Application of Risk Management Principles to Assess Unmanned Aerial Vehicle (UAV) Routing Options and Other Hazards for Commercial Delivery in Urban Areas

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Abstract

The FAA currently restricts the operation of small Unmanned Aerial Vehicles (sUAVs) by requiring the UAV (drone) pilot to maintain visual contact with the UAV, that is, restricting operations to line-of-sight control. This limits the operation of UAVs to a very short distance, which is not conducive to commercial deliveries, especially in an urban setting with numerous tall buildings. However, some commercial operators have already demonstrated completely autonomous UAV operations, although in rural settings. This paper proposes the application of risk management techniques to assess the feasibility and safety of progressing to an interim phase of semi-autonomous UAV operations in an urban setting, which could serve as a blueprint for progressing towards commercial package deliveries. The author identified two major problems preventing the approval of UAV operations beyond line-of-sight: the hazard to personnel on the ground if a UAV goes down, and the related concern of controlling UAV traffic to avoid inflight collisions as the numbers of UAVs increase. The purpose of this study is to explore the feasibility of replacing line-of-sight control with semi-autonomous UAV procedures based on a two-camera system for see-and-avoid, along with a continuous communications system for the monitoring, control, and recording of UAV operations.

The method proposed by this paper is to first identify the ten most significant hazards associated with semi-autonomous UAV operations in an urban setting. This will be followed by assessing the risk posed by each of these hazards, using a federal government risk assessment matrix. Finally, risk management strategies will be proposed to control and mitigate these risks. The ten hazards, along with their risk assessment and proposed risk mitigation strategies, will then serve as ten propositions or questions in a qualitative survey. Purposive sampling will be used to identify ten participants, drawn from a population of pilots trained in UAV operations. The survey will be administered to these participants, asking them to evaluate the proposed risk mitigation strategies. Some of the main topics included in the study are route planning, altitude control, and separation of UAVs in flight. The study will assess the use of established urban roadways as the main routing structure, where UAVs are visualized as flying cars above an already organized flow of traffic, the exposure of risk to pedestrians is minimized, obstacles such as buildings are avoided, and vehicle enclosures serve to protect the occupants of motor vehicles. The study will also address the use of altitude control both to separate UAV traffic in opposite directions (and at intersection turns), and to overfly overpasses and wires. Control and self-separation of UAVs may initially be accomplished with an open registry on a server, accessible by all users and government officials, where operators input proposed flight plan routes. A route is activated for each airborne UAV. UAV use of computerized speed control and GPS for lateral control is so precise, that users may generate an accurate moving target display of all UAVs on a monitor based solely on the flight plan. Two educational benefits of this study are a demonstration of risk management techniques in the solution of a real-world problem, and the importance of addressing operational considerations in the design and manufacture of devices such as UAVs.

The results of this study indicate that overall, the estimates of likelihood, severity, and level of risk assessed by the participants closely matched predictions, and that these proposed safety procedures should reduce the overall risk of commercial drone operations in urban areas.

Keywords-Unmanned Aerial Vehicle (UAV); Notice to Airman (NOTAM); Risk Management; Human-Computer Interaction (HCI); Federal Aviation Administration (FAA): Time-Based Management (TBM); Vertical Takeoff and Landing (VTOL)

Introduction

In recent years there has been much interest in using small Unmanned Aerial Vehicles (sUAVs) for commercial delivery of packages. However, current FAA rules limit the radius of operations by requiring the UAV operator to keep the UAV in sight. Although some commercial operators have already demonstrated completely autonomous UAV operations, in rural settings, this may represent too much of a jump in the operational use of technology in urban areas without first proving their safety and reliability. This paper proposes a gradual, controlled evolution of UAV operations beyond line-of-sight by applying risk management principles, to assess proposed risk mitigation procedures that are designed to provide an equivalent level of safety. One of the benefits of assessing the feasibility and safety of UAV operations in interim, semi-autonomous phases is that a plan can be developed to serve as a blueprint for progressively integrating UAV commercial deliveries in urban areas. This paper addresses the commercial delivery of packages in urban areas with high-rise buildings, congested streets, and an increasing density of UAVs in the airspace, which presents a more demanding area of operations.

