MP 03W00000272

MITRE PRODUCT

Summary of Airport Surface Marking Project

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Sponsor: Federal Aviation Administration
Dept. No.: F041
Contract No.: DTFA01-01-C-00001
Project No.: 02044205-6R

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Abstract

This document provides a summary of activities in support of developing and evaluating several proposed airport surface markings. This effort has been sponsored by the Federal Aviation Administration's (FAA) Office of Runway Safety and the Office of Airport Safety and Standards to 1) identify marking concepts to be evaluated further within a field demonstration and 2) support potential revisions to Advisory Circular (AC) 150/5340-1H, Standards for Airport Markings.

During 2002, a number of proposed surface markings aimed at improving pilot situational awareness in the runway holding position environment were created. Four marking proposals were evaluated by general aviation and transport pilots within two lab simulations conducted at the MITRE Corporation. Based on favorable findings from these lab evaluations, three marking proposals were recommended for evaluation within a field demonstration.

The field demonstration was conducted at the T. F. Green State Airport (PVD) in Providence, Rhode Island. Data collection from the pilot community began at PVD in June 2003 and ended in September 2003. The data collected included pilot surveys, structured interviews, and field evaluations. Feedback from the pilot community on the proposed markings was overwhelmingly positive. In addition to the pilot data collection, an initial cost estimate was developed for the proposed surface marking concepts. The cost of implementing the combined elements of the proposed marking was found to be approximately 24 to 40 percent higher (depending on bead type selection) per holding position marking location than the standard markings in use at airports today.

Findings from all these efforts will be used to support potential revisions to AC 150/5340-1H, Standards for Airport Markings.

KEYWORDS: Airport Surface Markings, Runway Incursion

Table of Contents

List of Figures

List of Tables

Section 1

Introduction

During 2002, the FAA Office of Runway Safety and the Office of Airport Safety and Standards invited several industry representatives, human factors practitioners, and technical experts to participate in a series of structured discussions to identify enhancements to airport surface marking standards and practices that would improve pilot situational awareness (Olmos, 2003). These discussions centered on three areas within the runway holding position environment where potential enhancements to the current standards could be applied (Figure 1-1):

1. **Improve markings in the taxiway environment prior to the runway holding position markings**: The current marking standards provide minimal information in advance of the runway holding position marking on taxiways. For example, taxiway centerline markings are depicted in the same manner whether leading into a taxiway intersection or a runway holding position marking. In this area, the enhanced markings should provide an advanced warning to pilots that they are approaching a runway holding position marking.
2. **Enhance runway holding position markings on taxiways**: Improving the visibility of the runway holding position markings could assist pilots in better detection of the holding position marking location.
3. **Improve markings in the runway environment after the runway holding position markings[1]**: Currently, the taxiway centerline marking standard is the same prior to and after crossing the runway holding position markings. Modifications to the markings after the runway holding position markings should improve pilot awareness that they are now in the runway environment and are no longer positioned in the taxiway area.

[1] While several marking proposals in the "post-hold" environment were discussed and refined, there were no definitive conclusions as to which to proceed with for subsequent evaluations. As a result, the consensus within the workshops was to not modify any surface markings in the runway environment after the runway holding position marking.

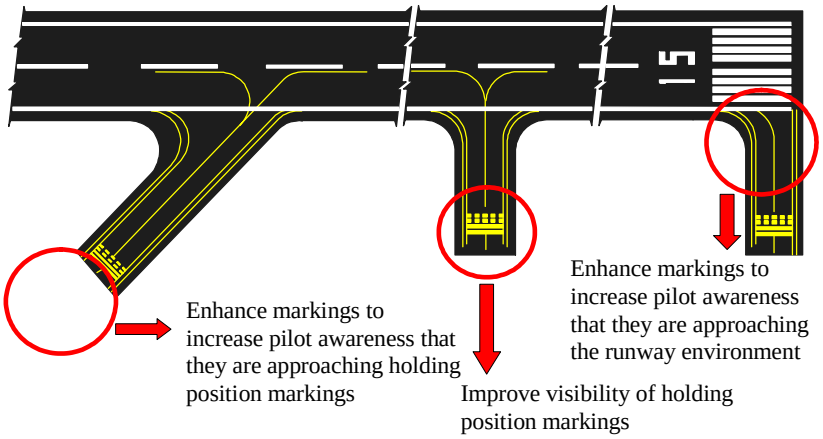

Figure 1-1. Runway Holding Position Environment: Areas for Potential Marking Improvements

1.1 Development of Marking Proposals

Over a nine month period beginning in March of 2002, several surface marking proposals were discussed and refined during four workshops. These workshops included FAA, human factors, and aviation industry representatives. Proposals were developed based on the following design goals and implementation considerations.

