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Determining Minimal Display Element Requirements for Surface Map Displays

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There is a great deal of interest in developing electronic surface map displays to enhance safety and reduce incidents and incursions on or near the airport surface. There is a lack of research, however, detailing the minimal display elements required to describe the airport surface for different uses of a surface map display. In order to address this question, 43 general aviation pilots were asked to rate the need for information required during phases of operations on or near the airport surface (taxi out, takeoff, final approach and landing, taxi in). Participants rated 88 different display elements that are found on current airport diagrams or made available by data from airport surveillance technologies. The data show the shifting need for information across different phases of operations. Additionally, the data reveal a drop in pilots' subjective need for runway information when pilots taxi in to the gate relative to the other three phases of operations.

Introduction

The airport surface is a complex and highly dynamic environment; the safety of operations is a serious concern. Unfamiliarity with the airport, deficiencies in airport surface markings (e.g., poor signage), or non-optimal weather or lighting conditions increases the difficulty of determining ownship position as well as the position of other vehicles and could lead to disorientation (Andre, 1995). Increases in traffic at airports combined with airport expansion projects make taxiing more difficult (FAA, 2001a, b). In fact, the former FAA Administrator, Jane Garvey, noted that "taxiing on the airport surface is the most hazardous phase of flight … when accident statistics – including those of near misses [sic] – were analyzed, today's airport surface was found to have the greatest potential for major catastrophes" (Gerold, 2001).

The Federal Aviation Administration (FAA) Safeflight 21 program office is examining the use of electronic surface map displays to enhance safety and reduce incidents on or near the airport surface. A surface map is expected to aid the visual acquisition of surface elements (e.g., runways, taxiways, or other aircraft) and increase pilots' awareness of the airport layout (Batson, Harris, and Hunt, 1994; Battiste, Downs, and McCann, 1996). As shown in Figure 1, the surface map is expected to be constructed from a database which contains positional data describing the location of airport runways, taxiways, non-movement areas, ramp areas, buildings, hold lines and stop bars. Additionally, data from GPS combined with other surveillance technologies, e.g., Automated Dependent Surveillance-Broadcast (ADS-B), provides a means to display real-time information regarding ownship position and the position of other aircraft and surface vehicles. It is anticipated that this display of vehicle information will increase pilots' awareness of traffic on or near the runway surface and allow pilots to infer traffic intent with respect to surface movements (RTCA, 2002a, b).

It is expected that electronic surface maps will have different levels of capabilities, and hence, different display requirements, depending on the quality of the map database. Electronic displays afford the map designer flexibility in determining the level of detail with which to depict the airport surface. Based on assumptions regarding surface information requirements, current surface maps typically depict ownship and traffic positions, runways, runway labels, taxiways, taxiway labels, non-movement areas, and buildings. These surface maps were demonstrated at a Safeflight 21 evaluation in Memphis in May, 2002, during which time ADS-B and Cockpit Display of Traffic Operation (CDTI) technologies for surface operations were tested.

The depiction of the airport surface and the ongoing events is challenging. The determination of whether or not to depict a display element results in a trade-off between the informativeness of the item and its contribution to display clutter. The costs of clutter may be reflected in information access, as when a target item is located, but is difficult to interpret because of the presence of other items in very close (or overlapping) spatial proximity. For example, pilots participating in an operational evaluation reported that the presentation of surface traffic on the CDTI display increased the difficulty in determining runway occupancy, particularly when they were asked to follow a target aircraft during approach. As the target aircraft approached the runway, it appeared to merge with surface targets, increasing the difficulty in determining whether or not the target aircraft had indeed landed (FAA, 2001c).

The determination of which elements to show and when requires an understanding of pilots' needs for the different display elements throughout the different phases of operations. Such an analysis was conducted by Schvaneveldt, Beringer, and Lamonica (2001) to determine the priority of information required for flight. In their study, a taxonomy of display elements for 7 flight phases (takeoff, climb, transition to cruise, cruise, descent, approach, and landing) and 2 planning phases (preflight and in-flight) was created by analyzing the information required for normal flight operations. Items included in their questionnaire represented both broad categories of information (e.g., general weather) and very specific items (e.g., altitude, distance). Pilot priority ratings revealed a shifting of priorities across the phases of flight as well as between flight and planning phases. Further analysis revealed relationships among the different display elements.