The author identified two major problems preventing the approval of UAV operations beyond line-of-sight: the hazard to personnel on the ground if a UAV goes down, and the related concern of surveilling and controlling UAV traffic to avoid inflight collisions as the numbers of UAVs increase. The purpose of this study is first, to explore the feasibility of replacing line-of-sight control with a two-camera system for see-and-avoid using a continuous communications system and second, the use of a central registry allowing the display of all active UAV flights for surveillance.

The ten hazards addressed in this paper are related to two overriding concerns: reducing the risk to personnel on the ground if a UAV goes down, and reducing the risk of inflight UAV collisions as the numbers of UAVs increase. Some of the risk mitigation strategies proposed include a routing system that overflies existing roadways like a flying car; a two-camera system for visual navigation and collision avoidance; a cell phone communications system for the continuous monitoring, control, and recording of UAV operations; a two-level altitude separation system for UAVs flying in opposite direction; and a low-cost surveillance system based on UAVs complying precisely with their GPS-based flight plans. This study sought to determine whether the use of commercial UAVs in urban areas can expand safely in controlled, progressive stages. It is predicted that this progressive approach using semi-autonomous UAV operations with continuous monitoring and control will indicate that the commercial use of UAVs in urban areas is viable with an acceptable level of safety. Some of the main topics included in the study are route planning, altitude control, separation of UAVs in flight, and safely controlling the descent rate if a UAV goes down.

The method proposed by this paper is to first identify ten of the most significant hazards that are associated with semi-autonomous small UAV commercial operations in an urban setting. This will be followed by propositions for risk mitigation strategies to control and reduce the risk posed by each hazard. It is assumed that without measures to reduce the risk posed by the hazards, the overall risk will exceed a desirable level of safety. Therefore, propositions for risk mitigation strategies will be presented as the second step in the risk management process. Assessment of the risks posed by the hazards will then be withheld until after the risk mitigation strategies are proposed and assumed to be in effect. Assessing the risk posed by each of these hazards will be accomplished with a simple federal government risk assessment matrix (Fig. 1). A complex federal government risk assessment matrix is also included for comparison (Fig. 2). An initial assessment of the risks was completed in a pilot study. Finally, the ten hazards, the proposed risk mitigation strategies, and the initial risk assessments will then serve as ten propositions or questions in a qualitative survey. Purposive sampling will be used to identify ten participants, drawn from a population of UAV Part 107-trained pilots. The survey will be administered to these participants, asking them to evaluate the hazards, the proposed risk mitigation strategies, and the initial risk assessments, followed by their own risk assessments and recommendations for revisions to the strategies.

Background

1. Definitions

Small Unmanned Aerial Vehicle (sUAV): an unmanned aerial vehicle weighing less than 55 pounds and governed by FAR Part 107 [1].

Notices to Airman (NOTAMs): notifications issued to pilots before a flight, advising them of conditions that may affect the conduct of the flight [10].

Risk Management (RM): a formalized method for dealing with hazards that affect a certain environment, providing for the identification of hazards, assessing the risk posed by the presence of the hazards, and strategies to eliminate or mitigate the risk posed by the hazards [8].

Human-Computer Interaction (HCI): A multidisciplinary field of study focusing on the design of computer interaction devices and the process of interaction between humans and computers [11].

Federal Aviation Administration (FAA): The governmental agency of the United States that regulates all aspects of civil aviation and the surrounding international waters.

Time-Based Management (TBM): An FAA Nextgen time-based scheduling tool that controls aircraft to arrive at specific fixes at specific times, allowing air traffic controllers to manage aircraft in congested airspace with a more efficient and consistent flow of traffic [12].

Vertical Takeoff and Landing (VTOL): a preferred flight capability for congested areas that allows hovering, vertical descent, and vertical ascent at a landing site.