1.1.1 Design Goals

1. Conspicuity: The markings should be developed to be as salient as possible and should also be visible under a range of environmental and visibility conditions.
2. Convey Directionality: The markings should support the perception of stopping from one direction (e.g., turning onto a runway from a taxiway) and passing through from the other (e.g., turning off a runway onto a taxiway). The markings should not, however, encourage a specific action (see 4 below).
3. Provide Preview Information: The markings should provide a degree of expectation to the pilot that they are approaching a runway holding position.
4. Increase Awareness and Not Encourage Action: As a general rule, the concepts should be developed to increase general awareness in the holding position environment. Care should be taken, however, to ensure the marking concepts avoid conveying a specific action to the pilot. For example, taxiway centerlines are used to both taxi off and taxi onto a runway so they should minimize incorporating a specific direction in the centerline.

5. Intuitive, Usable, and Explicit: The markings should be easy to learn, use, and remember.
6. Unique at a Global Level: The markings should be unique and defined across several dimensions. For example, a proposal should not consist of changes within a single attribute (e.g., color only).
7. Internal Consistency of Marking Proposals: The marking elements that are proposed should be internally consistent (e.g., similar use of patterns and colors).
8. Preserve Essential Elements of Current Markings: Pilots and vehicle operators are familiar with the current markings and have been trained on their meaning. As such, to minimize additional training requirements, the marking proposals should avoid detracting significantly from the current standards (e.g., continue use of color yellow for taxiways, color white for runways).

1.1.2 Implementation Considerations

1. Eye Height: Airport users include a range of aircraft and vehicles with varying eye heights. Some representative eye heights include general aviation aircraft as well as surface vehicles, or large transport category aircraft, such as a B747. The visibility of the markings should be effective across all these heights.
2. Durability: The markings and associated materials should have minimal changes over time in color (e.g., darkening of white markings) or material (e.g., peeling) across exposures to extreme temperatures, precipitation, sunlight or other weather factors.
3. Complex Runway/Taxiway Intersections: There are several runway/taxiway intersection configurations that are unique to a specific airport and may vary considerably from airport to airport. As such, marking concepts that may be useful for cases depicted in Figure 1-1 may not be applicable at a more complex runway/taxiway configuration. A range of intersection configurations should be taken into account when evaluating the usefulness of a given proposal.
4. Ease of Implementation: Application of the markings should be relatively simple and not require special technical skills or unique equipment. As such, the markings should not be especially complex and the amount of downtime for implementation should be considered. In addition, application of the pavement marking should use current paint spray equipment and practices without modification or new procedures.
5. Cost-Effectiveness: Assessments of the paint and labor expenses associated with applying the markings should be considered.
6. Compatibility with Current Markings: Consideration of any new marking concept should be considered within the context of the marking standards identified in AC150/5340-1H. As such, proposals should ensure that they do not conflict with

airport marking standards used elsewhere (e.g., Surface Movement Guidance Control System (SMGCS) markings).

1.2 Surface Marking Proposal

During the workshop discussions, several surface marking concepts were recommended for evaluations within a cockpit simulation platform. These marking proposals, as well as the rationale for their recommendation, are described below (Figure 1-2):

1. **Runway Holding Position Markings on Taxiways:** Two runway holding position marking proposals were recommended for follow-on simulation evaluation. The first proposal consisted of extending the runway holding position markings onto the shoulder beyond the taxiway edge lines. This extension would help pilots of transport type aircraft to better position themselves with respect to the runway holding position marking (i.e., they can continue to see the position markings out the sides of the cockpit) and could also assist other surface operators (e.g., vehicles). Extending the position markings is also intended to increase the overall salience of the markings from any vantage point.

   The second proposal consisted of the use of white in the dashed portion of the runway holding position marking to identify the runway side of the hold line. The use of white in the marking is intended to help convey directionality to the pilot. That is, the white portion of the position marking will always be on the runway side (where white is primarily used) with the yellow portion being on the taxiway side (where yellow is primarily used). In general, both proposals were developed to avoid significantly altering the basic runway holding position marking pattern.

