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ORIGINAL ARTICLE

The design of a collision avoidance system for use by Pilots operating on the airport ramp and in taxiway areas

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Abstract Ground collisions have serious implications from both a safety and a commercial perspective. This paper reports on human computer interaction (HCI) research related to the advancement of a collision avoidance system, for use by Pilots operating on the airport ramp and in taxiway areas. Primarily, this paper focuses on the key findings of this research and the emerging HCI design solution.

Keywords Human factors · Human computer interaction · Participatory design · Collaborative prototyping · Scenario-based design · Collision avoidance · Ground collisions · Flight crew · Cockpit · Airport ramp and taxiways · Flight operations · Procedures · Operability

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1 Introduction

Ground collisions have serious implications from both a safety and a commercial perspective. As reported by the Flight Safety Foundation (Weener 2007), the aircraft industry loses up to US $11 billion worldwide each year due to accidents and incidents on the ground. The accident literature details many incidents resulting in human injury and aircraft damage related to aircraft maneuvers on the ramp and in taxiways areas (Lacagnina 2007). In addition, near misses frequently occur, albeit they are rarely formally reported. In this respect, an analysis of air safety reports from NASA's Aviation Safety Reporting System indicates that accidents are likely to occur 43 % at the gate stop area, 39 % at the gate entry and exit area and 18 % outside the ramp entry area (Chamberlain, Drew, Patten and Matchette 1996).

The wing span of commercial aircraft is getting longer (for example, consider the latest Airbus 380). This adds to the complexity of aircraft ground maneuvering—taking into account that the task of judging clearances/distances between objects is completed by the Pilot without any aids. Further, with the introduction of low-cost operations, aircraft turnaround times have been reduced. This puts added pressure on the operation. In particular, it places a strain on ramp operations which is coordinated by many different stakeholders—some of whom may not adequately be trained (McDonald 2000, 2002).

Much human factors research has been conducted in relation to the advancement of airborne collision avoidance systems, for use by Pilots during flight (i.e., Traffic Alert and Collision Avoidance System and Enhanced Ground Proximity Warning System) and when crossing active runways when taxi-ing out for take-off or taxi-ing into the gate after landing (i.e., Runway Incursion Systems). Little

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attention has been accorded to the development of technology systems supporting Pilot situation awareness and collision avoidance when maneuvering on the ramp and in taxiway areas. There has been no effective change in this area of operations since the earliest days of aviation.

The Wing Watch (WW) project is sponsored by Enterprise Ireland—the Irish government organization responsible for the development and growth of Irish enterprises in world markets. The objective of the WW project is to advance a 'proof of concept' demonstration of a collision detection/warning system (hereafter referred to as the WW system) for use by Pilots operating on the airport ramp and in taxiway areas. Following proof of concept, the proposed system will be further developed for other ramp users. This includes Tow Truck Drivers, Air Traffic Controllers and Ground Marshallers.

The WW project started with preliminary research by a Pilot concerning the introduction of new aircraft/cockpit-based technology to facilitate collision identification and avoidance during ground operations (excluding the runway). Follow-up research funded by Enterprise Ireland was undertaken by a team of Software Engineers from the Graphics and Visualisation Group (GV2) at Trinity College Dublin (TCD)—in cooperation with this Pilot—to establish whether new vision-based technology advanced by the GV2 might be used for this purpose. This research resulted in the definition of a high-level technical specification for a new aircraft/cockpit system. At this time, a human computer interaction (HCI) design concept for the proposed system did not exist. This technical specification was reviewed by industry experts and representatives from Enterprise Ireland. It was agreed that the initial 'proof of concept' required further technical and human factors research. A research team was established for this purpose. This comprised the Captain from Aer Lingus, one HCI researcher from the Aerospace Psychology Research Group (APRG) at TCD and two Software Developers from the GV2.

The WW project involves two integrated strands of research. The first strand concerns the identification of the user requirements for the proposed tool and modeling of the associated HCI design concept. The second strand relates to the advancement of the underlying vision-based collision detection and avoidance technology, and the allied technical specification and implementation of the proposed system. Primarily, this involves research in the area of visual mapping and robotics. The project commenced in October 2007 and finished in June 2011.

This paper focuses on the first strand of this research. First, an introduction to the Flight Crew task and existing collision avoidance methods is provided. The research design is then outlined. Field research findings are then summarized. The emerging HCI design solution is then presented. Issues related to the design solution are then discussed. Lastly, some preliminary conclusions are outlined.

2 Introduction to task and existing systems/tools

2.1 Task

Flight Crew maneuvers on the ramp and in taxiway areas include pushback, taxi out, taxi in and stand/gate parking tasks. Overall, these are team-based tasks involving considerable co-ordination with other actors spanning multiple operational processes (i.e., Flight Operations, Air Traffic Control, Ground Operations and Airport/Gate Management). Depending on the task and operational context, Pilots collaborate with a range of other agents. Primarily, this includes ground handling personnel (i.e., Tow Truck Driver, Wing Walker and Marshaller) and Air Traffic Controllers (ATC). In addition, the crew co-ordinate indirectly with personnel working for the Airport Authority and relevant Ground Handling Management functions. Communication tools vary. Usually, a combination of VHF radio communications, head set voice communications and hand signals are used. Collision responsibility also varies. During push-pack, Ground Handling Agents are responsible for collision avoidance. Once the aircraft is operating under its own power (i.e., taxi), the crew are responsible. Depending on the parking system in use (i.e., manual or automatic), either the Marshaller or the Flight Crew are responsible.

2.2 Roles and responsibilities

In the current situation, collision avoidance during push-back or tow is the responsibility of the tow truck driver and not the Pilot. The Pilot is responsible for collision avoidance, once the engines are started and the pin has been removed. In the case of aircraft taxi, the Pilot must hit the brakes, if he/she sees a vehicle approaching. Obviously, in a taxi hold scenario, the Pilot has minimal leverage over moving. Specifically, if an aircraft or vehicle approaches close behind, and the Pilot moves forward, he/she runs the risk of taxi-ing into the aircraft ahead. If parking with the assistance of a Ground Marshaller, the Ground Marshaller is responsible for collision avoidance. If parking using the automatic guidance system, the Pilot is responsible.

2.3 Existing systems/tools

In addition to systems monitoring incoming and outgoing air traffic, both ATC and Airport Authority personnel have systems that monitor ground traffic on the ramp and in taxiway areas (i.e., surface movement radar). However, equivalent systems have not been developed for Flight Crew. Currently, a range of low technology solutions ensure that the aircraft is protected from ground vehicle conflict. Existing fixes tend to be simple—and are often procedural. For example, (1) crew training, (2) the use of cones, ground markings (i.e., parking bay, apron and taxiway markings) and taxiway lighting and (3) the development of procedures (i.e., ATC procedures related to clearances for transiting vehicles, specific Flight Crew procedures and airport authority policies).

3 Research design

3.1 Overall HCI objective and methodological approach

The specific objective of HCI research is (1) to identify the user requirements for a cockpit-based version of the proposed system and (2) to model a preliminary version of the associated HCI design concept and allied operational procedures.

The overall methodological approach can be characterized by the design mantra 'design for operability'. Specifically, a scenario-based, participatory design approach was adopted. As such, the researcher endeavored to understand (1) collision scenarios and (2) contributory factors in context of the broader operational system. Further, the specification of the future solution included both (1) the HCI requirements for the alerting system and (2) the broader operational concept and associated procedures. In relation to the latter, this includes the specification of (1) roles and responsibilities, (2) information flow (both cockpit based and information flow between any other stakeholders involved in the task activity) and (3) specific operational procedures for all relevant roles (i.e., cockpit and noncockpit).

To date, the research design has involved the application of a range of formal HCI design methodologies (e.g., user interviews, task analysis), informal HCI methodologies (e.g., stakeholder workshops, task observations, collaborative prototyping and evaluation with end users and problem-solving sessions with the project team) and process analysis methods used in the Organizational Ergonomics Field. As detailed in Table 1, this has involved several phases of HCI research, comprising several parts.

Phase 1 research was conducted between November 2007 and July 2008. Phase 2 research was conducted between July 2009 and March 2010. Phase 3 research commenced in May 2010 and finished in June 2011. In the first phase, the research objective was to understand the end-user task and associated collision avoidance procedures, to identify the contributory factors to collision incidents and accidents, to specify the high-level requirements for the new collision avoidance system and to advance a provisional HCI model for a cockpit-based version of the collision avoidance system. The objective of phase two research was to further refine and evaluate the proposed HCI concept for the collision avoidance system. The last phase of research concerned the final evaluation and specification of the emerging HCI design concept, taking into account feedback from the technical team, in

Table 1 Summary of HCI research phases and methods

No.	Part	Description	Methods
1	1	Task analysis	Stakeholder workshops, Pilot jump-seat observations and interviews
	2	Preliminary scenario specification and tool envisionment	Scenario specification and collaborative prototyping and evaluation sessions with one Pilot
	3	Development of HCI 1	Collaborative prototyping and evaluation sessions with one Pilot
2	1	Development of HCI 2	As above
	2	Validation of HCI concept	Workshop with a panel of eight Pilots
	3	Specification of complex routine scenarios and HCI	Scenario specification and collaborative prototyping and evaluation sessions with one Pilot
	4	Specification of nonroutine taxi scenarios and HCI	Scenario specification and collaborative problem solving between HCI and software teams
	5	Validation	Semi-structured interviews with stakeholders including Pilots
	6	Review	Collaborative problem solving with Pilot and Software team
3	1	Alpha test	Demonstration of technology underpinning HCI
	2	Desktop evaluation	Collaborative problem solving with eight Pilots
	3	Beta test	Demonstration of technology underpinning HCI and integration of HCI specification
	4	Review	Collaborative problem solving with Software team
	5	Evaluation/validation	Collaborative problem solving with panel of five military Pilots

relation to technology functionality and limitations. This comprises several phases of HCI design and evaluation activities, linking to the parallel Alpha and Beta technology evaluations undertaken by the technical team and a series of evaluations with both commercial and military Pilots.