2. Current State of Authorized Small UAV Operations

The focus of this study is on the rules governing the use of small Unmanned Aerial Vehicles (UAVs), which are addressed in FAA Part 107 [1]. Small unmanned aerial vehicle means a UAV weighing less than 55 pounds on takeoff, including any cargo or other expendable items attached to the aircraft [1]. However, this study intends to apply risk management principles to assess whether commercial use of small UAVs can be allowed in urban areas with an acceptable level of safety, in which case certification would proceed in accordance with FAA Part 135 [2]. Currently, one of the biggest restrictions to UAVs is the requirement for the operator or observer to remain within unaided visual line of sight (VLOS) of the UAV [1], which would negate the viability of commercial operations. Part 107 also requires small UAVs to remain at or below 87 knots (100 mph) and at or below 400 feet above the ground [1], which will not impact this study.

For addressing surveillance of UAVs, the FAA established the Unmanned Aircraft System (UAS) Traffic Management (UTM) Pilot Program (UPP) in April, 2017, under the FAA Extension, Safety and Security Act of 2016 [3]. The intent of this UTM program is to identify the initial set of industry and FAA capabilities for surveillance of UAVs. This is a huge program, with established test sites, that will take some time to realize operational capabilities. One of the proposals of this paper is to establish an inexpensive, near-term surveillance system, based on the inherent precision in the NextGen system design.

For addressing flight over personnel, the FAA has released a Notice of Proposed Rulemaking (NPRM) [4] that would allow the operation of small UAVs over people under certain conditions, based on three categories of operation. This NPRM would result in changes to FAA Part 107. The FAA has also released an Advance Notice of Proposed Rulemaking (ANPRM), announcing its intention to finalize guidance concerning the remote identification of small UAVs prior to finalizing the rule on the operation of small UAVs over people [5]. One of the proposals of this paper is to establish a method for controlling the rate of descent if a UAV goes down, which fits within the guidelines of these proposed rules. The FAA has also published AC 107-2 [6], which provides guidance for complying with FAR Part 107, including the certification of small UAV remote pilots and small UAV operational restrictions.

There are currently a limited number of commercial delivery drone services operating under the FAA’s UAS Integration Pilot Program [7]. These include medical package delivery by UPS in Wakefield County, North Carolina, and residential package delivery by Wing (associated with Google) in Christiansburg, Virginia.

3. Principles of Risk Assessment and Management

Risk management is based on the premise of comparing risks and benefits, that is, are the benefits worth the risk. The risk management process involves three steps: identification of significant hazards, assessment of the risk posed by these hazards, and management of the risk to control or mitigate the outcome if an event associated with the hazard occurs [8]. The application of these three steps should be accomplished by personnel familiar with the equipment and operating environment under study. This study begins with the identification of ten significant hazards faced by UAVs involved with commercial delivery of packages in urban areas. The FAA defines a hazard as a condition that could lead to, or contribute to, an unplanned or undesired event [8]. The process continues with the assessment of the risk posed by these hazards, if an undesirable event associated with the hazard occurs. Risk assessment involves the quantification of risk by combining two attributes for each hazard: estimates of the likelihood of an event occurring and the severity of the outcome if the event occurs, as in Fig. 1.

The FAA publishes four guidelines for assessing likelihood. Probable means that an event will occur several times. Occasional means that an event will probably occur sometime. Remote means an event is unlikely to occur, but is possible. Improbable means an event is highly unlikely to occur. The FAA also publishes four guidelines for assessing severity. Catastrophic means that an event results in fatalities and/or total loss of property. Critical means that an event results in severe injury and/or major damage. Marginal results in minor injury and/or minor damage. Negligible results in less than minor injury and/or less than minor damage. With an assessment of the risk posed by each hazard complete, risk management involves the introduction of strategies or procedures to control or mitigate the risk posed by these hazards. Risk management then becomes a cyclical process in which the effectiveness of risk mitigation procedures is re-assessed by applying the matrix again. The application of the three risk management steps for this study are amplified in the following paragraphs, with one exception. It is assumed that the current risk of UAV operations in urban areas is unacceptable without mitigation strategies. Therefore, after identifying the hazards associated with these operations, the second step will present risk mitigation procedures, followed by the assessment of risk after the safety procedures are assumed to be in effect. This is the same procedure used in the survey, where participants trained in UAV operations are asked to assess the risk after assuming that the risk mitigation procedures are in effect.