2. **Surface Painted Holding Position Signs***:* With respect to surface painted holding signs, this proposal would go beyond the marking requirement defined within AC 150/5340-1H. In cases where the width of the holding position on the taxiway is greater than 200 feet, the current standard requires a surface painted holding position sign positioned to the left of the taxiway centerline just prior to the runway holding position marking. The revision to the current standard would include the following:

   (a) Implement the painted holding sign on both sides of the taxiway centerline as opposed to the current standard which only requires the painted sign to the left of the taxiway centerline.

   (b) Implement them at all runway holding position areas regardless of taxiway width. As described earlier, the current standard only requires surface painted holding position signs at holding positions greater than 200 feet in width.

   Overall, this concept was recommended because it is salient and helped to increase the conspicuity of the runway holding position marking. The proposal also helps to convey directionality (i.e., when turning off the runway, text is upside-down).

Finally, this proposal, as presented, would provide visible cues to surface operators who, due to eye height, may have difficulty seeing the surface painted sign to the left of the centerline.

3. **Modified Taxiway Centerline:** This proposal consisted of dashed yellow lines that are placed on both sides of the taxiway centerline. The modified taxiway centerline would be implemented approximately 150 feet (45 m) prior to the holding position markings (if sufficient space is available). A pilot taxiing at 14 knots would be provided an additional runway holding position detection time of six seconds.

   The overall intent of this marking proposal was to provide increased awareness that pilots are approaching a runway holding position marking. This proposal was developed such that the core taxiway centerline marking (i.e., a solid line) was maintained while still providing a unique preview pattern prior to the runway holding position location. In addition, the coloring scheme (e.g., yellow) was developed to be consistent with the overall taxiway marking coloring schemes.

4. **"RWY AHEAD" Label:** This proposal consisted of placing a "RWY AHEAD" label approximately 150 feet (45 m) prior to the runway holding position marking and would only be implemented on a limited basis. Advantages of this proposal are that it is a salient marking that indicates, along with the modified centerline (see #3 above) proposal, the beginning of the runway environment, and it also includes directionality within the marking itself. That is, taxiing off the runway pilots will see the text as upside-down. Also, the use of the yellow background color was intended to help to improve visibility during dark conditions.

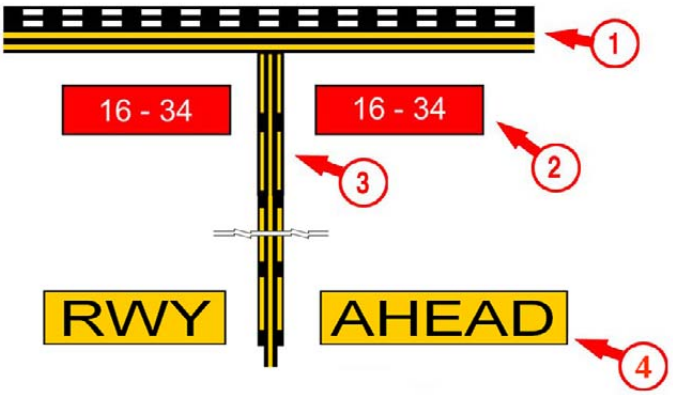

Figure 1-2. Overview of Surface Marking Proposals

A summary of findings from two simulation evaluations and a follow-on field demonstration are provided in the remaining sections.

Section 2

Lab Evaluations of the Proposed Markings

2.1 Background

Recommendations resulting from the workshops were assessed in a series of controlled laboratory evaluations. These evaluations - subsequently referred to as Evaluation 1 and Evaluation 2 - provided objective and subjective data on the affect of the proposed markings on runway awareness and conspicuity of the runway holding position marking. Evaluation 1 focused on quantifying the effects of the markings as individual elements (e.g., only surface painted holding position signs), with the pilot acting as a passive observer. In Evaluation 2, the markings were evaluated as combinations (i.e., modified taxiway centerline, runway holding position markings, and SPHPS) with a particular focus on assessing the utility of the "RWY AHEAD" label. During Evaluation 2, the subject acted as the pilot-in-command and an operational environment was created by including communication with a ground controller, taxi clearances, and checklists. Thirty-two pilots evaluated the proposed markings in the two evaluations conducted at the MITRE Corporation's Center for Advanced Aviation System Development (CAASD) Air Traffic Management (ATM) Lab (Figure 2-1). These subject pilots included 20 transport pilots (e.g., B757) and 12 General Aviation (GA) /business pilots (e.g., Citation, Gulfstream III, Cessna 172).

Figure 2-1. CAASD Platform for Evaluation of Proposed Markings

During the evaluations, subjective (surveys) and objective data (holding position marking and runway environment detection distance) were collected to evaluate how the proposed markings - individually and in combination - compared to the current marking standard at addressing the initiatives of increasing holding position marking visibility and enhancing pilot runway awareness.

