Hooey, B. L. (2005). Proceedings of the 13th International Symposium on Aviation Psychology. Oklahoma City.

Improving Taxi Efficiency through Coordinated Runway Crossings

Becky L. Hooey
San Jose State University / NASA Ames Research Center
Moffett Field, CA 94035

Coordinated runway crossings is a novel concept aimed to improve runway-crossing efficiency by providing taxi clearances containing a time or speed component. The goal is to enable pilots to arrive at, and cross, active runways without a delay. Eight commercial captains participated in a ninety-minute semi-structured interview that explored issues associated with coordinated runway crossings. The results of these interviews were used to generate preliminary information requirements, system requirements, and procedural requirements for a future coordinated runway crossing system.

Introduction

In current-day airport surface operations, the need to cross active runways while taxiing from gate to runway or vice versa often leads to extensive delays. One reason for these delays is that taxiing aircraft take third priority in runway usage (first priority is given to landing aircraft, second priority to departing aircraft). Another related reason is that air traffic control (ATC) tends to queue crossing aircraft on taxiways until there are sufficient numbers, and then cross all aircraft at once in a single crossing window between arrivals and departures. This approach to runway crossings is ultra-conservative, necessitated by the dynamic and uncertain nature of surface operations and the lack of information regarding predicted runway-occupancy times and predicted time-of-arrival of taxiing aircraft.

Efforts to increase aviation system capacity have focused a great deal of effort on improving arrival and departure efficiency. Ironically, these capacity-increasing initiatives, such as adding runways to existing airports and reducing the separation between aircraft on final approach, are likely to compound delays on the airport surface, and create new bottlenecks and problems (Cheng & Foyle, 2002).

As the aviation system expands to accept more traffic, airports are increasingly looking to alleviate the arrival and departure bottlenecks by adding runways, often adding one or more runways parallel to existing ones (Cheng, Sharma & Foyle, 2001). These additional parallel runways increase airport layout complexity, and displace the traffic bottleneck to surface operations. For example, Cheng and Foyle (2002) noted that when Dallas/Fort Worth (DFW) International Airport expanded from six runways to eight, the complexity of the airport configuration also increased. Adding runways resulted in some runways blocking the traffic between the gates and the outer runways causing more taxiway intersections and runway crossings to manage. The DFW Airport Development Plan (1997) proposed to address this via the addition of perimeter taxiways to route aircraft around the north and south ends of the runways. However, Cheng, Sharma, and Foyle (2001) note that this option is costly and results in increase in taxi time and fuel burn.

An alternative proposal designed to increase capacity of the air transportation system is to reduce the spacing minima between landing aircraft. It has been proposed that speed cues from new on-board guidance systems will help enable precise spacing at the runway threshold (Barmore, Abbott, & Krishnamurthy, 2004) resulting in improved spacing consistency while eliminating excess spacing between landing aircraft, and increasing throughput. However, as arrival rates increase, there will be fewer opportunities for taxiing aircraft to cross active runways, and the length of available crossing windows may be shorter. Cheng, Sharma, and Foyle (2001) note that this is problematic given the current approach to queuing aircraft for a single runway crossing slot because an aircraft takes more than twice as long to cross the active runway if starting from a standstill as opposed to a continuous taxi (at 30 kts). Therefore, the number of aircraft that will be able to cross between arrivals may be reduced.

Coordinated Runway Crossing Concept. These 'solutions' to increase system throughput may have a significant negative impact on airport surface operations. In order to achieve the system-wide benefit that is expected, solutions must also be developed to enable efficient surface operations and runway crossings. If a controller could better predict gaps between arrivals and departures, and predict when a taxiing aircraft will arrive at the runway, aircraft could potentially be provided with a taxi clearance that enables them to cross the runway as they arrive, rather than waiting for a sufficient number of aircraft in a queue to cross at once. Cheng, Sharma, and Foyle (2001) concluded that this would not only reduce taxi time and delays due to hold-short operations, but also minimize taxi traffic back-ups, and ease the impact on the arrival and departures on the runway. Thus, in order to improve the efficiency of surface operations, the concept of coordinated runway crossings has been proposed which make use of new procedures, automation, and display technology to minimize or eliminate the need for aircraft to stop and wait to cross active runways.