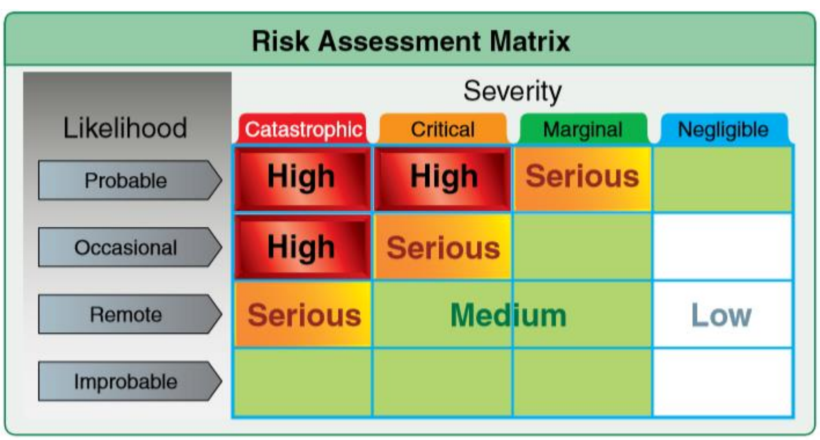

Figure 1. Simple FAA sample risk assessment matrix (FAA-H-8083-2)

Risk Likelihood		Risk Severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Figure 2. Complex FAA sample risk assessment matrix (AC 107-2)

Methods

1. Hazard Identification

Adopting a principle of gradual evolution, several operating conditions have been identified as being more demanding and should be deferred for future evolutionary stages. Some of these deferred operating conditions include night flying, flight in low visibility, and heavy-weight package delivery. Considered high-risk conditions, the current risk mitigation strategy for these conditions may be considered to be elimination of the risk by the avoidance of these conditions. After reviewing potential operating conditions in urban areas, ten hazards of UAV operations have been identified as the most significant, and are listed below.

- Route planning must consider the danger that UAVs pose to personnel and property on the ground, in the event that a UAV goes down.
- The possibility of inflight collisions is an additional hazard with UAV operations, which is addressed with altitude separation for opposite direction UAVs.
- As the number of UAVs increase, the surveillance and separation of UAVs must be addressed with procedures for lateral and longitudinal separation, and a capability for monitoring UAVs in motion.
- Extending operations beyond line of site represents an increased hazard unless continuous control is maintained, supplemented with a two-camera system for see-and-avoid capability.
- The possibility of UAV engine or systems failures is a hazard that requires advance planning and procedures, including a capability for controlling the descent if a UAV goes down.
- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations.
- The delivery area requires a safe and secure landing and takeoff site.
- The potential for accidents requires an ability to review flight parameters and camera video leading up to the time of the event.

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV systems reliability.
- Unforeseen hazards, usually temporary restrictions to operations, may pop-up at any time and must be monitored and avoided.

2. Risk Management and Mitigation

Propositions to mitigate risks for the ten hazards are now discussed.

- Route planning. Although direct flights over sparsely populated areas (fields, railroad lines, transmission lines, waterways) are optimal for UAV operators, this is usually not an option in urban areas with high-rise buildings and overpasses. This study proposes the use of established urban roadways as the main routing structure, where UAVs are visualized as flying cars above an already organized flow of traffic, the exposure of risk to pedestrians is minimized, obstacles such as buildings are avoided, and vehicle enclosures serve to protect the occupants. This system also allows the use of automotive GPS navigation apps to reach all street addresses.