2.2 Results

Over the course of Evaluations 1 and 2, the proposed markings performed better than the current markings for both GA and Transport category pilots. Further, of all the marking proposals seen by the pilots in Evaluation 1, the Combined condition consistently produced the best objective results for both GA and Transport category pilots (Figure 2-2). Evaluation 2, which compared the efficacy of the Combined condition with and without Runway Ahead Labels, showed that some of the benefit gained from the Combination is lost when the Runway Ahead Labels are removed (Figure 2-3). This is balanced by survey data indicating that while GA pilots showed a consistent preference for the combination of all proposed markings, Transport pilots gave the Combined condition lower ratings due to clutter (Figure 2-4).

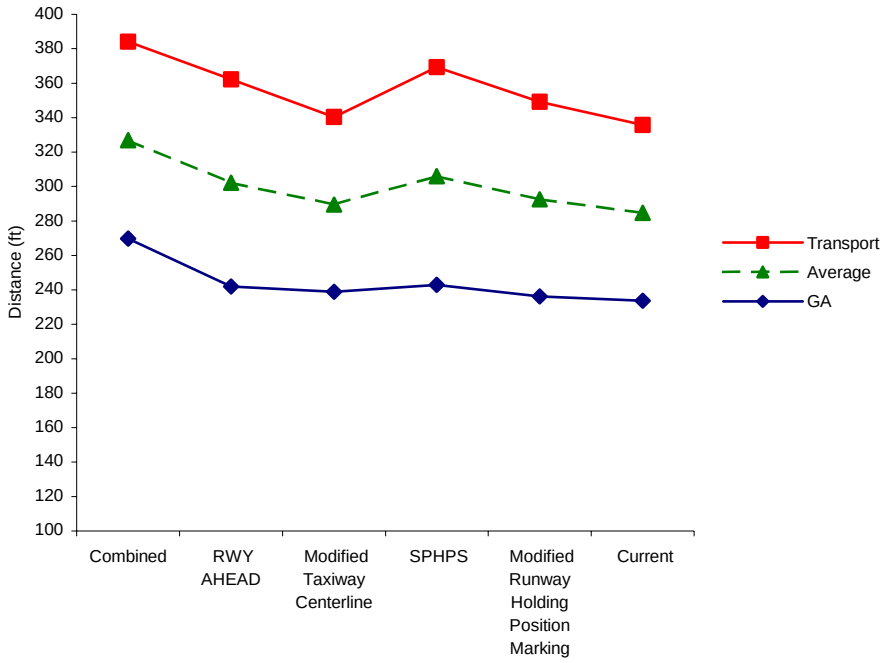

Figure 2-2. Average Detection Distance for the Runway Holding Position Marking by Marking Condition (Evaluation 1)

Pilot comments generally indicated that the combination of all of the proposed elements provided a beneficial redundancy, especially in conditions where the markings may be contaminated. In fact, one reason for the superior performance of the combined condition in the simulator may have been redundancy rather than a larger visual cue. For example, several pilots noted the red Surface Painted Holding Position Signs in conjunction with the Modified Centerline allowed one cue to confirm the other. Pilots, as previously mentioned, did comment that using all of the elements may produce too much clutter, particularly at complex intersections. These comments are supported by the fact that the proposed markings, both in combination and individually, did not produce as dramatic an effect at complex intersections. Transport pilots showed particular concern for issues of complexity and clutter, as reflected in their survey ranking of the Combined condition (Figure 2-4).

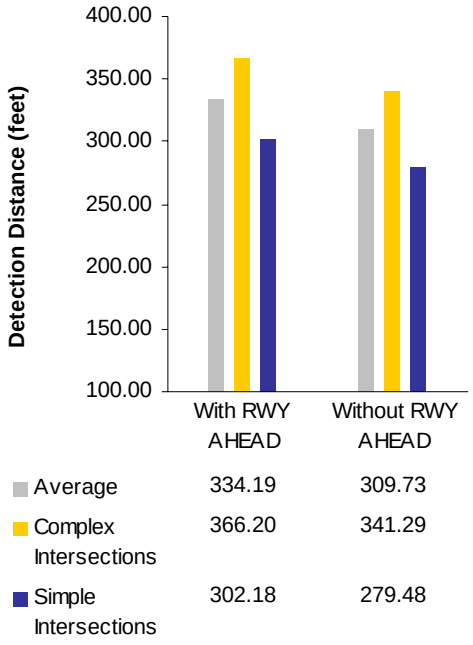

Figure 2-3. Average Detection for the Runway Environment with and without Runway Ahead (Evaluation 2)