There is a lack of research, however, detailing the minimal display elements required to describe the airport surface for different functions of a surface map display (FAA, 2001). Furthermore, there is no research basis defining the *need* for each element throughout different phases of operations on or near the airport surface (taxi out, takeoff, final approach and landing, taxi in). To determine a set of minimal display elements, airport information found on current chart designs (e.g., Jeppesen charts and National Oceanic and Atmospheric Agency airport diagrams) could be compared and evaluated with respect to pilots' needs (FAA, 2001). Such an understanding would be useful in organizing and prioritizing the display elements, so that the pilot is presented with the necessary elements in each phase of operations on or near the airport surface. This was the goal of the present study.

We used a technique similar to that used by Schvaneveldt, et al. (2001) to assess pilots' needs. Operational emphasis was placed on phases on or near the airport surface, that is, up to 1000 feet above ground level. Consequently, there was little overlap between the display elements considered here and those considered by Schvaneveldt, et al. Pilots were presented with a list of display elements, and asked to rate the need for each display element for different phases of operations near or on the airport surface. The questionnaire included airport features found on current taxi charts (e.g., runway and taxiway information) or that are made available with ADS-B technology (e.g., the location of air and surface vehicles). The pilots' ratings will be used to determine the need for each display element and can be used to define a prioritization structure that may then be coordinated with the different levels of surface map capabilities that are beginning to emerge.

Methods and Procedure

Participants. 43 (36 male, 7 female) general aviation pilots were recruited for the study. Pilots were FAA employees or members of a federal flying club. They had an average of 3632.9 flight hours. Participants were compensated with a $50 gift certificate for pilot supplies for their participation.

Questionnaire. Pilots were presented with a set of forms, which included a consent form, a demographics questionnaire, forms listing display elements for four phases of operations on or near the airport surface (taxi out, takeoff, final approach and landing, and taxi in), a glossary of terms, and an airport diagram for reference. The display elements considered consisted of items that are currently available on paper charts or that will be available with ADS-B technology. The elements can be categorized into 8 classes: runway information, taxiway information, ownship information, traffic information, status indications, geographical features, and obstructions. A list of the display elements is presented in Table 1.

For each of these display elements, pilots were asked to rate how much they *needed* it for each phase of operations on or near the airport surface, using the following scale:

- **5** Very high need
- **4** High need
- **3** Moderate need
- **2** Low need
- **1** Very low need
- **0** No rating

The phases of operations were defined as follows:

- taxi out: taxi from the gate (or hangar) to the runway
- takeoff: enter the runway to wheels off the ground
- final approach and landing: established on the final approach to landing and turnoff
- taxi in: taxi from the runway to the gate (or hangar)

Procedure. The questionnaire was conducted on-site at the FAA. Additionally, 30 questionnaire packets were distributed to members of the flying club with self-addressed, stamped envelopes. Of the 30 packets, 23 were returned (a 76.6% return rate). The questionnaire took approximately 45 minutes to complete.

Results and Discussion

Mean ratings were calculated for each display element within each of the four phases of operations on or near the airport surface. There was no difference in ratings between the pilots recruited from the FAA and those recruited from the federal flying club; hence the data sets were collapsed. Analyses of Variance (ANOVA), conducted on the data for each phase of operations, revealed significant differences in the display element ratings [taxi out, $F(87, 3494) = 13.97$, $p < 0.01$; takeoff, $F(87, 3518) = 16.36$, $p < 0.01$; final approach and landing, $F(87, 3564) = 12.88$, $p < 0.01$; taxi in, $F(87, 3439) = 21.97$, $p < 0.01$)]. To determine if a set of minimum display elements could be identified based on the similarities in the need ratings, a Newman-Keuls analysis was conducted for each phase of operations. A set of high and low need display elements were defined to be the groups with the highest and lowest ratings, respectively. The results are discussed below.

High Need Display Elements. Display elements that were rated as high need are presented in Table 2. The high need items listed here define a starting point in creating a set of "minimum display elements" for each phase of operations on or near the airport surface. The set of high need display elements, however, still comprises of a number of items, the presentation of which will result in a cluttered display.