- Collision avoidance between UAVs. It is proposed that UAVs overflying roadways follow the flow of traffic, which means bearing to the right of a roadway. It is further proposed that UAVs utilize a two-level altitude separation structure, where UAVs proceeding in opposite directions are separated by 100 feet, and maintain this fixed altitude until completing any turn at an intersection. Fixed altitudes will also provide for the safe overflight of any overpasses and wires. Opposite-direction altitudes could be governed by several schemes. One scheme could be based on the labeling of our interstate highways, which continuously change direction, but have an overall east-west or north-south direction. If the overall direction is east-west they have even-number labels, while overall north-south directions have odd labels. Labeling all roadways in a similar manner, the FAA hemispheric rule could be used to determine assigned altitudes: overall north and east directions use odd altitudes (300 feet), while overall south and west directions use even altitudes (200 feet). A second scheme could be based on a single municipal reference point, placed northeast of and outside of the city limits, with north-south and east-west imaginary lines emanating from the point. Using the hemispheric rule, if a flight direction is (overall) towards the reference lines (north and east) use an odd altitude (300 feet), while a direction (overall) away from the reference lines (south and west) uses an even altitude (200 feet). A third scheme for separating opposite direction traffic could involve labeling all roads as one-way paths (similar to New York’s one-way street system). A fourth scheme could be assigning opposite-direction altitudes to all roads individually, even with changing altitudes along the road (like changing speed limits), easily accomplished with automotive GPS-based navigation databases.

- Surveillance and longitudinal separation of congested UAV traffic. Control and self-separation of UAVs may initially be accomplished with an open registry on a server, accessible by all users and government officials, where operators input proposed flight plan routes. A route is activated for each airborne UAV. UAV use of computerized speed control for time-based management (TBM) [12], and GPS for lateral control, is so precise that users may generate an accurate moving target display of all UAVs based solely on the flight plan. these moving target display devices may be designed by using the principles of Human-

Computer Interaction (HCI) [11]. It is proposed that each operator utilize a team of dispatchers to activate, monitor, and deactivate all UAV flights.

- Extending operations beyond line of site represents an increased hazard unless a see-and-avoid capability from onboard the UAV is maintained. Adopting a principle of gradual and controlled evolution, it is proposed that UAVs utilize a two-camera visual navigation system (one downward looking and one forward looking). This also requires a continuous communications and control system for accessing the cameras and flight parameters. This may be accomplished with a cell phone system which is designed for seamless contact with vehicles in motion.

- The possibility of UAV engine or systems failures is a hazard that requires advance planning. Failures causing UAVs to come down should have provisions to control descent rate in order to minimize impact damage with personnel or property below. Engine failure could include a backup engine or, for quadcopters, the drag of wind-milling rotors that slow the vertical descent rate. If the UAV cannot continue flight, its descent rate must be slowed, such as with a small, light-weight parachute that deploys when exceeding a specified descent rate. An alarm that activates in these situations would alert personnel on the ground below. Loss of UAV cameras and/or communications may be handled with autonomous guidance systems that have already been proven by some UAV manufacturers. These systems could guide the UAV to a landing, a return to the takeoff point, or continuation to destination where the flight will be terminated. Provisions should include ground retrieval capability with company or contract vehicle pickup.

- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations. Using the principle of gradual and controlled evolution, it is proposed that the first stage of UAV operation be limited to daylight conditions with 3 or more miles of inflight visibility, wind speed 10 mph or less, and no inflight icing conditions. Operating weight and speed should also be restricted during initial phases of evolution.

- The delivery area requires a safe and secure landing and takeoff site, with required dimensions established by the manufacturer. It is proposed that each building (residence, apartment, business) have a secure area allowing for vertical landing and takeoff, with a receiver on hand for each delivery. It is assumed that a customer order constitutes authorization by the building owner for use of the airspace above the landing area.

- The potential for accidents requires an ability to review flight parameters and camera video leading up to the time of the event. Rather than weigh down the UAV with a heavy recording system, it is proposed that streaming video and flight parameters over the communications link be used to record the flight data at a remote recording site.

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV operational reliability. It is proposed that a history of vehicle system failure rates be maintained with appropriate information categories such as UAV model, number of flights, system failures, operating conditions, time in service, etc.

- Unforeseen hazards, usually temporary restrictions to operations, may pop-up at any time. It is proposed that an operator's team of dispatchers also monitor any temporary conditions that may affect flights, such as parades, and post them in a central repository for viewing by all operators. This is similar to the NOTAM system [10] used for aircraft operations.

