remains illuminated.
- When ATC issues an erroneous clearance to permit the pilot to enter the runway and extinguishes the stop bar, but the RELs system illuminates indicating the presence of traffic aircraft on the runway.

In the first situation, it may be hypothesized that viewing the RELs extinguish could lead pilots to initiate their movement onto or across the runway, even without ATC clearance. While this event is not likely to cause a safety concern, as the runway would in fact be clear, it does generate a procedural concern and could lead to an incursion if the logic underlying the RELs was imperfect. In the second situation, the RELs serve as an automated backup system to the ATC, reducing the potential impact of human error. For the system to be effective, however, it is critical that the pilot understand the significance of the RELs illuminating and stop the aircraft from moving onto the runway regardless of the state of the stop bar. If users have no training on the operation of these systems, they are more likely to misunderstand the message the alert is sending (or when it works and why), and may respond inappropriately. Two Human-in- the-Loop (HITL) simulations were run to explore potential issues that may arise from using the RELs and SMGCS stop bars concurrently. Questions specifically targeted in the HITLs included:

- Are pilots confused when both RELs and stop bars are used concurrently and provide different information? Do they respond appropriately?
- Are pilots confused when the runway is clear but clearance has not been given?
- Can pilots learn to use the systems with minimal training?

## METHOD

To answer these research questions, two studies were run at The MITRE Corporation's Center for Advanced Aviation System Development's (CAASD) Aviation Integration Demonstration and Experimentation for Aeronautics (IDEA) laboratory, using a medium fidelity enclosed cockpit flight simulator. In the first simulation, pilots were trained, and in the second, pilots were untrained.

### Study One—Trained Group

Eleven pilots participated in this simulation. There were two female and nine male participants. The average age of the pilots was 45.1 years (yrs), with a range of 30-67 yrs. All were ATP rated pilots. Of the eleven pilots who participated in the study, nine of them had experience with both RELs and stop bars. Two did not have experience with either of the lighting systems. None of the pilots had used the two lighting systems concurrently.

This study was conducted as a within-subjects design. In study one, the trained pilots were exposed to 3 experimental conditions: (1) RELs only, (2) stop bars only, and (3) RELs and stop bars combined.

The pilots in this study an in-brief, some time to familiarize themselves with the cockpit simulator, the experimental scenarios and questionnaires, and a final debrief. The pilots were provided information on the lighting systems they would see in the scenarios. After each experimental scenario, the pilots were given questionnaires for feedback on the lighting system. During the debrief, the pilots were provided the opportunity to elaborate on their comments throughout the experiment, and ask questions.

In the RELs only condition, no trials contained a conflict. The RELs always provided correct information on the status of the runway to the pilots. The trials in the stop bar only condition also contained no conflicts. The stop bars were only extinguished in conjunction with a verbal clearance by ATC. On half of the trials in the RELs and stop bars combined condition, pilots were correctly cleared onto a clear runway without a conflict aircraft. When there was no conflict, the RELs and stop bars provided compatible information to the pilots. For example, a pilot is instructed to hold short of a runway, so the stop bar is illuminated. There is traffic landing on the runway, so the RELs are illuminated. Once the arriving traffic lands, the RELs extinguish, and the controller issues a clearance onto the runway, while extinguishing the stop bar. For the other half of trials in the combined REL/stop bar condition, pilots were erroneously cleared onto an active runway where a conflict aircraft caused the RELs to re-illuminate. When there was a conflict, the RELs and stop bars provided different information. For example, a pilot is instructed to hold short of a runway, so the stop bar is illuminated. There is traffic landing on the runway, so the RELs are illuminated. Once the arriving traffic lands, the RELs extinguish, and the controller erroneously issues a clearance onto the runway, while extinguishing the stop bar. The RELs re-illuminate for another arrival aircraft. All trials were in low visibility conditions (~1200 RVR).

**Study Two—Untrained Group**

Eight pilots participated in the second simulation. All pilots were males who ranged in age from 37 to 57 years old ($M$ = 47.9 years), and held ATP pilot certificates. Six of the eight participants reported having seen the SMGCS stop bars in operational use, but never having been exposed to RELs. One of the eight participants had used an airport that employs the RELs system, but had never used the stop bars in operation. Finally, one participant noted never having used either of the lighting systems. No differences in performance were found as a function of pilots' experience with prior lighting systems.