For more detailed information on the specific methodological approach adopted in this research, please see Cahill et al. (2008, 2010, 2011).

3.2 Phase 1 research

In the first phase, the research objective was to understand the end-user task and associated collision avoidance procedures, to identify the contributory factors to collision incidents and accidents, to specify the high-level requirements for the new collision avoidance system and to advance a provisional HCI model for a cockpit-based version of the collision avoidance system. This research was structured in three parts.

3.2.1 Part 1: literature review and task analysis

First, a literature review was conducted. The literature review included an analysis of the accident/incident literature, ramp safety research (McDonald 2000, 2002) and relevant current research concerning ground collision avoidance systems (Moller et al. 2007). In addition, Pilot bulletin boards/websites, airport information (i.e., airport maps and taxi maps) and airline documentation (i.e., pushback, taxi and parking procedures) were reviewed.

Following this, a group workshop was conducted with relevant stakeholders to evaluate the feasibility of the preliminary system concept and scope further research.

More detailed field research was then undertaken. This includes (1) follow-up interviews with workshop participants, (2) further interviews with different stakeholders (i.e., Pilot, Tow Truck Driver and Walker, Ground Marshaller, Maintenance, ATC, Airport Authority, Aer Lingus Safety Department and Accident Authorities), (3) eight Flight Crew jump-seat observations and (4) observations of both ATC and Airport Authority work processes and operator activity.

The overall findings of this research were then analyzed. First, a high-level process model linking key operator tasks and relevant underlying processes (i.e., Ground Operations, Flight Operations, Maintenance and ATC) was developed. Following this, a user/task matrix and associated task descriptions were outlined. This included an analysis of contributory factors to collision incidents and accidents. The high-level human factors/user requirements for the proposed system were then specified.

Further, proposed collision avoidance scenarios were defined. In relation to Flight Crew scenarios, the researcher advanced high-level collision scenarios for all flight phases (i.e., pushback, taxi out, taxi in and parking). Scenario information included Pilot task/flight phase, collision responsibility, operational procedure and Pilot action. Potential collision scenarios for other roles (i.e., Tow Truck Driver and Maintenance Engineer) were also documented. Please see Table 2 below for a list of these high-level collision scenarios.

3.2.2 Part 2: tool envisionment and preliminary collaborative evaluation and prototyping

The particular envisionment and collaborative prototyping approach adopted integrated Carroll's scenario-based design approach (1995, 1997, 2000, 2001) with participatory design methods utilized by Muller (2003). The participatory modeling and evaluation activities focused on collision scenarios for the Pilot role only. A series of collaborative prototyping and evaluation sessions were conducted with one Pilot and one of the Software Developers. As part of this, scenarios were defined for three flight phases, namely pushback, taxi and parking. Table 3 below provides a list of these scenarios.

In support of this, a scenario timeline map was advanced for each of the potential collision scenarios, to support scenario development and problem solving in relation to the design of the user interface. This included a timeline depiction of the aircraft and the potential threat, in relation to proposed threat detection zones. Figure 1 provides an example of one such map in relation to the post pushback, taxi and turn scenario.

Table 2 High-level collision scenarios

No.	Role	Scenarios
1	Pilot	Pushback from gate, taxi from remote stand, taxi onto the de-icing stand, taxi to runway, taxi to holding point, taxi to runway lineup, taxi from runway to parking gate, parking using an automatic guidance system, parking using a self system and marshal assisted parking
2	Tow truck driver	Pushback of aircraft and drive to/from the parking gate
3	Maintenance engineer	Taxi to hangar bay and maintenance tow (to hangar and parking, or tow out of the hangar)
4	Marshaller	Pilot parking

Table 3 Flight crew collision scenarios

No.	Flight phase	Title
1	Pushback	Pushback underway, aircraft 2 behind aircraft 1 which is being pushed back
2	Ready to taxi	Ready to taxi (following pushback): human object detected near nose wheel
3	Taxi out	Flight crew taxi and turn (post pushback), aircraft 2 parked—potential collision
		Taxi and turn (following pushback), aircraft 2 parked—potential collision, WW fail—cannot provide collision guidance
		Taxi and turn (following pushback), multiple objects to consider
		Taxi past other aircraft parked
		Over-take stationery aircraft at runway holding point
4	Taxi in	Flight crew taxi in from runway to apron
5	Parking	Taxi in/parking—marshall assisted
		Taxi in/parking—self guidance system

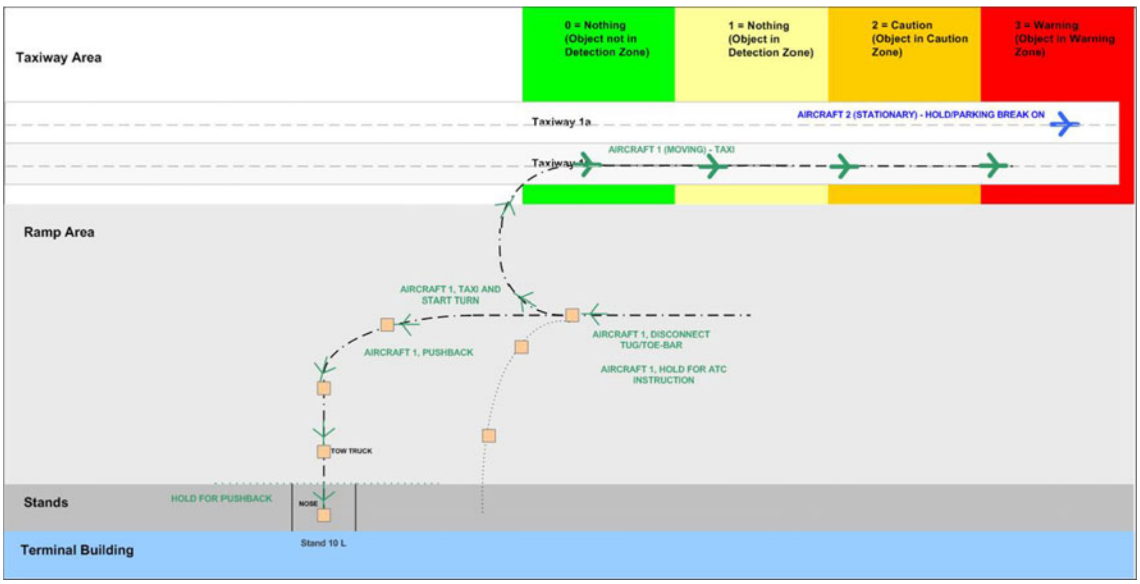

Fig. 1 Scenario timeline map

A provisional HCI concept was then developed for each of these scenarios. As part of this, several HCI dimensions were further specified. This includes flight phase, aircraft state, collision object state, alert level, aural message, visual message, procedure, Pilot strategy/action and technical rules.

3.2.3 Part 3: detailed collaborative evaluation and prototyping of simple taxi scenario

The next phase of collaborative prototyping and evaluation activities addressed one core scenario in more detail. It was decided to focus on a routine taxi scenario. That is, taxi following pushback (involving no turn). To simplify things, the potential collision threat was assumed to be stationary. However in practice, it is likely that the threat might be moving, or there might be multiple objects. In terms of the specific collision aspect, it was assumed that the aircraft is on a collision course with a wingtip of another aircraft. A series of participatory sessions were conducted with the same group. The aforementioned HCI dimensions were further specified and refined. Findings were recorded in a word document. This included a textual description of the scenario and an outline of the HCI requirements for the proposed visual and acoustic alerts. Further, the proposed visual alert was documented using Microsoft Visio. Moreover, all open issues and outstanding technical issues were recorded.

3.3 Phase 2 research

The objective of phase 2 research was to further refine and evaluate the proposed HCI concept for the collision avoidance system. This research was structured in terms of six parts.

3.3.1 Part 1: collaborative evaluation and prototyping of simple taxi scenario

The first part of this research involved the further specification and validation of the emerging HCI requirements for the core taxi scenario. A series of participatory sessions were conducted with the same group. The nature of both the visual and auditory alert was specified in more detail.