The above propositions to mitigate risk will now be assessed using the simple FAA risk assessment matrix (Fig. 1).

3. Risk Assessment

Risks are assessed after application of proposed mitigation procedures, using the FAA's simple matrix (Fig. 1), with estimates for likelihood and severity. Risk mitigation strategies for all hazards are assumed to be combined, when considering the overall risk for a specific hazard.

- Route planning in congested areas to minimize risk to personnel and property on the ground.

  Strategy: overflying existing roadways like a flying car allows the use of automotive GPS navigation apps to reach all street addresses, while avoiding buildings and minimizing risk to pedestrians and vehicle-enclosed occupants below.

  Estimated Likelihood: occasional (when combined with failure backup strategies)

  Estimated Severity: marginal (when combined with strategies to control descent rates)

  Predicted Risk: medium

- Collision avoidance by vertical separation of congested UAV traffic.

  Strategy: follow the organized flow of roadway traffic (bearing to the right) while utilizing a two-level altitude structure to separate UAVs traveling in opposite directions by 100 feet (and where turns at intersections are completed before changing altitudes).

  Estimated Likelihood: remote (when combined with both UAV surveillance and camera-communications strategies)

  Estimated Severity: critical (less when combined with strategies to control descent rates)

  Predicted Risk: medium

- Collision avoidance by horizontal separation and surveillance of congested UAV traffic.

  Strategy: the precision of GPS (lateral navigation) and computerized speed control (longitudinal TBM separation) allows for a moving display (surveillance) of all active UAV aircraft, based on activated flight plans published in an open registry.

  Estimated Likelihood: remote (when combined with both UAV collision avoidance altitudes and extended sight via camera-communications strategies)

  Estimated Severity: critical (less when combined with strategies to control descent rates)

  Predicted Risk: medium

- Maintaining control of UAVs while extending visual operations beyond line of sight.

Strategy: use of an extended-sight 2-camera system with continuous cell phone communications (for monitoring, control, and recording) to maintain see-and-avoid and visual navigation capability beyond line-of-sight.

Estimated Likelihood: occasional (when combined with failure backup strategies for autonomous operations, tracking of UAV reliability, and strategies to control descent rates).

Estimated Severity: marginal (when combined with failure backup strategies for autonomous operations and strategies to control descent rates).

Predicted Risk: medium

- The possibility of UAV engine or system failures is a hazard that requires advance planning.

  Strategy: use of UAVs with redundant capabilities for propulsion and other systems; provisions to control descent rate if a UAV goes down (to minimize impact with personnel or property below); reversion modes for autonomous navigation and flight control; a dispatcher team to monitor UAV performance and implement alternate procedures; and company or contract vehicles for UAV retrieval.

  Estimated Likelihood: occasional (when combined with the tracking of UAV reliability for preventive maintenance).

  Estimated Severity: marginal.

  Predicted Risk: medium

- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations.

  Strategy: defer operations in these conditions for future phases until experience is gained, while adopting now: UAV lights, heated surfaces, and limitations for weight and wind.

  Estimated Likelihood: remote (when adopting recommended limitations).

  Estimated Severity: marginal (when combined with strategies to control descent rates).

  Predicted Risk: medium

- The delivery area requires a safe and secure landing and takeoff site.

  Strategy: use of UAVs with VTOL capability at an enclosed or protected delivery area (dimensions established by UAV manufacturer), with building owner authorization and a human receiver on-site.

  Estimated Likelihood: remote (when combined with failure backup strategies).

  Estimated Severity: marginal (when combined with strategies to control descent rates).

  Predicted Risk: medium

- The potential for accidents requires an ability to review historical flight parameters and camera video leading up to the time of the event.

Strategy: use of the cell phone communications system to record UAV flight parameters and streaming video from the 2-camera system, in lieu of a heavier on-board recorder.

Estimated Likelihood (of not having a record): remote (when combined with failure backup strategies and the tracking of UAV reliability).

Estimated Severity (if not having a record): marginal (when combined with strategies to control descent rates).