Across all four operational phases, the ratings identified a subset of display elements considered to be "high need": runways, traffic location, and indication of traffic status (whether the vehicle is in the air or on the ground). It is noteworthy that, with the exception of runways, these high need items are available through ADS-B, and are not currently available on paper charts. Additionally, the ratings reveal subsets of operation-specific display elements, i.e., those important to the taxi phases of surface operations (taxi in, taxi out) and those specific to the flight phases (takeoff, final approach and landing). In examining ratings for the taxi phases, pilots needed airport information relevant to their surface movement, i.e., where they could move (taxiways and ramp areas), where they could not (areas under construction, restricted areas, ILS critical areas), where to wait for instructions (ILS hold lines, hold short lines), and who might be in their way (traffic on the ground). During the flight phases, pilots needed detailed information regarding runways (runway heading, runway edges) and the positions of proximate traffic in the air.

The ratings also reflect the changing need for display elements, similar to that found by Schvaneveldt, et al (2001). In particular, it is interesting that the data revealed less need for the depiction of runways during the taxi-in phase relative to the other three operational phases. The average need for runways was rated at 4.70 during taxi out, 4.74 during takeoff, and 4.79 during final approach and landing, but dropped to 3.85 during taxi in. T-test comparisons showed that the difference between taxi in and each of the other three operational phases was significant (taxi in vs. taxi out: $t(82) = 4.51$, $p < 0.01$; taxi in vs. takeoff, $t(82) = 4.72$, $p < 0.01$; taxi in vs. final approach and landing: $t(81) = 5.10$, $p < 0.01$). The ratings suggest a shift in focus during taxi-in to other sources of information besides runways, although pilots may have complex taxi clearances that require them to cross runways.

Finally, the results identify the need for display elements that are *not* currently depicted on many prototype surface map displays; these items are presented in bold in Table 2. For taxi phases, these items included ILS information (hold lines and location information of ILS critical areas). For flight phases, high need display elements not currently depicted on prototype displays consisted of detailed runway information.

Low Need Display Elements. Also interesting is an examination of those items that the pilots considered to be of "low need", as shown in Table 3. Items, which were rated to be low need but are being depicted on prototype surface displays, are presented in bold typeface. It is important to note that the depictions of some of the low need items are predetermined by the presentation of certain high need items. For example, by definition, the presentation of taxiways necessitates the presentation of the areas between taxiways, i.e., grassy areas. Additionally, certain display elements classified to be "low need" are displayed at the pilots' discretion, on prototype displays, e.g., traffic altitude (absolute/relative) and ground track vectors.

The ratings identified a subset of display elements, considered by pilots to be of low need throughout all four operational phases. These display elements can be separated into two categories: runway information (runway weight bearing capacity) and geographical features (airport reference point, grassy areas, latitude/longitude, magnetic variation, railroad locations, and water features). Examination of whether display elements could be classified as "low need" as a function of operation (taxi versus flight) revealed similarities in information needs for the two flight phases but differences during taxi in and taxi out.

In first considering the flight phases, the ratings show the low need for information regarding surface movement. Surface attributes providing information about buildings (hangars, terminal buildings, FBO, and building identification), movement (aprons, deicing areas, ground track vector, holding pens, non-movement areas, ramp areas, taxiway edges, taxiway bearing strength, taxiway centerlines, taxiway width), and geography (water features, railroads, airport reference point) were rated to be of low need for both takeoff and final approach and landing phases.

The data for the taxi phases reveal more differences than similarities. Here, only 4 geographical features were rated as low need for both taxi in and taxi out phases: air traffic control boundaries, electrical pole lines, spot elevations, and trees. Rather, the classification of display elements as low need, and in particular, the predominance of low need ratings for runway information during taxi in, highlights the task differences between the taxi in and taxi out phases. During taxi out, pilots are still planning their takeoff so runway information is important, whereas during taxi in, pilots are more focused on taxiing to the FBO or hangar and are less concerned with runways.

Conclusion

The goal of this research was to identify pilots' needs for display elements for phases of operations on or near the airport surface. Only a handful of elements were rated as "high need" for all phases of operations considered here; these items were runways, traffic location, and indication of traffic air/ground status. In general, "high need" display elements varied according to phase of operations, particularly, whether the phase of operations was a flight phase or taxi phase. During taxi, pilots rated information relevant to surface movement to be "high need". In the flight phases (takeoff and final approach and landing), "high need" elements included runways and the positions of proximate traffic in the air. The results reflect pilots' changing needs, similar to those reported by Schvaneveldt, et al. (2001), and illustrate the challenge in designing a surface map display that presents the appropriate information at the proper time.