3.3.2 Part 2: validation of HCI concept

The emerging solution was then validated with a team of Pilots. A group workshop was conducted with a panel of eight Pilots, from the Irish Airline Air Pilots Association (IALPA) Safety and Security Committee. First, the Software Developer provided an introduction to the underlying technology. The HCI Researcher then reviewed the scope of HCI research to date and the preliminary HCI concept/philosophy. Following this, the HCI Researcher presented the example collision scenario and associated HCI prototype. Critically, participants were invited to state what questions the proposed HCI might answer in relation to threat detection and collision avoidance. Participants were then invited to provide feedback about the HCI concept and any improvement recommendations. Following the workshop, the prototype was updated.

3.3.3 Part 3: further routine scenario/HCI development

As noted above, the preliminary HCI was advanced in relation to a simple routine collision avoidance scenario. Part three research involved the validation and further specification of the design solution in relation to (1) a more complex routine scenario and (2) nonroutine scenarios—both simple and complex. As a first step, the HCI researcher detailed certain more complex routine scenarios. The existing taxi scenario was broadened to include one or more dynamic threats. The HCI researcher then met with the Software team to review the existing HCI concept in relation to (1) single dynamic threat objects and (2) multiple threat objects, at similar or different threat levels (i.e., level 1 and level 2)—both stationary or moving. For problem-solving purposes, all potential threat objects were considered. This includes (1) other aircraft (stationary or moving), (2) vehicles (stationary or moving), (3) stationary random obstacles (i.e., light pole and air-bridge), fixed obstacles such as buildings (stationary) and people (stationary or moving). As part of this, the team reviewed the ongoing technical development and expected functionality in relation to collision detection and alerting. The team then reviewed various design options in relation to the presentation of the visual alert message. During the course of this session, it was agreed to move from a presentation format that focused on presenting the threat object in relation to location in a detection zone, to a presentation that prioritized the threat level of the potential collision object or objects. The HCI researcher then updated the visual alerting message. Following this, a series of review sessions were conducted both with the Pilot and with the Software team, to further refine the revised HCI concept.

3.3.4 Part 4: further nonroutine scenario/HCI development

The HCI researcher then specified a series of nonroutine scenarios, for the purpose of validating the HCI concept in relation to all possible collision scenarios. As part of this, a series of nonroutine taxi scenarios both simple and complex were defined. Particular scenarios were distinguished in terms of Pilot responsibility, as defined in Table 4.

The Researcher then reviewed the HCI concept in relation to these scenarios. This resulted in the specification of different visual and acoustic messages/alerts in different contexts—albeit in line with the overall HCI concept. Further, this led to a specification of different options for the visual alert (i.e., 2D display).

The researcher then reviewed these scenarios and the associated HCI specification with the software team. The different options for the visual alert were reviewed, in relation to a generic collision avoidance requirement, and the specific requirement of the individual nonroutine scenarios. Various design solutions were problem solved, taking into account technology constraints. The HCI researcher then modeled these design solutions in Visio and reviewed the proposed concepts with both the software team and the Pilot. Following feedback from both parties,

Table 4 Nonroutine flight crew collision scenarios

No.	Pilot responsibility	Scenario
1	Yes	Taxi out and WW fail
2		Taxi out—as deal with one threat object, another threat emerges
3		Multiple threats: forward and behind
4	No	Executing pushback—threat emerges
5		Parked at holding point—threat emerges
6		Parked at runway line-up—threat emerges

the design specification was updated, along with the relevant Visio files. The output of this was then circulated to the full team for review.

3.3.5 Part 5: validation

A series of validation sessions were then conducted. As part of the specification of the high-level requirements for the system (i.e., phase one research), the researcher conducted a workshop with different stakeholders and post workshop interviews. It was decided to go back to these people and elicit their feedback in relation to the emerging HCI solution. Two semi-structured interviews were conducted with members of the Irish Aviation Authority (IAA) and the Air Accident and Investigation Unit (AAIU). The researcher first reviewed the overall project objectives, the nature of the technology, the scope of the HCI research and the high-level HCI concept. Following this, the researcher presented the HCI prototypes for the taxi scenarios and invited feedback. The researcher then reviewed the different options for the 2D concept in detail. Participants were then invited to rank the different HCI options and to suggest improvement recommendations. Following the sessions, the Researcher updated the HCI specification and associated documentation. This was then circulated to both the Pilot and the Software Developer for review.

3.3.6 Part 6: review

In the final stage, the researcher met with the Software team and the Pilot in individual sessions, to review the validation feedback and allied updates to the HCI specification. Further, the Researcher reviewed the plan for the forthcoming Alpha and Beta tests with the Software team—see below.

3.4 Phase 3 research

Overall, this stage of research concerned the final evaluation and specification of the emerging HCI design concept, taking into account feedback from the technical team, in relation to technology functionality and limitations. This comprised several phases of HCI design and evaluation activities, linking to the parallel Alpha and Beta technology evaluations undertaken by the technical team. Further, it involved a series of evaluations with commercial and military Pilots.

3.4.1 Part 1

The purpose of the Alpha test was to assess the integration of the different technical elements that comprise the collision avoidance technology. As part of this, the HCI researcher attended a demonstration of the technology arranged by the technical team and assessed the implications of the technology capability from a HCI perspective.

The relevant hardware (i.e., camera technology and laser) was fitted to the roof-rack of a vehicle, as illustrated in Fig. 2. The vehicle was parked at a location on the university campus. The team sat inside the vehicle, which was fitted with a computer. As depicted in Fig. 2, the user interface demonstrated the functionality of the emerging system (i.e., the capability of the technology to detect both threat and nontreat objects). Importantly, this interface did not reflect how the proposed 2D visual alert might look (Fig. 3).

Following the demonstration, the team discussed the scope of the technology and agreed which of the proposed 2D HCI options might be most feasible to execute, given existing technology constraints.

3.4.2 Part 2

Part 2 research comprised a desktop evaluation of the proposed collision avoidance system with eight Pilots from IALPA. Overall, this evaluation involved a scenario-based design and evaluation approach, evaluating the overall HCI concept, along with the specific design options for the visual alert (i.e., 2D display). After the evaluation, five participants completed an evaluation questionnaire that consisted of thirty-four questions (using a 5-point

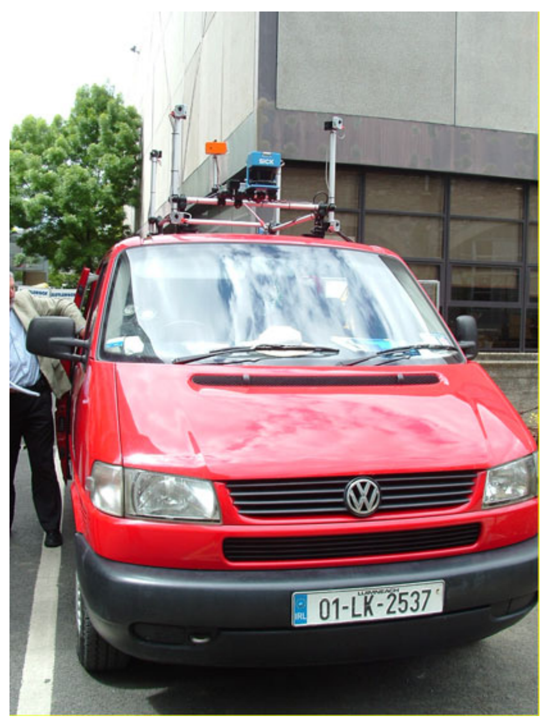

Fig. 2 Roof rack demonstration at Trinity College Dublin Campus

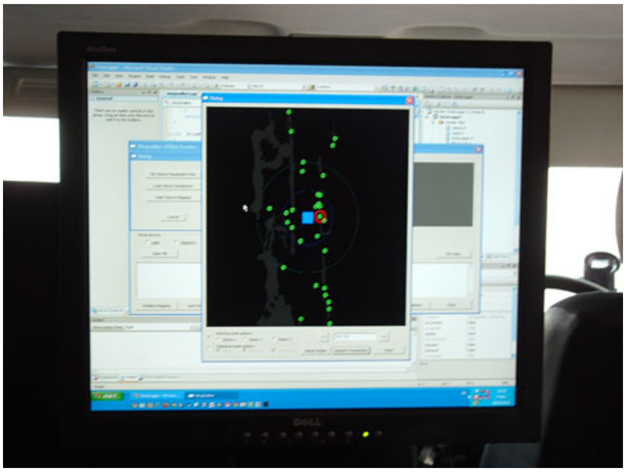

Fig. 3 User interface depicting technology capability

Fig. 4 Beta test: WW test vehicle in action at Dublin airport

Likert-type scale) and four open questions. The primary purpose of the questionnaire was (1) to ascertain a measure of whether end-user requirements are addressed effectively, (2) to assess the usability of specific alert messages and (3) to identify any design changes required. The five participants who completed the questionnaire had a total of 57 years of experience in the field of aviation and an average of 11.4 years experience. Following an analysis of questionnaire feedback, design recommendations were structured in terms of (1) existing design features to retain, (2) design features to change and (3) open issues.

3.4.3 Part 3

A Beta test was then conducted by the technical team at Dublin Airport. This test was facilitated by the Dublin Airport Authority (DAA). The set-up was similar to the Alpha test (i.e., the hardware was fitted to the roof-rack of a vehicle, and a computer was installed in the vehicle); see Fig. 4. However, in this case, the HCI specification had been integrated with the technical system. As such, the computer presented the actual 2D visual alert that the Pilot would see. Thus, the Beta test allowed the HCI researcher to assess how the HCI design specification had been implemented by the technical team.