Predicted Risk: medium

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV operational reliability.

  Strategy: maintain a record or history of individual and fleet UAV performance with appropriate information categories that include UAV model, number of flights, time in service, system failures and failure rates, operating conditions, etc., to follow standards for the preemptive removal from service or replacement of parts when planned service life is reached, in order to minimize inflight failures.

  Estimated Likelihood (of inflight failure): remote (when combined with failure backup strategies).

  Estimated Severity (if inflight failure): critical (when combined with strategies to control descent rates).

  Predicted Risk: medium

- Unforeseen hazards may pop-up at any time and temporarily affect or restrict operations.

  Strategy: The dispatch team monitors the news, weather, GPS notams, municipal information systems, etc. for parades, fires, and other events that may limit UAV operations.

  Estimated Likelihood (of encountering unanticipated events): remote.

  Estimated Severity (if encounter unanticipated events): marginal (when combined with collision avoidance by vertical separation).

  Predicted Risk: medium

Results and Discussion

Qualitative surveys were constructed in accordance with standard qualitative guidelines [9], and distributed to participants trained in the current rules of operation pertaining to Unmanned Aerial Vehicles (UAVs). There were 10 usable responses collected from these aviation professionals. All of the data was self-reported by the participants and provided voluntarily.

1. Predicted Estimates of Likelihood, Severity, and Risk

A pilot study was used to have aviation professionals provide initial estimates of likelihood, severity, and risk, for the paired hazard and mitigation propositions. The individual values for these risk assessment estimates are detailed in Table 1

Table 1. Predicted estimates of likelihood, severity, and risk after adopting mitigation strategies.

Hazard & Proposition numeric label	Likelihood	Severity	Risk
1 (path)	occasional	marginal	medium
2 (altitude)	remote	critical	medium
3 (surveillance)	remote	critical	medium
4 (cameras)	occasional	marginal	medium
5 (descent rate)	occasional	marginal	medium
6 (environment)	remote	marginal	medium
7 (landing site)	remote	marginal	medium
8 (records)	remote	marginal	medium
9 (UAV reliability)	remote	critical	medium
10 (pop-up hazards)	remote	marginal	medium

The overall estimates of the respondents to the pilot survey indicate that the overall risk can be reduced to an acceptable level (medium). These estimates assumed that the entire set of safety propositions (risk mitigation strategies) are combined, providing a coherent operational environment for UAVs that allows the safe commercial delivery of packages in urban areas.

2. Participant Estimates of Likelihood, Severity, and Risk

The survey was administered to participants who had completed training in small UAV operational requirements. The individual values for the participant responses regarding their estimates of the likelihood of a problem developing, for each paired hazard and safety proposition, are detailed in Table 2. In this study, the estimates of likelihood were found to have no major difference among the participants. When compared to the predicted values of likelihood estimates, the results closely matched expectations.

Table 2. 10 Participant estimates of likelihood after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem
2	Occ	Rem	Rem	Rem	Rem	Rem	Im	Im	Rem	Occ
3	Occ	Occ	Rem	Occ	Occ	Rem	Occ	Rem	Rem	Occ
4	Occ	Rem	Rem	Occ	Occ	Occ	Occ	Rem	Rem	Occ
5	Rem	Rem	Rem	Rem	Rem	Rem	Occ	Rem	Rem	Rem
6	Rem	Occ	Rem	Occ	Rem	Occ	Rem	Im	Im	Rem
7	Rem	Rem	Occ	Rem	Rem	Rem	Rem	Rem	Im	Occ
8	Occ	Occ	Occ	Occ	Occ	Rem	Rem	Rem	Rem	Rem
9	Rem	Rem	Rem	Occ	Rem	Occ	Rem	Im	Im	Rem
10	Rem	Rem	Occ	Rem	Rem	Rem	Rem	Rem	Rem	Rem

The individual values for the participant responses regarding their estimates of the severity of a problem if it developed, for each paired hazard and safety proposition, are detailed in Table 3.