There are many ways that a coordinated runway crossing system may be implemented, and each will have an impact on the task of the pilot, ATC, and the interaction between the two. The development of a human-centered system begins with an understanding of the current-day operations, and consideration of potential issues as perceived by operators within the system. This paper reports the findings from a series of interviews in which the objective was to initiate a dialogue with subject matter experts, in this case commercial pilots[1], to solicit their initial impression of the coordinated runway-crossing concept and to identify issues that must be addressed in the subsequent research and development program. The results of these interviews were used to generate preliminary information requirements, system requirements, and procedural requirements.

Method

Participants

Eight commercial airline captains, representing five different U.S. airlines, participated in this study.

Procedure

Each pilot participated in a semi-structured interview that lasted approximately 1.5 hours. Each interview began with a discussion of the Captain's taxi experience, and issues faced during current-day taxi operations including factors that hinder airport efficiency and safety. Each captain described the airports they most frequently fly into and the typical runway crossing delays associated with each airport. Subsequently, a series of open-ended questions guided the discussion about procedures and technologies that could improve the efficiency of runway crossings.

The coordinated runway crossing system concept was introduced to the participants including a description of the intended system-wide efficiency gains expected from eliminating the need for aircraft to hold short of active runways. Two potential implementations (time-based, and speed-based taxi clearances) were described. For time-based clearances, two potential formats: Zulu[2] time and elapsed time were suggested. An example of a Zulu time command ("Cleared to cross Runway 22R at 22:13Z") and an elapsed time command ("Cleared to cross Runway 22R in 45 seconds") was presented. For speed-based clearances, pilots were told that clearances would contain a speed advisory such as "Taxi Alpha, Bravo, Charlie, maintain 16 kts". Such a clearance, if followed, would ensure a taxiing aircraft would be able to cross the active runway without delay. Focused questions were then asked regarding the implementation of each clearance type.

A transcript of the interviews was analyzed to identify sources of efficiencies in current-day surface operations. Preliminary information requirements, system requirements, and procedural requirements for coordinated runway crossing systems were generated. Given the semi-structured nature of the interview, the findings presented herein are qualitative in nature. They are presented with the intent to identify issues for consideration and guide subsequent research.

Results

Sources of Inefficiency in Current-Day Operations

Delays associated with crossing active runways were identified as the largest contributor to surface operation inefficiencies. Pilots cited delays of up to 20 minutes at some airports (including Dallas Fort Worth International, Phoenix Sky Harbor International, and Seattle-Tacoma International) and suggested that operations could be more efficient if the need to stop and start-up again could be eliminated. Pilots cited airport layouts as the largest source of inefficiency, particularly when the gates are on one side, and all traffic must cross active runways to get to their destination (gate or departure runway).

Pilots noted a lack of consistency among controllers attempts to maximize runway-crossing efficiency, primarily due to ATC workload and traffic loads. Under some conditions, controllers possess the ability to forecast future traffic patterns, and can therefore expedite traffic and minimize delays. For example, controllers may command longer taxi routes than the most direct route, if it actually minimizes the runway crossing delay and overall taxi time. However, this is not consistent, and controllers cannot accomplish it when it is needed the most, during peak traffic times.

[1] The importance of soliciting feedback from other stakeholders has not been overlooked. Similar interviews with ATC are currently being conducted.

[2] Zulu Time, also known as Coordinated Universal Time or Greenwich Mean Time, is used as the standard clock for international reference of time in communications, military, maritime and other activities that cross time zones.

This implies that some controllers are already trying to maximize efficiency at runway crossings by eliminating holds, but they do not have the information and the tools to do it consistently. More typical is the experience as described by one pilot:

> "At Phoenix and Dallas Fort Worth, ATC stacks up crossing aircraft until there are enough of them to break the arrival or departure stream. This leads to delays of 10 to 15 minutes."

Another reported source of operational inefficiency is the variability in response timeliness among pilots, which leaves ATC with uncertainty as to whether a pilot will respond to, and execute, the clearance promptly. If ATC issues a command and expects it to be carried out expeditiously, any delay in response could cause significant disruptions (e.g., could impact other traffic or cause a landing aircraft to initiate a go-around maneuver). Given the nature of the consequences, ATC must be more conservative in their commands and, if in doubt, issue a hold command rather than an expedite command. To illustrate this, one pilot reported:

> "Spacing is a lot closer for [X Airline] than other airlines because they are reliably fast and efficient".