In similar terms to Alpha test, the HCI researcher sat inside the vehicle (with the other team members). The vehicle was driven around a designated ramp area, adjacent to hangar buildings and a small number of parked aircraft. As the vehicle was driven closer to the target object (in this case a parked aircraft), the computer simulated the visual and acoustic alerts that would be relayed to the Pilot.

3.4.4 Part 4

The HCI researcher then met with the technical team to review feedback from both the IALPA evaluation and the Beta test. Prior to the meeting, the HCI researcher compiled a set of rules for both the visual and acoustic alert. These rules included certain design changes to be agreed with the team. In relation to the acoustic alert, the Researcher documented several problems with the execution of this alert in instances where there are multiple caution-level threats. The advantages and disadvantages of several alternative options were noted. During the meeting, the team reviewed these rules and associated design options/changes. It was agreed to undertake additional research with a panel of Pilots, to validate the proposed changes to the 2D visual alert and to evaluate the relative usability of the new options proposed for the acoustic alert, for instances where multiple caution-level threats exist.

3.4.5 Part 5

The final phase of research involved a usability evaluation with a panel of five military Pilots. The purpose of this evaluation was to (1) validate the final changes to the visual alert, (2) to validate the acoustic alert—taken generally and (3) to identify a user-friendly solution for the acoustic alert in cases where there are multiple caution-level threats.

First, the HCI researcher demonstrated a video of the technology in action. Specifically, the video featured doctored video footage of a potential collision scenario, using video data taken of the test vehicle in action at Dublin Airport, as part of the Beta test. The HCI Researcher then gave a short presentation on the HCI research to date, the HCI concept/philosophy and the evaluation objectives. Following this, the HCI Researcher outlined an example collision scenario and the proposed WW solution (i.e., HCI prototype). Participants were then invited to provide initial feedback about the HCI concept and the usability of the visual and acoustic alerts.

This was followed by a more detailed usability evaluation of both the visual and acoustic alerts. As part of this, the panel both reviewed and rated four different variations of the 2D visual alert. The different versions varied according to the level of information provided on the 2D display, in relation to both threats and nonthreats. After this, there was a team discussion. At this point, the participants disclosed their preferences as to which visual alert option was most suitable, and the reasons for this. The usability of the acoustic alert was then examined. First, the panel reviewed the acoustic alert—for both caution- and warning-level threats. This was followed by a more detailed examination of the acoustic alert for situations where there are multiple caution-level threats. In so doing, the Researcher provided each participant with a printed summary of the different options available (i.e., the different options for the acoustic message were printed on a piece of paper). As a group, the panel discussed the strengths and weaknesses of the different options and indicated their preferences. The session closed with an overall review of the panel's recommendations for improvement.

4 Summary of research findings

4.1 Contributory factors

Research validates certain general ramp safety issues identified in the SCARF project (McDonald 2000, 2002), which contribute to collision both on the ramp and in taxiway areas. This includes problems related to fatigue, communication and co-ordination issues, Pilot distraction and workload, equipment issues and training issues. Further, research has identified specific contributory factors related to visual judgment and response times, environmental limitations (i.e., poor weather conditions and night-time) and the design limitations of existing tools. In addition, a number of commercial and operational factors have been highlighted. The movement toward a low-cost business model has led to requirements for quick turnarounds. This puts pressure on the operation. All operators (i.e., Ground Crew, ATC and Flight Crew) are working at faster rate, and there is a higher risk of error. Typically ground handling personnel (outsourced from different service companies) move between multiple aircraft on the ramp—using different equipment. Further, increased airport traffic puts pressure on the overall operation. Often, there are multiple aircraft involved in pushback and taxi maneuvers.

In relation to actual accident data, it was noted that most accidents occur when the aircraft is stationary. In the words of one participant, 'it is not a problem of the aircraft/Pilot; rather the problem is with vehicles that are either servicing the aircraft or transiting by the aircraft'. An air-bridge may be inappropriately parked or may strike the aircraft when it is being moved. Toe bar shearing is a known occurrence—and is not seen as having major safety implications. Many vehicles and objects have to make contact (e.g., steps). Often, there is inappropriate contact—but the damage is minor. Overall, feedback suggested that an aircraft taxiing into another aircraft is a rare event. Often, there are conflicts without contact (i.e., the aircraft stops suddenly because a vehicle has taxied into the wrong location). For more information on contributory factors, please see Appendix 2.

4.2 Flight crew collision scenarios

As indicated earlier, research focused on elucidating the nature of Pilot/aircraft collision scenarios on the ramp and taxiway areas and allied contributory factors, which must be taken into account in terms of the design of the proposed system. In terms of all scenario development, the starting point is when (i.e., operational timeline/flight phase) and where (i.e., ramp, taxiway area, etc.) the collision takes place. Following from this, the collision scenario can be elucidated. In so doing, we must detail: (1) the role of Pilot (i.e., responsibility for collision avoidance) and (2) the ability of the Pilot to maneuver. This led to the classification of three overall types of collision situations. This includes situations where:

- The Pilot is responsible and is in a position to maneuver (i.e., taxi out, taxi in, parking using automatic guidance system)
- The Pilot is responsible (along with others) and is not in a position to maneuver (i.e., taxi hold or runway hold)
- The Pilot is not responsible (i.e., pre-pushback/parked in turnaround, tow/pushback operations and parking with assistance of Ground Marshaller)

For the purposes of advancing a proof of concept demonstration of a new collision detection and avoidance system, it was decided to focus on those scenarios where the Pilot is responsible (i.e., WW system relevant). Assuming the situation is one in which the Pilot is responsible for collision avoidance, we can then examine the nature of proposed threat (or threat situation) in more detail. In so doing, the following aspects of the threat situation can be defined: (1) the number of threats, (2) the threat level of each of the threats (i.e., caution level or warning level), (3) the location of the threat, (4) the nature of the threat (i.e., aircraft, vehicle, a random obstacle such as an air-bridge, a fixed obstacle such as building, and people) and (5) whether threat is stationary or moving. As highlighted by the different Pilots involved in the scenario specification activities, the nature of the threat is of interest. Specifically, if the threat is an aircraft, the situation is rated as serious. Moreover, the status of the threat (i.e., if stationary or moving) also has a bearing on the Pilots assessment of the severity of the situation. If the threat is a moving aircraft or vehicle, then fast response is essential. Added to this, if both objects are moving (i.e., own aircraft and the threat object), the situation is perceived as even more serious.

As demonstrated in this research, an examination of the threat situation facilitates the identification of routine situations (i.e., happen frequently) and nonroutine situations (i.e., rarely happen but must be considered). In each case, both simple and complex scenarios were defined. An example of a simple routine situation might be a potential collision with a moving aircraft, which is located ahead of the aircraft. However, potential collisions with two moving aircraft in different forward locations are also possible. In terms of nonroutine scenarios, this includes potential collisions with multiple threats objects (positioned both forward and behind the aircraft)—at different threat levels. A more complex nonroutine scenario might be as the Pilot deals with this situation, another threat (routine or nonroutine) emerges. For more information on these scenarios, please see Appendix 1: Research Phases and Threat Scenarios.

Lastly, scenario development must address the mechanics of the collision scenario. As evidenced in this research, Pilots conceptualized this in terms of a series of their specific activities at different points in time. This includes (1) before stop, (2) braking (slow) and/or braking (fast), (3) stopped before making maneuver and (4) in maneuver.

4.3 Collision situation and pilot questions

During the scenario definition and user interface evaluation activities with both Pilots and stakeholders, it emerged that to properly support Pilot situation awareness and collision detection and avoidance, the proposed HCI should prioritize communications in relation to a subset of questions that may be posed by Pilots at this time. As depicted in Table 5, these questions are grouped into two high-level categories corresponding to two overall collision detection situations. This includes (1) routine monitoring and (2) situations where a threat (or group of threats) exists. The specific questions are defined in relation to the (1) collision scenario timeline (i.e., before taking a response/stopping after stopping and during the follow-up maneuvers) and the (2) aircraft state (i.e., whether the aircraft is stationary or moving). The aircraft may be moving, but it may be before the Pilot has taken an action (i.e., before slowing down or immediate stopping). Also, the aircraft may be moving, but it may be subsequent to stopping. Critically, it emerged that the proposed HCI should primarily focus on answering questions concerning threat detection (1) during routine monitoring and (2) if a threat(s) exist, before taking action (i.e., slowing down and/or immediate stopping). As such, it was agreed that the HCI should be optimized to effectively

Table 5 Collision situation and Pilot questions

Generic situation	Aircraft state	Collision scenario timeline	Questions	Priority
Routine monitoring	Moving or stationary	N/A	Is there a threat?	High
If a threat exists	Moving or stationary	Before taking action (i.e., slowing down and/or immediate stopping)	What is the status of the threat—i.e. level one (amber) or level two (red)?	High
			What action should I take (i.e., slow down to a safe stop, or stop immediately?)	
	Stationary	After taking action and before maneuver	What outside corresponds to the threat alert information I am receiving?	Medium
			Location of threat?	
			Distance from aircraft?	
			Is the threat moving or stationary?	
			What is the threat (e.g. fixed obstacle, other aircraft, vehicle etc.)?	
			What should I do/what action should I take e.g. call Marshaller, maneuver myself	
			How best maneuver?	
	Moving	During maneuver	How best maneuver?	Low
			What is the status of the threat while I am Maneuvering?	
			Is there another threat?	
	Stationary	After maneuver	What is the status of the threat	Low
			Is there another threat?	

answer the questions 'Is there a threat', 'What is the status of the threat i.e. level one (amber) or level two (red)', and 'What action should I take (i.e. slow down to a safe stop, or stop immediately)?' It should be noted that priority was assigned by the HCI Researcher, in co-operation with the Pilots and stakeholders participating in the research.