The availability of an electronic surface map display of aircraft and vehicle position via ADS-B and other surveillance technologies enables new capabilities for enhancing the safety of airport surface operations. While the focus of this study was general aviation pilots, we are conducting a similar study with air transport pilots. Additionally, we plan to validate the pilot ratings through simulation, in which pilots are provided with a surface map that presents only the high need display elements, and asked to fly arrival and departure scenarios. The pilot ratings also provide a start for defining a decluttering scheme based on need, with which to organize the display elements.

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Table 1. Display elements considered.

Runway Information	**Geographical Features**	**Ownship Information**	**Obstacles**
Runways	Air traffic control boundaries	Ownship	Condition of surface areas (other than runways)
Runway centerlines	Airport beacons	Ownship heading	Obstructions
Runway displaced thresholds	Airport name	Ownship ground speed	**Status Indications**
Runway edges	Airport reference point	Lubber line	Compass rose/arc
Runway elevation	Airport terrain features	**Traffic Information**	Range information
Runway end elevation	Aprons	Indication of traffic status (in air/on ground)	Full range ring
Runway heading	Areas under construction	▪ Traffic in air	Half-range ring
Runway hold short lines	Buildings	▪ Traffic call sign (traffic in air)	Map scale
Runway labels	▪ Building identification	▪ Traffic on the ground	**Taxi Information**
Runway landing length	▪ Control tower	▪ Traffic call sign (traffic on ground)	Ground track vector
Runway length	▪ Fire station	Traffic altitude	Gate numbers
Runway lighting	▪ FBO	▪ Absolute	
Runway markings	▪ Hangars	▪ Relative	
Runway shoulder	▪ Terminal buildings	Traffic location	
Runway slope	Deicing areas	Selected target indicator	
Runway stopways	Grassy areas	▪ Selected target speed	
Runway surface information	Helicopter landing pads	▪ Selected traffic identification	
Runway weight bearing capacity	Holding pens	▪ Selected target aircraft class	
Runway width	Latitude/Longitude	▪ Selected target distance	
Taxiway Information	Magnetic variation	Predictor	
Taxiways	Non-movement areas		
Taxiway bearing strength (when less than associated runway)	North indication		
Taxiway centerlines	On airport navaids		
Taxiway edges or boundaries	Pole line		
Hold short lines	Railroads		
Taxiway labels	Ramp areas		
Taxiway width	Restricted areas		
ILS critical areas	Roads		
ILS hold lines	Spot elevations		
	Trees		
	Wind cone / wind sock		
	Water features		

Table 2. Display elements, rated to be of "high need"; items in bold are not currently depicted on prototype surface map displays.

Taxi Out	**Takeoff**	**Final Approach and Landing**	**Taxi In**
1 Runways	1 Runways	1 Runways	1 Taxiways
2 Taxiways	2 Traffic location	**2 Runway displaced thresholds**	2 Hold short lines
3 Hold short lines	3 Traffic in air	3 Traffic location	3 Areas under construction
4 Runway hold short lines	4 Indication of traffic status (in air/on ground)	4 Traffic in air	4 Restricted areas
5 ILS hold lines	5 Traffic altitude	5 Indication of traffic status (in air/on ground)	5 Ramp areas
6 ILS critical areas	**6 Obstructions**	6 Runway centerlines	6 Traffic on the ground
7 Traffic location	7 Runway heading	7 Traffic altitude	7 Taxiway labels
8 Taxiway labels	**8 Runway length**	**8 Obstructions**	8 Indication of traffic status (in air/on ground)
9 Traffic on the ground	9 Runway centerlines	**9 Runway landing length**	9 Traffic location
10 Runway labels	10 Relative altitude	10 Runway heading	10 Taxiway edges or boundaries
11 Ownship	11 Ownship heading	**11 Runway lighting**	**11 ILS hold lines**
12 Runway edges	12 Ownship	12 Traffic on the ground	12 Runway hold short lines
13 Areas under construction	13 Runway edges	13 Runway markings	**13 ILS critical areas**
14 Restricted areas		14 Runway edges	14 Buildings
15 Obstructions		**15 Runway length**	15 Taxiway centerlines
16 Runway heading		16 Relative altitude	16 Aprons
17 Indication of traffic status (in air/on ground)		17 Ownship	17 Selected target indicator
18 Taxiway edges		**18 Runway elevation**	18 Runways
19 Ramp areas		**19 Runway end elevation**	
		20 Runway labels	
		21 Airport terrain features	

Table 3. Display elements, rated to be of "low need"; the display elements are ranked in order of lowest need (with 88 being the lowest rated item). Items in bold are depicted on prototype surface map displays. Of these items, those whose depiction is necessary given the presentation of certain high need items are designated with an **(N)**; those items whose presentation is at the pilots discretion are designated with a **(D)**.