Pilot Information Requirements

It is clear that both pilots and controllers in current-day operations are attempting to maximize efficiency, but lack the information needed to support coordinated runway crossings. Pilot information requirements are discussed below in terms of traffic, navigation and speed/time management.

Traffic. During the interviews, pilots suggested the need for improved sharing of information regarding traffic flow, aircraft sequencing, and runway use. For example, knowledge of upcoming breaks in the arrival stream would enable pilots to better gauge their taxi speed and be prepared to cross runways or take-off at the appropriate time.

> "The problem is not that I have to stop and wait to cross the runway, but that I have no information. If I know that I can't cross the runway for the next 5 minutes due to a heavy arrival stream, then I won't rush to get there".

The flow of relevant information about traffic and runway use can be improved in a number of ways. Most simply, this can be addressed procedurally, with ATC providing relevant information about traffic sequencing. Pilots suggested minor changes to ATC phraseology that could help pilots gauge the time urgency associated with a runway crossing command. Suggested examples included: "Cross after company '47", and "Traffic on 2 mile final, expedite crossing of Runway 26R". However, while these types of clearances are already used to a limited extent in current-day operations, it is problematic on a wide-scale because it adds to radio frequency congestion, and is often not possible at peak times. Another option for improving flow of traffic information is cockpit display technology that provides a real-time graphical depiction of traffic and runway occupancy to pilots. This shared awareness of runway traffic would lessen opportunities for errors and runway incursions, and could also help pilots cross-check ATC clearances.

Navigation. Pilots reported that their ability to accurately estimate and predict their time to arrive at a runway crossing point would be largely dependent on their familiarity with the airport. This suggests that flying into new and unfamiliar airports, or receiving a non-standard taxi route, could make complying with a time-based coordinated runway crossing command difficult for many pilots. On the other hand, those with routine and familiar routes stated that meeting a required runway crossing time would not be difficult.

> "For airports that I fly into, I know how many minutes it normally takes to get from runway to gate. I don't see this as a big problem."

This finding highlights the need for navigation displays that depict the airport layout, the location of the gates and runways, and the cleared taxi route. Such navigation displays have been developed (e.g., Hooey, Foyle & Andre, 2001; Theunissen, Rademaker, Jinkins & deHaag, 2002) and are under consideration for implementation by industry (Comstock et al., 2004). The wide-scale deployment of such displays should be considered a minimum requirement for the coordinated runway-crossing concept.

Speed and Time Management. Pilots reported that their cockpits lack even the most basic speed and time management tools necessary to enable coordinated runway crossings. Specifically, many stated that their ground speed indicator is inaccurate at taxi speeds and this would make complying with a precise speed advisory unnecessarily difficult. Further, only those flying more modern aircraft are equipped with GPS-precision clocks. Therefore, complying with time commands in Zulu time formats would be difficult as it would required synchronization between pilots and ATC and confirmation of both actual and commanded times. Although most aircraft are equipped with stopwatches, using elapsed time creates other time synchronization problems, especially if pilots are slow to start their clocks in response to ATC time commands. Therefore, the inaccuracy of aircraft clocks, and the lack of synchronization among pilots and ATC, could contradict the precision required for closely-spaced taxi maneuvers.

Minimal information requirements, then, include accurate speed indicators and synchronized clocks. Beyond these minimal requirements, further augmentations to cockpit displays will also be required. Displays that depict deviations between commanded and actual speeds in a graphical or status-at-a-glance format would aid pilots in the speed maintenance task. Displays that show both time elapsed and time remaining in an integrated fashion would allow pilots to better estimate their conformance to time-based commands. Pilots recommended a conformance monitoring system that would alert them when they are required to make a speed adjustment in order to attain their runway-crossing goal. The nature of the information that will be required, however, will be largely dependent on the required degree of precision with which the aircraft must arrive at the runway. The automation and display technology must be considered carefully to adequately support the required level of precision.

Summary of Preliminary Information Requirements
1) Traffic Management - Sequencing information - Location/intent of traffic 2) Navigation - Airport layout - Route depictions 3) Speed and Time Management - Accurate ground speed - GPS-precision clocks - Pilot-ATC synchronized timers

System Requirements

It is clear that a pilot's support for a coordinated runway crossing system would be dependent on the actual algorithms used to derive the speed or time commands. Factors that pilots determined must be considered in the development of a coordinated runway crossing system were grouped into four categories: Aircraft-specific, airport-specific, operating conditions, and traffic flow. Each is discussed below.