In study 2, the untrained pilots were exposed to 2 experimental conditions: (1) stop bars only, and (2) RELs and stop bars combined.

The pilots in this study an in-brief, some time to familiarize themselves with the cockpit simulator, the experimental scenarios and questionnaires, and a final debrief. The pilots were told that the goal of the study was to explore situation awareness under low visibility flight conditions. After each experimental scenario, the pilots were given questionnaires asking about their situation awareness. During the debrief, the pilots were given a full disclosure of the experimental goals, a brief training on the lighting system, the opportunity to provide feedback on the lighting systems, and the chance to ask questions.

In the stop bar only trials, there were no conflicts presented to the pilots. The stop bars were only extinguished in conjunction with a verbal clearance from ATC. As in study one, on half of the trials in the RELs and stop bars combined condition pilots were correctly cleared onto a clear runway without a conflict aircraft. In this scenario, the RELs and stop bars provided the pilots with compatible information. For the other half of trials in the combined REL/stop bar condition, pilots were erroneously cleared onto an active runway where a conflict aircraft caused the RELs to re-illuminate, and the RELs and stop bars provided pilots with different information. All trials were in low visibility conditions (~1200 RVR). This paper will focus on the condition that was present in both studies; that is, the REL and stop bars combined trials.

## RESULTS

Objective and subjective data were collected in both study one and study two. The objective data included: pilot response to RELs and stop bars (i.e., application of brakes or changes to the throttle setting); pilot response time to RELs in conflict scenarios; and aircraft stopping location in response to RELs in conflict scenarios. The subjective data included and pilot feedback on concurrent use of RELs and stop bars.

**Study One—Trained Group**

*Pilot Response to RELs and Stop Bars.* In the trained group, no pilots crossed an illuminated stop bar. No pilot initiated a runway crossing when the RELs extinguished. Among the trained group of pilots, all of them stopped on all trials in response to the RELs re-illuminating for a conflict after receiving both a verbal ATC clearance, and a visual indication with the stop bar being extinguished.

*Pilot Response Time to RELs Re-Illuminating on Conflict Trials***.** In the trained group, the average response time to the RELs re-illuminating was 2.3 seconds (s). There was no learning effect over time, with the response times remaining similar between the first and last error exposure.

*Stopping Distance when RELs Re-Illuminated.* Distance from the hold short line when the pilots stopped the aircraft was measured for each trial in which the RELs re-illuminated. In the trained group, 93% of the time the pilots stopped the aircraft behind the hold short line (HSL). In 7% of the trials, the nose of the aircraft was over the HSL. On average, pilots who stopped prior to the HSL did so by 57.7 feet (ft). Of those who crossed the hold line before stopping, the average distance over the HSL was 48.4 ft, see Figure 2.

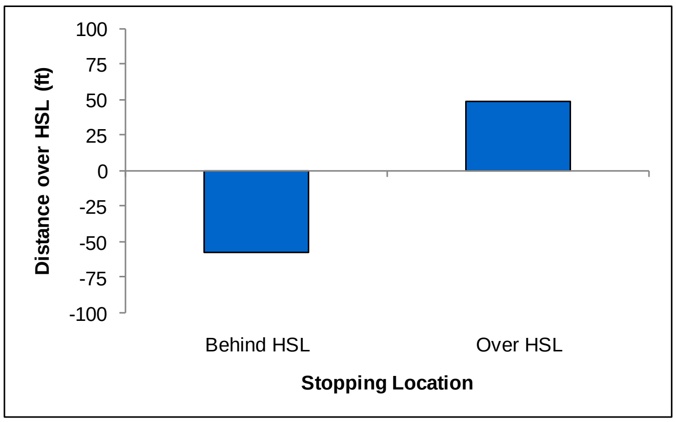


**Figure 2. Distance over the Hold Short Line at Stopping Location for Trained Group**

### Study Two—Untrained Group

*Pilot Response to RELs and Stop Bar***s.** In the untrained group, one pilot, on one trial crossed the illuminated stop bars when the RELs extinguished. This event occurred in conjunction with the start of a verbal ATC clearance, but was prior to the stop bar being extinguished. The data suggests that the pilot was anticipating the ATC clearance, and was not reacting to the RELs extinguishing. The throttle began to increase approximately one second after ATC began to issue a verbal clearance. This occurred 4 seconds after the RELs extinguished. In the untrained group, pilots stopped in response to the RELs re-illuminating on 67.5% of the trials.