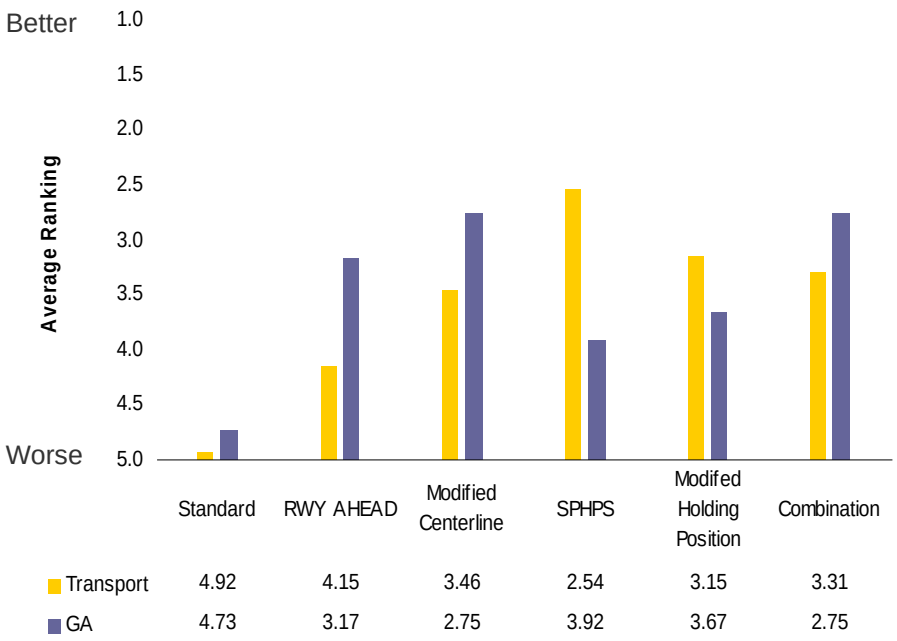

Figure 2-4. Average Ranking When Pilot Asked to Rank Order Marking Conditions (Evaluation 1)

Section 3

Field Demonstration of the Proposed Markings

3.1 Background

In December of 2002, the findings from the lab evaluations were briefed to the FAA, industry, and human factors working group that developed the proposed markings. Based on these findings, the working group recommended this effort move forward with a field demonstration of the proposed markings.

The field demonstration (Andrews, 2003) began at T. F. Green State Airport (PVD) in June of 2003 and included the following three marking proposals (Figure 3-1):

1. **Runway Holding Position Markings on Taxiways***:* The runway holding position markings were extended onto the taxiway shoulder beyond the taxiway edge lines. Also, the dashed portion of the current runway holding position markings pattern was painted white instead of yellow to identify the runway side of the hold line.
2. **Surface Painted Holding Position Signs***:* Placed on both sides of the taxiway centerline (if sufficient space was available).
3. **Modified Taxiway Centerline***:* Dashed yellow lines were placed on both sides of the taxiway centerline. The modified taxiway centerline was implemented approximately 150 feet prior to the runway holding position markings (if sufficient space was available).

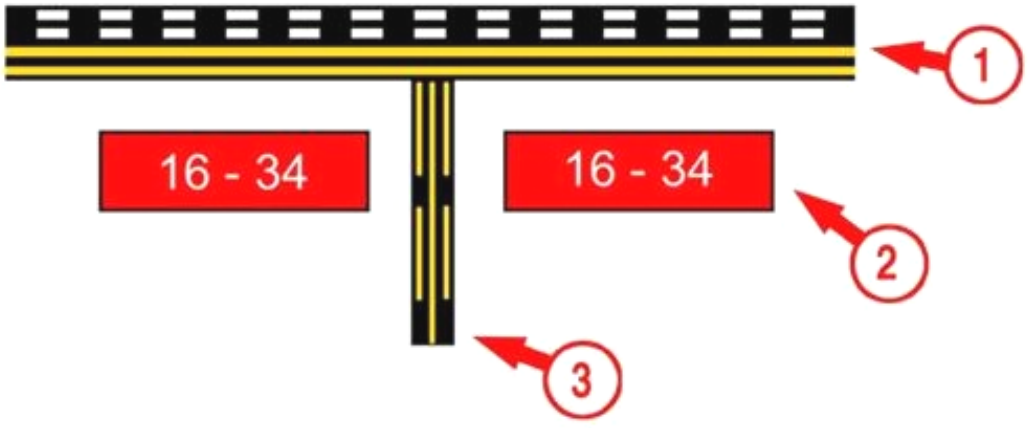

Figure 3-1. Overview of Surface Marking Proposals for PVD Field Demonstration

These three marking proposals were implemented at every taxiway/runway intersection (Figure 3-2). The “RWY AHEAD” label was not evaluated within this field demonstration as PVD did not have a specific intersection at which this proposal would be useful.