The estimates of severity were found to have a little more variation among participants than participant estimates of likelihood. However, there was still no major difference among the participants. When compared to the predicted values of severity estimates, the results matched expectations, but not as closely as the estimates for likelihood.

Table 3. 10 Participant estimates of severity after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Mar	Crit	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Mar
2	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar	Mar
3	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar
4	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar
5	Crit	Crit	Crit	Mar	Mar	Neg	Neg	Mar	Mar	Mar
6	Crit	Crit	Mar	Mar	Mar	Mar	Crit	Neg	Neg	Crit
7	Crit	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg
8	Mar	Mar	Mar	Mar	Mar	Neg	Mar	Neg	Neg	Mar
9	Crit	Crit	Crit	Mar	Crit	Mar	Mar	Neg	Neg	Neg
10	Crit	Crit	Mar	Crit	Crit	Neg	Mar	Mar	Mar	Mar

The individual values for participant responses regarding the final, overall risk are not estimates, but are determined by entering the risk assessment matrix with the estimates of likelihood and severity for each paired hazard and safety proposition. These results are detailed in Table 4. These determinations of risk were found to have a small variation among participants, however, there was still no major difference among the participants. When compared to the predicted values of risk, the results matched expectations. Assuming that a risk value of medium represents an acceptable level of risk, the participant assessments closely match the predictions of medium risk if the ten risk mitigation strategies are combined and adopted.

Table 4. 10 Participant estimates of risk after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Med	Med	Med	Med	Med	Med	Med	Med	Med	Med
2	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med
3	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
4	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
5	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med
6	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
7	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low
8	Med	Med	Med	Med	Med	Low	Med	Low	Low	Med
9	Med	Med	Med	Med	Med	Med	Med	Low	Low	Low
10	Med	Med	Med	Med	Med	Low	Med	Med	Med	Med

The overall consensus of the individual respondents to the survey, all of whom are trained in current UAV operations, is that the overall risk can be reduced to an acceptable level (medium). This occurs when the entire collection of safety propositions (risk mitigation strategies) are combined into a coherent system of procedures, so that UAV operations for the commercial delivery of packages in urban areas may be conducted safely.

Conclusions

The study presented in this paper examined ten hazards associated with the use of UAVs for the commercial delivery of packages in urban areas. Several strategies and procedures, designed to reduce the risk associated with these hazards, were then presented. A risk assessment, using an FAA matrix designed to assist with risk management, was then used to estimate the effectiveness of the risk mitigation procedures. This involved a pilot study to estimate the likelihood of a problem occurring, the severity of a problem if it occurred, and the net risk involved if the problem occurred. It was predicted that the risk involved with these hazards would be reduced to an acceptable level (medium), after the safety procedures were incorporated. Qualitative surveys were then distributed to ten stakeholders, personnel who are knowledgeable in UAV operations, soliciting their evaluation of the effectiveness of the risk mitigation strategies. This was accomplished by having the participants estimate the likelihood, severity, and overall risk with commercial drone operations, if the safety procedures were adopted. The survey also solicited open-ended comments and recommendations from participants that would further improve the safety of commercial drone operations in urban areas. The results of this study indicate that overall, the estimates of likelihood, severity, and level of risk assessed by the participants closely matched predictions, and that these proposed safety procedures should reduce the overall risk of commercial drone operations in urban areas. One educational benefit of this study is a demonstration of the application of risk management procedures in the design and development of a new vehicle. Another educational benefit of this study is that the importance of testing in an actual operational environment should be apparent. That is, although completely autonomous UAV capability has been demonstrated, regulating authorities will likely require additional functionality to allow for a more gradual integration of new vehicles into an existing environment.

Recommendations for Further Research

One recommendation for further study is to have commercial drone operators demonstrate limited proving runs in an urban setting, that include an evaluation of route following accuracy, and the demonstration of emergency landing procedures. This is similar to airline proving runs required for the addition of a new aircraft to their fleet. Another recommendation for further study is the setup and testing of an open server that accepts and stores UAV flight plans, allowing the associated display of UAV traffic in motion, to evaluate its effectiveness as a surveillance system based on NextGen precision.

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