Aircraft-specific Characteristics. Speed or time-based advisories must be determined based on aircraft-specific minimum and maximum taxi speeds. The type of the aircraft will determine how quickly it can taxi and maneuver around turns. Airline policy, particularly policy regarding engine use during taxi, must also be considered. Some airlines require pilots to taxi on one engine, others taxi on two, at least until clear of all runways. This will influence how quickly an aircraft can taxi across a runway and prepare for take-off. Also, as technology is developed and adopted by airlines, the presence of technology on-board will influence an aircraft's ability to comply with time and speed commands. If cockpit display technology is gradually phased in, a system must be able to accommodate mixed-equipped fleets where some aircraft may be equipped with automation and display technologies to help them achieve their runway crossing time, but others are not. Unless it is clear which aircraft are equipped and able to comply, the result would be increased uncertainty for both ATC and pilots.

Airport-specific Characteristics. The runway crossing system must also be flexible enough to adapt to particularities at each airport. Characteristics that the system must consider include taxiway geometry, taxiway weight restrictions, and taxiways that are temporarily closed for maintenance. Also, many airports have unique characteristics for which the system must be adaptable. For example, Las Vegas McCarran (LAS) Airport has a long downhill taxi and requiring a pilot to ride the brakes to maintain a slow taxi speed could overheat the brakes creating a threat to safety in the event of an aborted take-off. New York's LaGuardia Airport (LGA) has some taxiways that limit taxi speed to 5 kts due to poor surface conditions. The ability for each airport to apply constraints based on their temporary and permanent taxiway circumstances will be required.

Operating Conditions. Pilots listed a number of operating conditions that limit or otherwise affect the speed at which a pilot can taxi. Specifically, the pilots advised that the system must be able to adapt speed and time commands to account for slower taxi speeds necessitated by poor visibility and surface friction conditions. Operational conditions that create the need for de-icing before take off must also be considered to ensure time/speed commands enable aircraft to taxi efficiently from the de-icing station to the departure runway and eliminate delays which will cause an aircraft to return to the deicing station.

Traffic Flow. Traffic flow is a large consideration in developing the time or speed algorithms. Clearly, a coordinated runway crossing system must include intelligence to allow for coordination among aircraft so that a following aircraft is not commanded to taxi faster than the lead aircraft. Similarly, aircraft cannot be sent along conflicting paths (a particular problem near gate alleyways), or at least their speeds must be adjusted to prevent conflict while still reaching their target runway crossing time.

Summary of Preliminary System Requirements
1) Aircraft Specific Characteristics - aircraft type - airline policy - equipage 2) Airport Specific Characteristics - taxiway geometry - taxiway weight restrictions - closed taxiways 3) Operating Conditions - visibility - surface friction - icing conditions 4) Traffic Flow - gate assignment - routing and speed conflicts - runway usage

Procedural Requirements

The success of a coordinated runway crossing system requires more than new technology and cockpit displays. It also requires the simultaneous development of new operational procedures. Pilots raised four procedural issues that merit consideration.

Contingency Plans. During the interviews, pilots emphasized the need for contingency plans which would accommodate circumstances in which a pilot cannot comply with a crossing command, and do so without heavily penalizing them with lengthy delays. The most important concern raised repeatedly by the pilots was that a coordinated runway crossing system could promote unnecessary rushing or a 'rush to comply mentality' in which crews rush through checklists and other duties in order to meet their runway crossing and departure times. This is particularly problematic given that ATC would not be aware of situations in the cockpit where the crew may be struggling with navigation or other cockpit duties. Pilots noted that it impossible to predict the time required to complete these tasks as it will depend on airline procedures, flight-crew experience, and cabin crew experience. Requiring pilots to maintain a specific speed or arrive at the runway at a specified time means the crew may arrive at the runway before they are prepared to take off because they have not completed checklists and safety items. It could also lead to the dangerous situation in which the first officer is removed from navigation tasks in an effort to attend to other tasks that must be completed.

Contingency plans could take the form of automatic adjustments to runway crossing slots based on taxi speed and/or speed conformance monitoring. A time-based clearance might take the form "Cross at 22:10Z, if unable expect next crossing at 22:35Z". This would allow pilots to assess their workload and ability to make the crossing, and at the same time be aware of the consequences of missing the window.