In total, 184 pilots participated in the field demonstrations at PVD. Of these 184, 163 pilots completed surveys, either online or via a paper copy made available through Fixed Based Operators and the Airlines. Fifteen more pilots participated in structured interviews in which the pilot was asked a series of open response questions. Each of these 15 pilots was interviewed three times over a two month period, supporting analysis of change in pilot opinion of the markings over time. The final six pilots took part in operational tests using a Piper Aztec Model F at T. F. Green and Bradley International, with data collected at Bradley used for creating a baseline. During the operational tests, measures of detection distance, eye-tracking data, and survey response were collected.

Figure 3-2. Proposed Markings at T. F. Green State Airport (PVD)

3.2 Results

The field demonstration resulted in favorable reviews of the markings in all phases of the assessment, including the surveys, structured interviews, and operational tests (Olmos, Estes, and Andrews, 2003). Survey responses to the proposed markings were particularly positive, with the strongest ratings given to the SPHPS and the Combination of all proposed markings (Figure 3-3).

Pilots participating in the structured interviews indicated the biggest benefit from the proposed markings would be to confused or distracted pilots, under reduced visibility, and to

pilots who are unfamiliar with the airport. In addition, pilots commented that training needs would be minimal. When, over the course of several months, pilots were interviewed a second and third time, very little change was found in their opinions. Data from the operational tests has supported simulator results, showing that the proposed markings improved detection distances (Figure 3-4).