*Pilot Response Time to RELs Re-Illuminating on Conflict Trials*. In the untrained group, the average response time to the RELs re-illuminating was 1.5 s. There was a significant reduction in RT over time **(**$\beta = -0.20$, $t = -2.49$, $p = 0.02$), suggesting there was learning over time.

*Stopping Distance when RELs Re-Illuminated.* In the untrained group, the nose of the aircraft was stopped behind the HSL on 42.5% of the trials, and was over the HSL on 25% of the trials. The average distance prior to the HSL for those who stopped behind it was 67.6 ft. For those pilots who stopped with the nose of the aircraft over the HSL, the average distance was 95.3 ft beyond the line, see Figure 3.

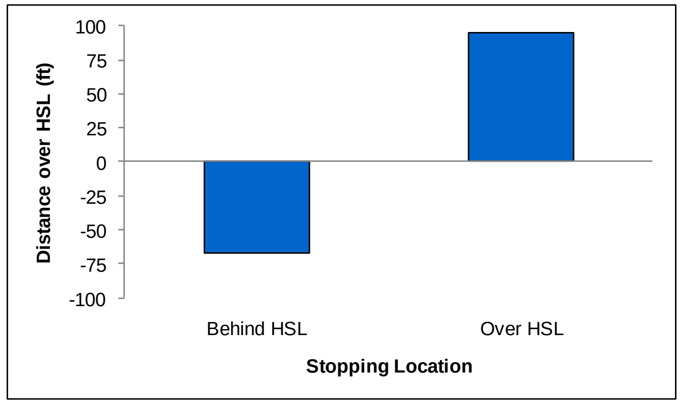


**Figure 3. Distance Over the Hold Short Line at Stopping Location for Untrained Group**

### Subjective Data—Trained and Untrained Groups

Pilots were given a questionnaire at the end of each scenario, as well as at the end of the experiment. They were asked to provide feedback on the concurrent use of RELs and stop bars. The untrained group was asked to provide this information after they received the full explanation of the purpose of the study and a short tutorial on both RELs and stop bars.

Pilots were asked whether seeing the RELs illuminate after the stop bar was turned off caused them any confusion. Among the trained pilots, 70% of pilots disagreed or strongly disagreed that seeing the REL re-illuminate was a cause for confusion, see Figure 4. Conversely, 30% of the pilots agreed or strongly agreed that seeing the RELs re-illuminate caused them confusion.

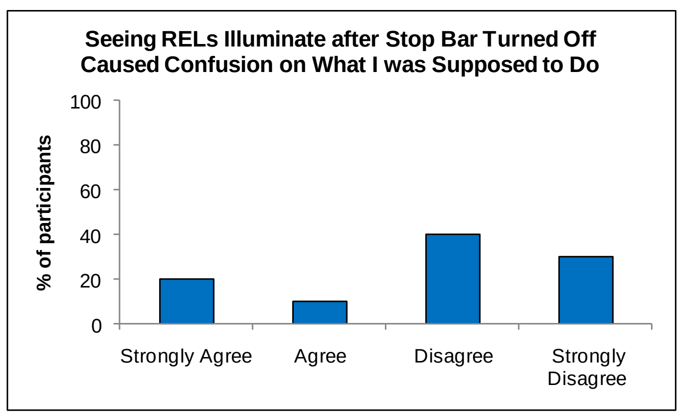


**Figure 4. Trained Pilots**

When the untrained group of pilots were asked a similar question, 37.5% of pilots reported that seeing the RELs re-illuminate after the stop bar was extinguished did not cause confusion, while 50% reported that it did cause confusion, see Figure 5. Conversely, 12.5% of the pilots reported that they did not notice the RELs re-illuminating. This pilot committed incursions on every conflict trial.