4.4 Human factors objectives

Two high-level human factors objectives for a Version One of the WW system have been defined. The primary objective for the WW system is to support Pilot situation awareness in potential collision situations, such that the Pilot takes the correct action according to the context (i.e., depending on the collision risk, generate a response to slow down to a safe stop and assess after, and/or stop now and assess after). A secondary objective for the WW system is to support the assessment of the nature of the threat (i.e., when look at window, is it clear what object(s) the WW system is referring to). It should be noted that this assessment occurs after the aircraft has stopped. It was decided that a future Version 2 solution might support route planning, and as such be integrated with new electronic taxi systems. This was considered as a potentially useful enhancement by both Pilots and stakeholders.

4.5 Key human factors/users requirements

As detailed earlier, HF requirements were specified following an analysis of the relevant literature and initial field research with Pilots and stakeholders. These are summarized in Table 6.

5 Introduction to the WW HCI solution

5.1 Introduction to technology

The scope of the WW system pertains to collision scenarios where the Pilot is responsible for ensuring collision avoidance. The system is active for ground movement on the ramp and taxiways and disabled when the aircraft is on the runway and during flight. It is assumed that the WW system is not installed on the other aircraft/vehicle.

The WW system features intelligence as to state of aircraft (and location) and expected objects in the vicinity. Further, the WW system deploys commercial off the shelf digital cameras, mounted at specific locations on the aircraft, to generate a real-time picture of the aircraft and its surroundings. State of the art computer vision techniques such as stereoscopy and simultaneous localization and mapping (SLAM) is used to translate the 3D camera images into a 2D plan view of the aircraft and its surroundings. The assessment of the collision risk level is determined using a proximity-based analysis of the plan view. Accordingly, an alert (either caution or warning level) is generated to the Pilot, depending on the collision risk.

5.2 Overall WW philosophy

In its current form, the system is conceived as an aid to the Pilot. The overall philosophy is to allow for Pilot judgment. The idea is to inform the Pilot of the collision risk/threat and to let them take the decision in relation to what is an appropriate stopping rate. Ideally, the Pilot responds to the caution alert and the warning alert is not required. In this scenario, the Pilot has sufficient time to brake and sudden/heavy braking is avoided. Although there may be many threats in the environment (i.e., at different distances from the aircraft), the WW collision alert corresponds to the most immediate threat (i.e., nearest object). It is anticipated that in most cases, this will be one object (i.e., immediate threat in caution zone, while other potential threats are in the detection zone, but not in the caution zone). The classification of threats is based on a risk assessment of the probability of a collision—taking into account the distance between the threat object and the aircraft, the speed the aircraft is moving at, the speed the threat is moving at (if dynamic) and aircraft braking rates (i.e., time/distance). The WW system exploits the proven and accepted TCAS & EGPWS two-stage alert principles; namely first crew awareness, then crew action.

Table 6 Wing watch system: human factors requirements

1	High reliability of system
2	The system should enhance situation awareness, while allowing for Pilot control/judgment
3	The system should be dark and quiet unless an alert is required
4	Clear operational procedures as to use of system (i.e., what do if alert generated—roles and responsibilities of all stakeholders defined)
6	Avoidance of false and/or nuisance alerts
7	The HCI design of alerts should maximize 'eyes out' behavior and as such, not entice/encourage head down behavior
8	The HCI design of alerts should avoid routine distraction/information overload
9	The HCI design of the visual alert should be consistent with other warning systems
10	The auditory alert should not cause distraction/startle

5.3 Procedures

In all situations other than pre-pushback, an alert is provided. If an alert is displayed, the Pilot is required to take action. The specific Pilot action/procedure varies according to (1) Pilot responsibility (yes/no), (2) If yes, whether Pilot in a position to make a maneuver and (3) if yes, level of threat (i.e., caution or warning). As detailed earlier, the design/prototyping activities focused on scenarios where the Pilot is responsible (i.e., taxi in, taxi out and parking using automatic guidance system). For these scenarios, the crew are expected (but not mandated) to slow down or brake when the crew awareness Caution Alert is generated. However, the crew must stop immediately, if the warning message is generated. Thus, for these scenarios, there are no changes to procedures from a Pilot perspective. The pilot is still responsible for collision detection and avoidance—not the WW technology. It should be noted that the WW system is focused on collision detection. As such, it addresses the first phase of the overall collision scenario, as depicted in Table 5. That is, it does not provide the Pilot with instruction as to a course of action (i.e., new routing to take to avoid the threat object), having stopped the aircraft. In such circumstances, existing procedures still apply. For example, if it is a taxi or parking situation, the Pilot typically contacts ATC to get further information/instruction. Also, a Ground Marshaller assists the Pilot.

5.4 WW HCI concept

5.4.1 Introduction

To avoid Pilot distraction, the system is silent and dark unless an alert/warning is required. The WW system has four modes: (1) WW warming up (i.e., initial calibration of system when turned on), (2) WW normal (i.e., no threats—dark and silent), (3) WW threat (i.e., if one or more potential threats exist) and (4) WW fail. The Pilot may be looking ahead (i.e., not heads down), and so we cannot assume that the interface is visible to the Pilot. Accordingly, alerting involves (1) acoustic cues and (2) visual information.

There are two levels of alert: caution and warning (no advisories). The underlying idea is that the audio (i.e., speech) captures the Pilots attention and the visual information (i.e., WW information on ND display) confirms the alert meaning and provides additional reference information.

The generation of a WW alert means that there is one or more potential threat objects. The specific nature of the alert (i.e., design of visual alert and message relayed in the acoustic alert) varies according to scenario context.

Nuisance or false alerts should be avoided. For example, warnings should not be generated if aircraft are 'moving up' in congested holding bays. Equally, the sensor should not perceive landing aircraft as a threat. Rather, it should expect them to be in the vicinity, if the aircraft is located at a runway holding point.

5.4.2 Design of visual alert

The visual alert is implemented on the navigation display for both Pilots. The normal navigation mode of the ND (and/or PFD) display changes to the WW threat mode, if a threat (or group of threats) is detected. The system reverts to WW normal mode (i.e., regular ND, navigation display) when the aircraft recommences moving and (1) the aircraft is no longer on a collision course with the detected threat or group of threats and (2) no other/new threats exist. The WW threat display would re-activate if after the aircraft commences moving, a collision threat exists.

Currently, two different layout options are provided for the different ND sizes. In both cases, the alert provides a 2D, bird's eye/exocentric representation of the threat (or group of threats) in relation to aircraft (i.e., aircraft centered track up). As such, the aircraft appears in the same location (i.e., notional perspective of stationary aircraft), even though in the real world, it may be stationary or moving. All objects (both potential threats and nonthreats) appear to move around the aircraft (although some objects may be stationary).

The WW alert features a black background. The black box represents the area surrounding the aircraft/detection zone. An outline of a circle is used to depict the distance between the aircraft and the potential threat or series of threats. A scale depiction is provided alongside the outline of the circle. Currently, the default for the scale is 15 m. However, it is possible that this scale may be customized by the user. Alternatively, the scale might update according to the location or state of the aircraft (i.e., lower scale if parked on ramp and/or higher scale if in taxi on taxiways, etc.). Evidently, this scale is in line with the maximum range of the vision system.

The visual alert provides information about all objects in the detection zone. This includes both threat objects [depicted in gray with a threat icons—either amber or red], and those object currently not presenting a threat [depicted in gray]). Thus, objects inside the circle represent (1) established potential threats (i.e., caution or warning level) and (2) current nonthreats (which may or may not have the potential to become threats). Items not a threat (e.g., in gray) might be too far away at the moment to represent a threat, or they might be moving slowly and not a threat, or they might be moving in the opposite direction to the aircraft.

The threat icon demonstrates that point of the threat object that presents the most immediate threat. Two threat icons are provided. This includes a caution-level icon that is amber in color, and a warning level icon that is red in color. Threat icons are positioned so as to provide an abstract indication of (1) the location of the threat object, (2) the distance between the threat object and the aircraft and (3) the direction the threat object is moving in (if moving). All warning-level threat icons feature a repetitive blink, which is color-coded red. An outline of a circle is used to depict the distance between the aircraft and the potential threat or series of threats. A scale depiction is provided alongside the outline of the circle (currently, the default for the scale is 15 m).