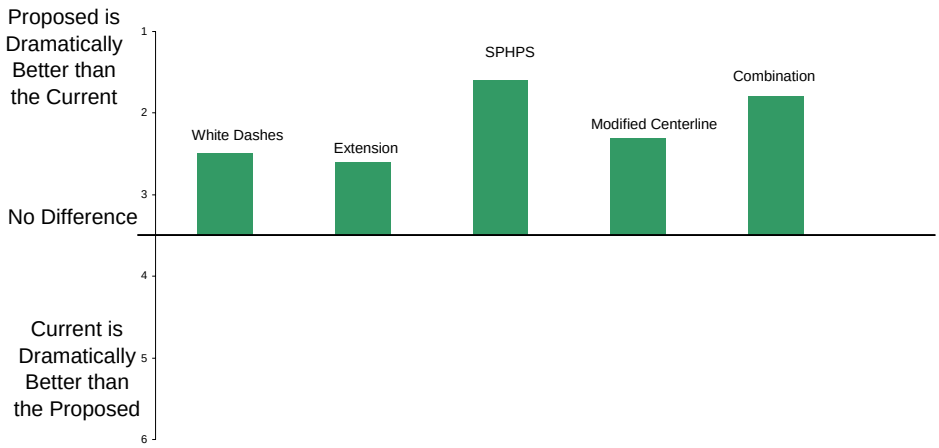

Figure 3-3. Average Ratings by Marking for Comparison to the Current Standard

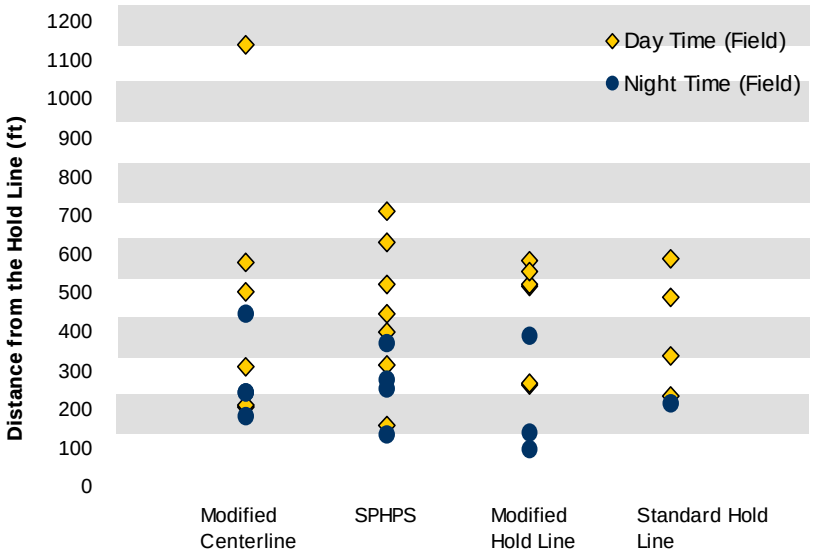

Figure 3-4. Distance from the Runway Holding Position Marking when detected

Through the use of a head mounted eye tracking system, it was also determined that the proposed markings do not appear to distract pilot scan patterns (Figure 3-5). However, it should be noted that the pilot did not have to complete all of the tasks normally associated with taxiing. Many of these tasks, such as communicating with ATC and referring to the taxi chart, were performed by the safety pilot.

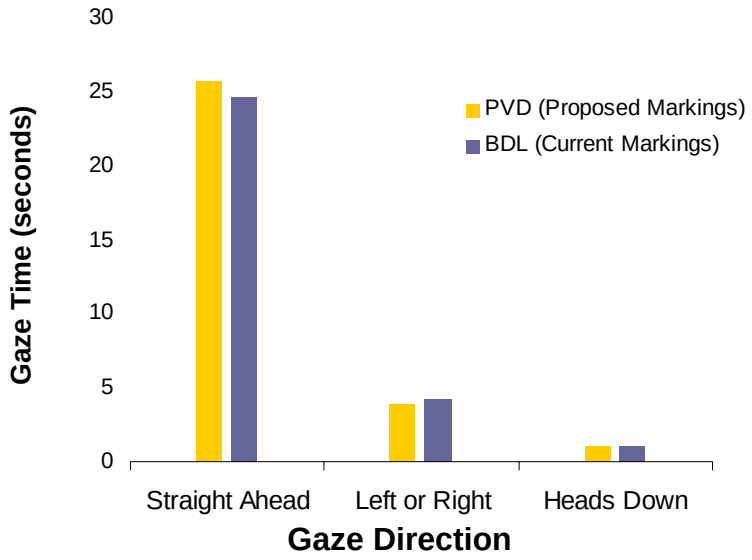

Figure 3-5. Average Time Spent in Gaze Direction While Approaching Runway Holding Position Marking

3.3 Summary of the Cost Estimation

3.3.1 Cost Variables

Many variables must be considered when developing NAS-wide implementation cost data for the proposed enhanced markings, not the least of which is whether an airport chooses to do the project with their own maintenance staff or hire an outside commercial paint contractor to perform the work. Some key issues that need to be considered when developing a cost estimate for the initial implementation of the proposed markings include the following:

- Bead Type selection
  - Typically, Type I beads are less expensive than Type III beads
- Total Footage

  - Number of runway holding positions at a single airport may vary from a few for a small airport to well over 100 at a large Hub
  - Solutions for "Unique" geometries may depend on the number of converging centerlines or physical characteristics of the pavement surfaces
  - Size and number of SPHPS alpha numeric(s) can range from 9 – 12 feet (3 – 3.67 m) and from one to up to twelve characters (i.e., "16 – 34 10L – 28R")
  - Black outline depends on surface type (asphalt or concrete)
- Contractor Pricing Practices
  - Economies of scale, the more runway holding position markings the cheaper the price
  - Profit levels can vary from 10 to more than 40 percent
  - Overhead amount may be similar to profit
  - Sub contract/bond may or may not be necessary
- Labor Days – crew size, surface availability due to operations or weather
- Surface preparation is site specific and difficult to calculate without a physical inspection.

3.3.2 Cost Estimate for Enhanced Markings

Rhode Island Airport Corporation (RIAC) used its own in-house maintenance staff to implement the proposed runway holding position marking enhancements: extension of the runway holding position markings onto the taxiway shoulder beyond the taxiway edge lines, the dashed portion of the runway holding position markings pattern painted white instead of yellow, two Surface Painted Holding Position Signs placed on both sides of the taxiway centerline, and dashed yellow lines placed on both sides of the taxiway centerline approximately 150 feet prior to the runway holding position markings.

These enhancements were placed at the nineteen taxiway/runway holding position markings for a total cost of $21,000 (not including stencils[2]) for the purpose of this demonstration. They used Type I beads. Therefore the average unit price for each enhanced runway holding position marking was approximately $1,100. This includes labor and materials. It is important to note that in-house maintenance installation pricing will generally be lower than commercially contracted services due to travel costs for example, and other factors mentioned in section 3.1.1 above.