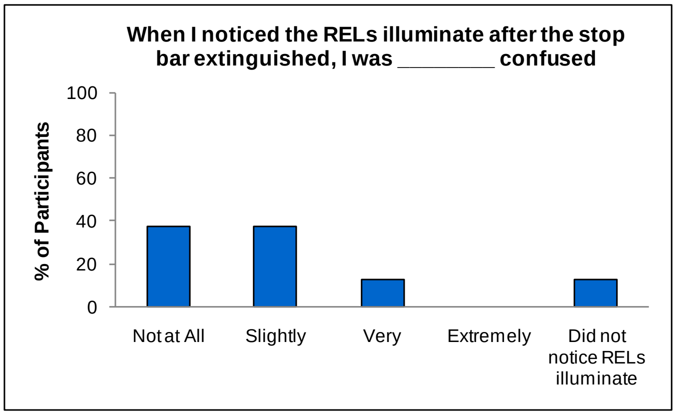


**Figure 5. Untrained Pilots**

When probed about the impact of the concurrent use of the systems on safety, 82% of the trained group of pilots stated that using the RELs and stop bars concurrently would not cause safety issues for pilots, while 18% felt that using them together has the potential to cause safety issues (see Figure 6).

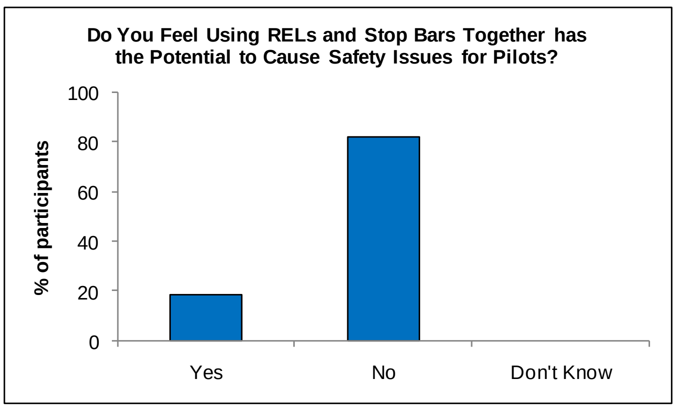


**Figure 6. Trained Pilots**

Among the untrained pilots, 87.5% agree or strongly agree that using the two lighting systems concurrently has the potential to increase safety (see Figure 7), while 12.5% (1 pilot) strongly disagreed. This pilot committed incursions on each conflict trial.

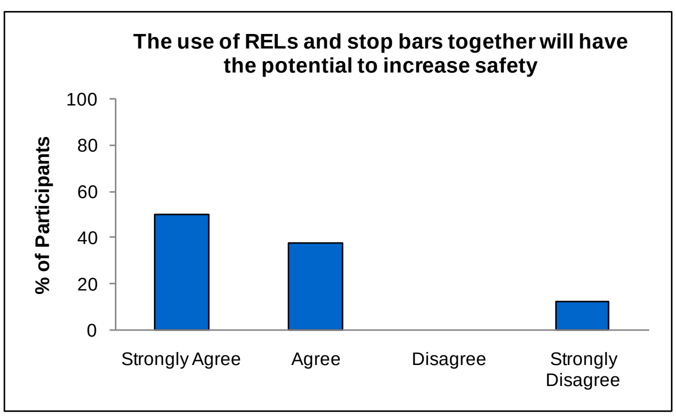


**Figure 7. Untrained Pilots**

## CONCLUSIONS

The results of these studies found that both trained and untrained pilots do not show evidence of crossing illuminated stop bars, even when the RELs extinguish. Pilots who are trained on the two lighting systems show evidence of appropriate responses when the REL illuminate after they have received a clearance to enter or cross a runway. They also exhibit evidence of a reduction in the severity of runway incursions with the use of RELs and stop bars concurrently. Pilots who were not trained on the concurrent use of the two lighting systems stopped the aircraft when the RELs re-illuminated 67.5% of the time, preventing or reducing the severity of the incursion. The untrained group of pilots also showed evidence of learning from operational errors, even without the benefit of training, responding appropriately to the RELs over time. Both the trained and untrained pilots indicate that the systems have the potential to improve runway safety. However, they also note that pilots may have confusion about how the systems operate together when RELs extinguish, but stop bars remain on, particularly when RELs re-illuminate to indicate the presence of a conflict aircraft. They indicate that confusion may be reduced, at least for some pilots, over time. Overall, the results suggest that training can improve the effectiveness of the concurrent use of RELs and stop bars.

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