The WW visual alert is continuously updated in time. Thus, the appearance of the WW alert may change in time. Firstly, nonthreats may become threats. Secondly, new threats may appear (i.e., simultaneous to existence of other threats). In relation to the former, an amber or red threat icon is presented at the relevant point or series of points that presents the threat, while the other areas that do not present a threat appear in the same gray format. In relation to the latter, relevant threat icons (i.e., amber or red) are displayed to indicate the location of the threat, distance from aircraft and direction moving in.

Figure 5 presents a prototype of the proposed Visual Alert, for situations where there is one caution-level threat.

Figure 6 presents a prototype of the proposed Visual Alert, for situations where there is one warning-level threat. In this instance, the blink is featured.

Figure 7 presents a prototype of the proposed 2D Alert for situations where there are two threats—one caution level and one warning level.

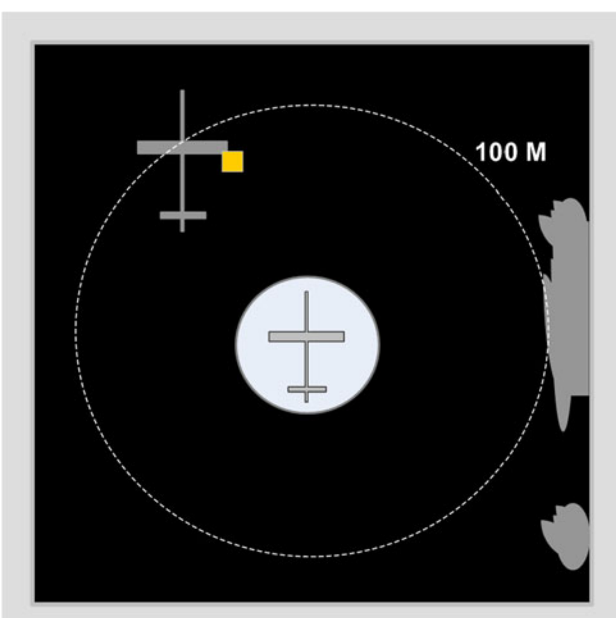

Fig. 5 Caution alert—one threat

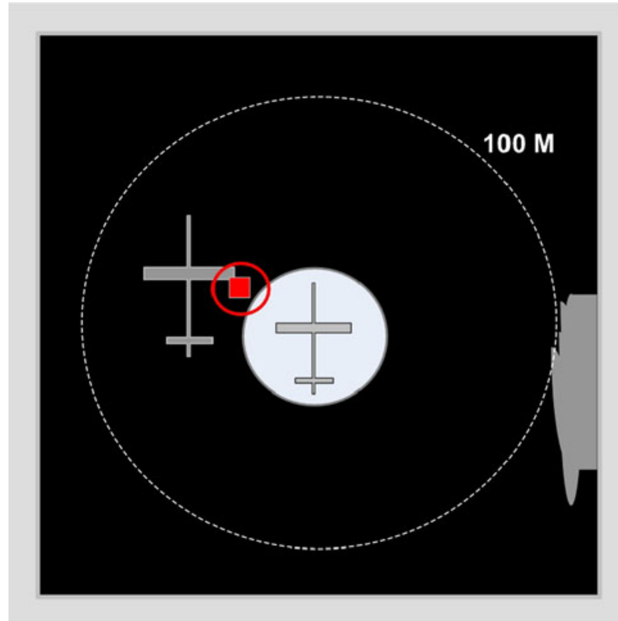

Fig. 6 2D alert (with blink)

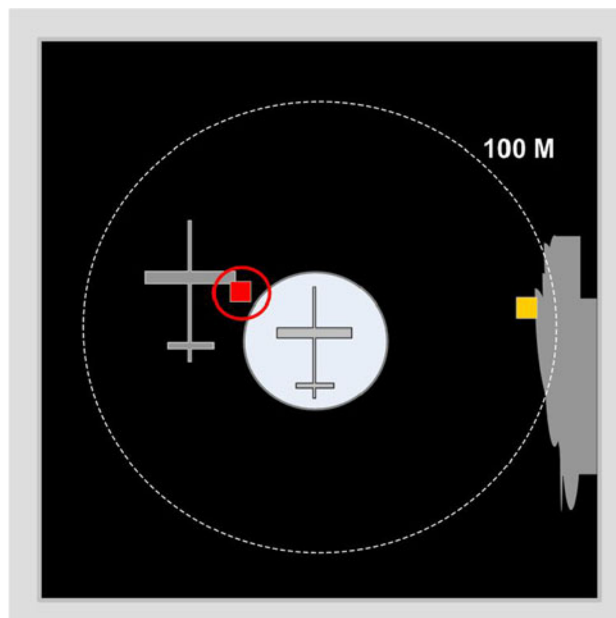

Fig. 7 2D alert (2 threats—different threat level)

5.4.3 Design of acoustic alert

The audio alert is presented, if one or more potential threats (caution or warning) exist. The audio alert re-activates if after the aircraft commences moving, a further collision threat exists.

The audio alert is presented using the cockpit loud-speakers, deploying a speech/synthesized voice in line with the TCAS and EGPWS system. The audio alert deploys a male voice. The specific message varies depending on how imminent the threat is (i.e., if caution-level or warning-level threat). The audio alert for both the caution and warning alert is repeated twice.

If one or more caution-level threats exist, the caution message is provided. In all cases (i.e., both single and multiple threats), the message provides feedback that a threat/object exists. The specific terminology is as follows: 'Object; Object'.

If one or more warning-level threats exist, the warning message is provided. In all cases, the warning message provides a stopping instruction. 'Stop Now; Stop Now'. If impact is very likely, a further warning message of 'Increase Braking' is relayed to the Pilot.

6 Discussion

6.1 Methods

6.1.1 Participatory approach

In support of participatory theorists, research testifies to the importance of designing 'with' end users as opposed to 'for' end users. To date, there has been much collaboration with both end users and project stakeholders. Feedback from the series of collaborative prototyping and evaluations sessions involving one Pilot and the IALPA panel helped advance the teams' understanding of collision scenarios, antecedents to collision incidents/accidents and related HCI design requirements. Further, this feedback helped ground the direction of the technical research. Moreover, the review and validation of the proposed HCI design concept with broader stakeholders (i.e., IAA and AAIU) proved invaluable. The expertise of these stakeholders in relation to understanding collision incident/accident contributory factors provided an alternative evaluation angle on the HCI. In this regard, participants evaluated the design solution, in relation to actual collision investigation data.

6.1.2 Scenario-based design approach

Overall, the integration of a scenario-based design approach with participatory prototyping and evaluation activities proved highly useful. Several rounds of scenario development have been undertaken. In the first phase of research, potential collision scenarios for different roles were analyzed. The team then selected certain scenarios to be examined in more detail, in order to advance a proof of concept demonstration of the system. The first phase of envisionment, design and evaluation activities focused on a simple routine taxi scenario for the Pilot role. This scenario was further refined in the second phase of research. Further, as this research progressed, the HCI specification was validated and extended in relation to more complex and nonroutine versions of this scenario.

In relation to the collaborative prototyping and evaluation research as part of the latter half of phase one research, and the first part of phase two research, the initial focus on a core/simple scenario proved useful. This ensured that HCI design efforts focused on a real-word task and the core requirements for the emerging WW system. As such, this helped kick-off HCI modeling activities. However, new tool concepts cannot be premised on basic scenarios alone. One of the key lessons of this research is that in adopting a scenario-based design approach, both routine and nonroutine scenarios must be considered. In so doing, both simple and complex scenarios should be elucidated. Critically, the final HCI concept needs to be scalable and flexible. That is, it must work for all possible collision scenarios, of which the Pilot is responsible. As shown, to progress the concept, the scenario-based design and evaluation activities moved from the specification of a simple routine scenario, to a more complex routine scenario, and then to nonroutine scenarios—both simple and complex. Interestingly, the design and evaluation activities in relation to the simple version of a routine scenario suggested one HCI design execution for the visual alert (i.e., focus on collision zones). Yet, the HCI requirement appeared slightly different, when the design activities moved to more complex version of this scenarios and nonroutine versions. That is, the HCI solution changed from a presentation that focused on the location of the threat in a collision zone, to a presentation that highlighted the location of the threat, the threat level of the object, and whether the object is static or moving. From the outside, this might seem like HCI research was going around in circles. However, this is not the case! The scenario-based design approach and associated selection of scenarios at different points in the design process led to a further refinement of the HCI concept and allied technology requirements.

6.1.3 Technology and operational procedures

The introduction of new technology provides the opportunity to change existing working practices and procedures. As such, the introduction of a collision avoidance system might change the scope of Pilot responsibility for collision avoidance, along with the particular collision avoidance procedures. Therefore, it is important that HCI research addresses issues related to how the technology will be used from an operational perspective. Critical here is eliciting information about existing procedures, specifying any gaps between existing operating procedures and the new technology, and identifying the requirements for new role task functions and associated procedures. As noted earlier, as part of the task analysis, the researcher addressed issues related to current procedures and collision avoidance responsibilities. Moreover, scenario definition directly addressed issues of operability. As such, issues such as process design, team concepts and system information flow were addressed. Further, the collaborative prototyping sessions with Pilots focused on defining the operational procedure to be followed.