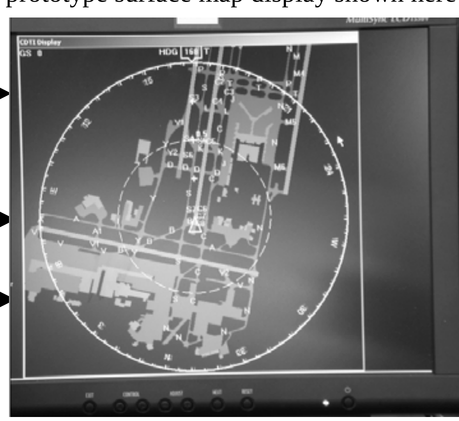
Taxi Out	Takeoff	Final Approach and Landing	Taxi In
88 Railroads	88 Deicing areas	88 Deicing areas	88 Magnetic variation
87 Airport beacons	87 Gate numbers	87 Holding pens	87 Deicing areas
86 Air traffic control boundaries	86 Holding pens	**86 Grassy areas (N)**	86 Railroads
85 Latitude/Longitude	85 Taxiway bearing strength (when less than associated runway)	**85 Non-movement areas (N)**	85 Runway end elevation
84 Spot elevations	**84 Non-movement areas (N)**	84 Taxiway bearing strength (when less than associated runway)	84 Runway landing length
83 Water features	83 Latitude/Longitude	83 Gate numbers	**83 Absolute altitude (D)**
82 Pole line	82 Magnetic variation	82 Latitude/Longitude	82 Runway weight bearing capacity
81 Magnetic variation	81 Fire station	81 Railroads	81 Airport beacons
80 Grassy areas (N)	80 Building identification	80 Magnetic variation	80 Latitude/Longitude
79 Fire station	**79 Grassy areas (N)**	**79 Hangars**	79 Runway slope
78 Trees	**78 Ramp areas**	78 Building identification	78 Runway elevation
77 Runway weight bearing capacity	**77 Taxiway centerlines**	77 Fire station	77 Air traffic control boundaries
76 Taxiway bearing strength (when less than associated runway)	76 Taxiway width	76 Roads	76 Runway length
75 Absolute altitude (D)	75 Railroads	75 Taxiway width	**75 Traffic call sign (traffic in air) (D)**
74 Airport reference point	**74 FBO**	**74 Aprons**	**74 Grassy areas (N)**
	73 Terminal buildings	**73 Ramp areas**	73 Runway width
	72 Hangars	**72 Terminal buildings**	72 Pole line
	71 Runway weight bearing capacity	71 Water features	71 Spot elevations
	70 Taxiway edges or boundaries (N)	70 Airport reference point	70 Holding pens
	69 Aprons	**69 Taxiway centerlines**	69 Water features
	68 Airport beacons	68 ILS hold lines	68 Runway stopways
	67 Ground track vector (D)	67 Runway weight bearing capacity	67 On airport navaids
	66 Helicopter landing pads	66 Spot elevations	**66 Relative altitude (D)**
	65 Airport reference point	65 ILS critical areas	65 Runway shoulder
	64 Water features	**64 Ground track vector (D)**	**64 Traffic altitude (D)**
		63 Taxiway edges or boundaries (N)	63 Airport reference point
		62 FBO	62 Wind cone / wind sock
			61 Runway displaced thresholds
			60 Runway centerlines
			59 Runway surface information
			58 Airport name
			57 Runway lighting
			56 Trees
			55 Traffic in air (D)
			54 Selected target aircraft class (D)

Figure 1. Surface map display system. The prototype surface map display shown here was developed at the William J. Hughes FAA Technical Center.

Database, providing positions of:
- Airport runways and taxiway
- Buildings
- Hold lines, stop bars

Ownship position

Position data for traffic on/near the airport surface (e.g., ADS-B)



Operational Goals

Allow the pilot to determine location of ownship and other traffic and obstacles on or near the airport surface. These are defined here to include the following phases of operations:
- Taxi out
- Takeoff
- Final approach and Landing
- Taxi In