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2 RIAC estimated stencils for this project at $1,000 for nine foot letters.

With these factors in mind, commercial paint contractor cost calculations were developed to provide an estimate of the initial implementation costs associated with the proposed markings – costs for implementing the markings at an entire airport (i.e., all taxiway/ runway holding position markings). In this case, a complete estimate for the T. F. Green State Airport was developed.

The implication is that the cost will vary depending on the methodology selected or available to a particular airport.

If 19 T. F. Green State Airport taxiway/runway holding positions had been contracted to be painted with the enhancements by a commercial paint contractor, a unit price for the 19 taxiway/runway holding position enhanced markings (with almost half of the holding position markings having a unique geometry or implementation issue) was estimated at:

$1,700.00 for Type I beads and

$2,100.00 for Type III beads

This estimate includes costs associated with labor, material, equipment, and other contractor expenses (but does not include surface preparation costs and stencil costs[3]). A separate unit price cost estimate was also developed for implementing a standard holding position marking using Type I or Type III beads and these were $1,370 and $1,500, respectively at all 19 T. F. Green taxiway/runway holding positions.

Using the figures above, an approximate percentage rate for the proposed marking to be paid over the standard runway holding position marking (by bead type) is as follows:

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3 Stencils could be a one-time investment and have been estimated at ~$1,800 for nine foot letters.

Table 3-1. Overview of T. F. Green Average Unit Price for Standard vs. Proposed and Comparison of Contractor vs. In-House Cost Estimates

	Commercial Airfield Paint Contractor Standard Marking Cost Estimate (includes Standard Runway Holding Position Marking plus 150 feet of taxiway centerline)	**Commercial Airfield Paint Contractor Proposed Marking Cost Estimate**	**Commercial Airfield Paint Contractor Estimate of Proposed Marking Cost Increase over Standard**	**T.F. Green In-House Maintenance Staff Proposed Marking Installation Cost Estimate**
Type I Bead[4]	$1,370	$1,700	+$330 (24%)	$1,100
Type III Bead	$1,500	$2,100	+$400 (40%)	Not Estimated

It should be noted that there may be regional pricing differences and subsequent life cycle maintenance costs to be considered. Also, some airports will need to repaint their markings more frequently than others.

4 While either Type I or Type III beads are acceptable to the FAA, most airports use Type I.

Section 4

Summary

Three surface marking elements were assessed within the PVD field demonstration for supporting improved awareness of the runway environment: modified centerline, surface painted holding position signs (SPHPS), and a modified holding position marking which included extending the holding position marking and the use of white dashes. These marking enhancements were developed and evaluated over a two year period. As discussed in Section 1, this effort began with several FAA, human factors experts, and representatives from a wide variety of industry groups meeting repeatedly to generate and refine numerous marking concepts (Olmos, 2003). During this process, nearly 20 marking enhancements were proposed. Each was discussed, prototyped in a cockpit simulation, and eventually four marking concepts were recommended by this FAA/industry group for evaluation within two simulation evaluations. Across both simulation evaluations, a total of 32 pilots (20 Transport and 12 GA participants) provided a structured assessment of the proposed markings. Findings from these simulations were favorable towards the markings concepts which led to the eventual recommendation for a field demonstration (Estes, 2003).

With this context in mind, a review of findings from the simulation evaluations and field demonstration has found strong support for implementation of three marking concepts. Specifically, the collective results have revealed the greatest benefits with respect to improved detection distance as well as subjective preference are associated with the combination of all marking elements (i.e., modified taxiway centerline, runway holding position marking, and SPHPS). Within both simulator evaluations, the combination significantly increased conspicuity of the runway holding position as well as provided an earlier awareness of the runway environment. In addition, the combination received the highest ratings and was the pilots' preferred implementation concept.

These results were supported by results from the field evaluation. The combination received ratings just behind that of the SPHPS during the survey. Further, pilots responding to the simulation survey indicated that the combination provided beneficial redundancy. For example, at night, when the red SPHPS are more difficult to see, the other marking elements are still visible. Likewise, during periods of snow, if one marking is contaminated, other marking elements may still be visible.

The cost of implementing the combined elements of the proposed marking was found to be approximately 24 to 40 percent higher (depending on bead type selection) per holding position marking location than the standard markings in use at airports today. As a whole, the combined marking concept will not be exceedingly difficult to implement and will not require new application equipment or extensive training. Evaluation of individual airport intersection geometries will, however, be required to determine layout geometries.

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