In relation to procedures design, it should be noted that these activities are not final. As noted previously, in the current situation, there are other scenarios to be addressed from a procedural perspective. This includes situations where the Pilot is responsible for collision avoidance along with others, and situations where the Pilot is not responsible. This requires further consideration. If the WW technology is used to provide instruction to Pilots (and potentially others such as ATC or the Ground Marshaller) in relation to these additional scenarios, this would create a new operational information picture, new workflows and new responsibilities. This would therefore necessitate a review and potential redesign of existing procedures. Further, in cases where new procedures are being considered, this will require validation with other agents. This is because changes for one role (i.e., Pilot) may have implications for the work practices of other agents (i.e., ATC and Ground Operations). Lastly, additional upgrades to system might necessitate the introduction of new procedures. For example, the WW system might be integrated with taxi maps to provide routing information/guidance in situations where a collision is anticipated. This would have an impact on the work activities/responsibilities of other roles (i.e., the Ground Marshal in a parking situation). In addition, any proposed changes would need to be assessed and approved from a regulatory perspective.

6.2 Evaluation feedback regarding the HCI design solution and areas for further research

As noted previously, the primary human factors objective for this system are to support threat detection and specifically to generate a response from the Pilot (i.e., slow down to a safe stop), if a threat exists. In this respect, the HCI prioritizes communications relating to threat detection. During the course of the different collaborative design and evaluation sessions with both Pilots and broader stakeholders, participants raised several issues regarding the usability of the visual alert (i.e., 2D alert), and the presentation of both threat and nonthreat information.

Firstly, some participants have expressed concerns over the provision of information about nonthreats (in addition to information about actual threats), on the visual alert. It has been suggested that the depiction of nonthreat information might prove a distraction to the Pilot. Specifically, this information might shift the Pilot's focus from stopping the aircraft to avoid a collision (i.e., the appropriate response if a potential threat exists), to situation assessment regarding the nature of the threat and route planning in relation to avoiding the potential threat. As noted previously, such assessment is intended to occur once the aircraft is stopped (and the potential collision averted). Secondly, in its current form, the visual alert appears to provide clear visual information about threat objects. For example, a clear picture of a potential aircraft threat is depicted in the proposed system prototype. However, it has been noted that the camera footage from which this image is derived may not present a similarly accurate picture. Further, given that the WW system detects whether a particular point in space is occupied, as opposed to differentiating different objects, certain objects may end up appearing as an extended gray blob. This is particularly true of nonthreat objects. As a result, the Pilot may expend unnecessary time, deciphering both threat and nonthreat objects. As suggested by certain Pilots, this may cause distraction at a time critical moment in the operation, and impact on response times. Lastly, if both threat and nonthreat information are provided in the 2D alert, then this might create unnecessary complexity in relation to the depiction of scale. This applies both to the presentation size of the of the threat icon, along with the presentation size of both threat and nonthreat objects.

To mitigate these different issues, the 2D alert might simply present an icon depicting the location of the threat, as highlighted in Figs. 8 and 9. As such, it may exclusively focus on threat detection (i.e., positive signal of either amber or red icon) and not provide any unnecessary distraction from the core requirement to respond to the alert (i.e., slow down to a safe stop).

The level of information provided on the 2D display requires careful consideration. It is likely that these issues will be addressed in follow-up research (i.e., simulator evaluations and live trials of the system).

6.3 Integration with other sensors

As reported by Pilots, there is an overall expectation that if an alert is generated, there is a potential threat that must be addressed. Conversely, if an alert is not provided, then the situation is safe (i.e., no potential collision threat). Given the limits of camera vision, the latter may not be true in all situations. Specifically, the camera does not have perfect vision in reduced visibility/poor weather conditions (i.e., fog, low hanging cloud, heavy rain and so forth). Further, although the aircraft beacon and taxiway lights provide some level of illumination in night conditions, this does not guarantee complete vision. In this way, the WW system is optimized for visual flight rules/good weather conditions. Thus, it is possible to imagine a situation where a threat exists but no WW alert is provided (i.e., if not detected by cameras given low-visibility conditions). As such, the WW

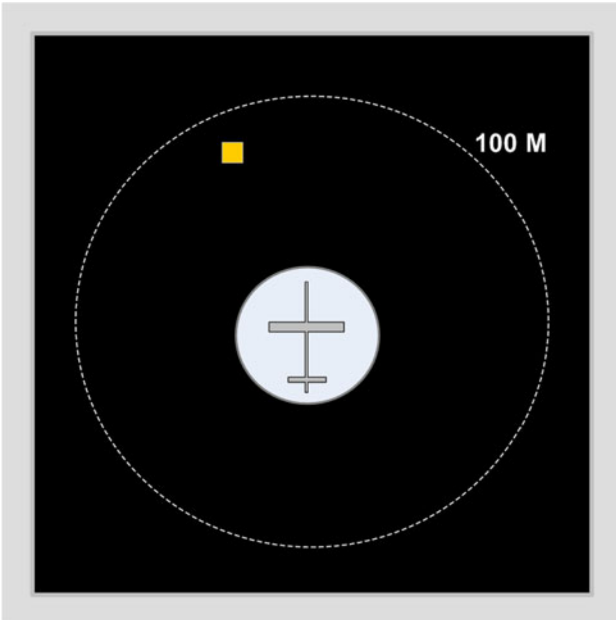

Fig. 8 Alternative option for 2D caution alert—one threat

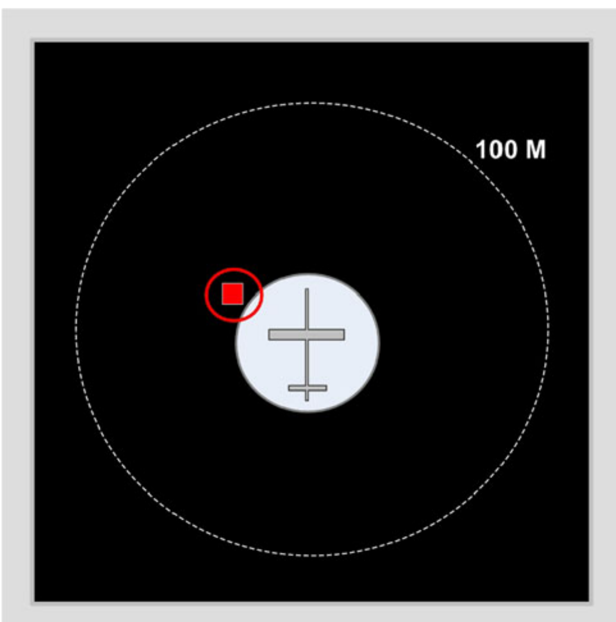

Fig. 9 Alternative option for 2D warning alert (with blink)

system might be further enhanced to support all conditions operations. This would involve integrating the WW sensors with other sensors (both on and off the aircraft). In relation to the latter, this might involve systems used by other stakeholders involved in ramp/taxiway operations.

6.4 Integration with other cockpit systems

Currently, the WW system is a stand alone system; alerts are presented on the cockpit navigation display (ND). However, using one system to cover many items might be attractive to manufacturers. Also, there are tangible HCI benefits such as information integration, the avoidance of information duplication and consistency in terms of the presentation of information, etc. In this respect, the WW system might be integrated and/or linked to other cockpit systems (i.e., moving maps, electronic flight bag and so forth). This possibility has also been suggested by Pilots, during the course of this research.

7 Next steps

To demonstrate proof of concept, prototyping activities have focused on a subset of potential collision scenarios. Primarily, this concerns situations where the Pilot is responsible for collision avoidance and is in a position to maneuver (i.e., taxi out, taxi in and parking using aircraft guidance system). As stated previously, collision alerts can be classified in relation to three overall types of collision situations. In this respect, research must also address the role of the WW system and the nature of WW alerts, for situations where the Pilot is responsible for collision avoidance along with others (and in a position to take action), and situations where the Pilots are not responsible. This will ensure a holistic HCI solution. This research has yielded a proof of concept prototype—characterized at technology readiness level 4. It is hoped that this system will be commercially exploited in the future. At a first stage, this might involve proof of concept demonstrations to potential partners. Depending on the outcome of such activities, further HCI research might be undertaken. Ideally, the proposed prototypes will be evaluated in a series of simulator trials. Further, real-world operational validation is also required. This will involve installing both the hardware and software to an aircraft and trialing the system as part of a live operation. Also, the core HCI concept might be developed for other personnel working on the airport ramp (i.e., Tow Truck drivers and Maintenance Engineers), along with other stakeholders (i.e., airport authority and Ground Control). This would ensure seamless information flow across the socio-technical system. Moreover, research might consider the possible transfer/extension of the WW HCI solution to rotary wing operations and other transport areas (i.e., marine and road transport).

8 Conclusions

The existing low technology solutions are accepted generally by operators, despite their failure rate, as no solution to the problems has been foreseen or envisaged. A successful collision avoidance device would allow re-evaluation of an economically ‘acceptable’ collision rate. In this regard, new technology offers the possibility of improving ramp/taxiway safety and specifically, Pilot situation awareness when maneuvering on the ramp and in taxiway areas.