ATC and Pilot Interaction. Procedure development must also define phraseology for pilots to communicate to ATC in the event that they cannot make their cleared runway-crossing window. If ATC receives this information early then route modifications can be issued and the runway-crossing slot can be reassigned to another aircraft to make efficient use of the runway, thus maintaining the intended efficiency of the system. Similarly, there could be a need for ATC to cancel a runway crossing command, if for example, an aircraft is slower to land than expected, or an aircraft aborts take off. Effective means to communicate this information with standard phraseology must be developed.

Need for Positive ATC Control. Pilots emphasized the need for positive control at the runway crossings, (i.e., the need for ATC to verbally clear them to cross the runway, rather than simply provide a runway-crossing window or time in the clearance). However, some pilots suggested this could take the form of datalink and display technology, not necessarily just the verbal commands over radio, as used today.

Conditions of Use. Procedures regarding when the system should be employed must also be developed. Pilots cautioned of 'system over-kill', suggesting that speed-based guidance should only be provided when relevant, otherwise pilots will ignore the advisories. If the airport traffic is light, the system may encourage a pilot to taxi at maximum speed, only to discover that the gate is blocked. These usage procedures must be generated in coordination with both the airlines and pilot unions.

Summary of Preliminary Procedural Requirements
1) Contingency plans 2) ATC-pilot interaction 3) Positive control of all runways 4) Conditions of use

Discussion

The need to cross active runways during taxi leads to highly inefficient operations. The dynamic and uncertain nature of surface operations, coupled with the lack of information regarding predicted runway-occupancy times and predicted time-of-arrival of taxiing aircraft, requires ATC to be overlyconservative and queue aircraft to cross the active runway as a group by building a gap between arriving and departing aircraft. This causes delays, sometimes in excess of 20 minutes, for taxiing aircraft and makes inefficient use of runways.

Evidence was provided to suggest that both controllers and pilots already attempt to improve the efficiency of surface operations by approximating coordinated runway crossings as time and workload levels permit. They accomplish this in a number of ways such as issuing an expedited crossing clearance, or by issuing or requesting a taxi route that is longer in distance but circumvents the need to hold short of an active runway. However, it was noted that the pilots and controllers lack the information and tools to do this consistently, and are unable to do this under high traffic loads, when it is most needed.

It is proposed that the concept of coordinated runway crossings, if accompanied by supporting procedures, automation, and display technology, could potentially increase the efficiency of airport surface operations by reducing hold delays and improving runway usage. Pilots indicated that the proposed coordinated runway-crossing system could be valuable to handle the traffic congestion problem, particularly if traffic flow increases as is predicted over the next several years. As one pilot remarked:

> "… with plans to reduce vertical separation, and with more airlines moving to smaller aircraft, there will be a big crunch on the airport surface. Smart movement of aircraft on the ground will be critical."

Several pilots highlighted the potential value of the system to help standardize taxi speed and conformance. Many noted that ATC currently must manage a great amount of uncertainty with some pilots responding quickly and others slower to comply. This uncertainty requires larger separation between aircraft. Pilots suggested that the separation could be reduced, and still be safe, with a coordinated runway crossing system and displays which increase pilot-ATC shared awareness and integrate traffic and runway information. These displays could improve awareness of runway traffic, lessen opportunities for mistakes and runway incursions, and could help pilots cross-check ATC clearances.

However, despite the general approval of the pilots involved in these interviews, a large hurdle that must be overcome before the development of a coordinated runway crossing system is to ensure user acceptance on a wide scale. Not surprisingly, some pilots felt that dictating taxi speed could be perceived negatively by pilots and could be met with resistance. It is important that the system demonstrates the value or benefit to the pilot and provides a clear rationale for the speed requirements (i.e., taxi 20 kts to cross in front of landing aircraft or hold for 10 minutes).

For this concept to be successful, a human-centered approach will be required that involves participation from pilots, ground controllers, local controllers, ramp controllers, and airlines. The pilot interviews reported in this paper represent the first discussions of the coordinated runway crossing concepts with subject matter experts. Similar discussions with other stakeholders in surface operations are planned, as are human-in-the-loop simulations to assess pilot conformance to speed- and time-based clearances.

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Acknowledgement

This research was funded by NASA's Airspace Operations Systems/HMP/HADMT and Virtual Airspace Modeling and Simulation programs, and supported by Dr. David Foyle of NASA Ames Research Center's Human-Centered Systems Laboratory.