Ground collisions should be elucidated in relation to: (1) the role of Pilot (i.e., responsibility for collision avoidance) and (2) the ability of the Pilot to maneuver.

Accordingly, collision situations can be categorized into three overall types. This includes situations where:

- The Pilot is responsible and is in a position to maneuver (i.e., taxi out, taxi in, parking using automatic guidance system)
- The Pilot is responsible (along with others) and is not in a position to maneuver (i.e., taxi hold, or runway hold)
- The Pilot is not responsible (i.e., pre-pushback/parked in turnaround, tow/pushback operations and parking with assistance of Ground Marshaller)

A future collision avoidance system should enhance Pilot situation awareness, while at the same time allowing for Pilot judgment. The system should be dark and quiet unless an alert is required. Clear operational procedures are required as to use of system in different collision contexts.

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Appendix 1

See Table 7.

Table 7 Research phases and scenarios

No.	Part	Description	Methods	Threat type	Scenarios	Flight Phase
1	1	Task analysis	Stakeholder workshops, Pilot jump-seat observations and interviews	All	All possible collision scenarios	Pushback, ready to taxi, taxi out, taxi in and parking
	2	Preliminary scenario specification and tool envisionment	Scenario specification and collaborative prototyping and evaluation sessions with one Pilot	Other aircraft (stationary)	Routine taxi scenario (simple)	As above
	3	Development of HCI 1	Collaborative prototyping and evaluation sessions with one Pilot	As above	As above	Taxi following pushback—no turn
2	1	Development of HCI 2	As above	As above	As above	As above
	2	Validation of HCI concept	Workshop with a panel of eight Pilots	As above	As above	As above
	3	Specification of complex routine scenarios and HCI	Scenario specification and collaborative prototyping and evaluation sessions with one Pilot	All	Routine taxi scenario (complex)	As above
	4	Specification of nonroutine taxi scenarios and HCI	Scenario specification and collaborative problem solving between HCI and software teams	All	Nonroutine taxi scenario (simple and complex)	As above
	5	Validation	Semi-structured interviews with stakeholders including Pilots	All	Routine and nonroutine scenarios	As above
	6	Review	Collaborative problem solving with Pilot and software team	All	As above	As above
3	1	Alpha test	Demonstration of technology underpinning HCI	Aircraft	Routine	Taxi in ramp area
	2	Desktop evaluation	Collaborative problem solving with eight Pilots	Aircraft	Routine	Taxi in ramp area
	3	Beta test	Demonstration of technology underpinning HCI and integration of HCI specification	Aircraft	Routine	Taxi in ramp area
	4	Review	Collaborative problem solving with software team	Aircraft	Routine	Taxi in ramp area
	5	Evaluation/Validation	Collaborative problem solving with panel of five military Pilots	Aircraft	Routine	Taxi out

Appendix 2

See Table 8.

Table 8 Contributory factors

Type	Description
Operational pressure	As operations get bigger and move to low-cost business models, there is a requirement for quick turnarounds. This puts pressure on the operation—the crew is working at faster rate, and there is a higher risk of error
	Time pressure—the crew do not want to loose their ATC time slot—press ahead instead of waiting for instruction from the 'follow me jeep' or ATC/ramp control
	Previously, airlines were the sole provider of ground handling. Had trained people and appropriate ground vehicles for nature of operation. Ground handling now subcontracted—competition—mix of aircraft associated with mix of handling equipment—may not have right equipment to service an aircraft.
Fatigue	Long shift times
	Flight crew fatigue
	Tow truck operator fatigue
	Maintenance fatigue
Response time	Insufficient time to stop
Distraction	Pilot distraction and workload
	Progressive taxi instructions—Pilots get distracted trying to follow instructions
	Pilots can forget what ground operative is doing
	The focus of the Marshaller is on the nose wheel. Nobody is focused on the big picture—bias in attention, etc.
	In pushback, it is difficult to see the object ahead—the crew are not looking out the window—rather they are getting on with other tasks such as monitoring engine starts
	Pilots—information overload—making turns—not paying attention to wing position
	High ace van driver—has radio on—not hear radio or get distracted
	Captain distraction—can hear ground ATC as well as Marshaller/ground crew but officially listening to ground crew. First officer supposed to be listening to ATC
Visual judgment	Pilot or vehicle driver does not see other object or aircraft positioned at side, behind or ahead
	Difficulty judging three-dimensional space
	Walker is walking and looking at engines and only seeing one side—dangerous—limited field of view
	Most parking bays have red line—sterile—equipment parked outside. Yet, hard to tell that red linen corresponds to size of aircraft
	Limited forward field of vision
	Self-parking system—the stand area may not be clear of obstacles, and this is not detected by person who operates the system (e.g., configures for aircraft type)
	In many airports—get conditional clearances—when other aircraft—pass you, you are clear for pushback and to start engines. Pilot relays this message to driver—rely on driver to check this—if driver make poor judgment might have collision
	When move a taxi line—the paint leaves a black shadow behind—in wet or dark conditions—equal reflexivity—hard to judge
	Flight Crew cannot see ground crew in pushback—out of sight under nose
	Can have set of steps that appear inside the line—but are projecting forward—difficult to judge
	Marshall directs aircraft into wrong stand—adjacent stand may not be wide body—problem for other aircraft
	Hard to judge location of wing when turning—assume that taxi marking is correct
	Pilots are multi-tasking—watching where aircraft is going while scanning the wing tip—do not have ability to stop and continue—as if stall too much the aircraft will lock
	The aircraft that is moving is responsible for not hitting the aircraft that is stopped. If turn away from the aircraft, the wing tip might hit the tail of the other aircraft—purely visual judgment. These are unregulated—no ramp guidance
	Equipment being moved around in a tiny space—difficult to judge.
	Difficulty judging speed and forward movement of wing tip—human judgment
	At night—only judging navigation light and anti collision light—difficult
	Once turn—wingtips move at different speeds—common cause of collisions—not see outer—its traveling faster than inner, etc.

Table 8 continued

Type	Description
	The distance between two stands can be difficult to judge. Vehicles driving between aircraft on designated roadways—may misjudge what is already a narrow distance.
	Somebody can be blocking the holding point—this is just visual—people stopped at different points—no yellow line to guarantee separation—different size aircraft moving to different taxiways
	Aircraft turning at the end of runway—nose wheel or main wheels can slip off edge of runway
	Hard to see 'yellow line' in dark wet snowy conditions. Hard to see red line (obstacle supposed to be outside it) in dark wet snowy conditions
	When taxi—cannot see behind you
	In MX hangars—no yellow lines—MX have to judge it.
	Close in on stand—cannot see—have to check out before got on stand—might forget to check
Equipment	Equipment can be in wrong location
	Objects positioned inside painted line when not supposed to be.
	Aircraft inappropriately parked—overhang stand position
	Stair case—blown in wind—supposed to be pegged and secure
	Inclement weather—blow and move equipment around the ramp
	Debris on taxiway or apron
Training	Poor training
	Bus drivers—unfamiliar with position of aircraft/size
	MX not trained for tow activity
	Ground Crew not well trained
	Flight Crew not well trained
Traffic	Volume of traffic at airport
	Early morning—many aircraft being pushed back or repositioned—apron congestion
Communication/co-ordination	Quality and timing of communication/information sharing between Flight Crew (FC)
	Quality and timing of communication/information sharing between FC and other relevant roles (e.g., tow truck driver, walker and ATC)
	Long confusing taxi instructions from Ground ATC, combined with looking at terminal map—attention lapse—task management issues
Tools and information	Vehicle don't have specific maps—although ramp becoming more complex
	All sorts of types of aircraft and vehicles—handling agents bringing all sorts of equipment to all sorts of aircraft—can make mistakes—operator incorrectly configure air-bridge or FMC—or use inappropriate tow vehicles for size of aircraft
Environment	Low visibility—at dusk
	Poor visibility at night
	At night—stands not brightly lit—people wear high visibility jackets—at 40 meters in bad visibility—difficult to judge distance—aircraft beside you in darkness
	Visibility and light change—move from dark light to bright light when taxi into stand
	Distance definition reduced in bad light, rain, mist, fog or snow
	Visibility and weather conditions (e.g., raining, ice, winds)
	Aircraft slipping due to surface conditions, for example wet, damp, paint
	Night—collection of lights causing confusion—this includes taxiway lights and aircraft lights (navigation lights). This is often described as a 'sea of moving and fixed lights'—in these situations, Pilots can have difficulty seeing objects
Markings	Inappropriate and inaccurate markings
	No defined taxi paths on occasion
	Visibility of taxi markings
Lighting	Incorrect lighting of ramp area at night-time
	Lighting causes problems—yellow lighting and yellow taxi way lighting—tried adding glass beads into paint, painting black lines beside yellow lines—nothing stays static—trying to improve
Staff	Turnover of staff
	No incentives

Table 8 continued

Type	Description
Pilot briefing	Pilot familiarity with airport/taxi layout and taxi procedures
	Poor crew resource management (CRM) on the part of Flight Crew
Problems on stand	Guidance system set wrong
	Markings incorrect
	Debris

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