SAFETY RISK ASSESSMENT FOR UAV OPERATION

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Safety Hazard Identification, Safety Risk Assessment, Safety Risk Mitigation
Safety Risk Documentation + Case Study

Drone Industry Insights | Safe Airspace Integration Project, Part One | Nov. 2015

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Rev. 1.1 Nov 2015

Content

Executive Summary

The drone flight safety is the desired optimum state in which drone operations executed in certain circumstances can be controlled with an acceptable operational risk.
By performing a safety risk assessment, commercial industry could help in advance to identify drone operation safety hazards.
The UAS safety risk assessment, based on a systematic approach from safety hazard identification to risk management, ensures the maintenance of the required safety standards for drone operations.
Drone Industry Insights presents a four-phase model of a UAS safety risk assessment. This approach is an appropriate solution, which fits according to the effort and usability, in everybody's organization.
This model, which should be used for drone flight permission and insurance applications, is the fundamental frame for a safe and reliable organization set up.
Not only the results but also the whole UAS safety risk assessment process should be documented to ensure a continuous safety assurance.

Risk assessment definition

The UAS safety risk assessment is an instrument used to identify and assess active and latent safety hazards for drone operation. This safety risk assessment includes actions for mitigating the predicted probability and severity of the consequences or outcomes of each operational risk.

An UAS safety risk assessment makes safety risks measurable so that risks can be better controlled.

Phases of UAS safety risk assessment

We recommends to separate the UAS safety risk assessment into the following four phases.

Figure 1: UAV safety risk assessment phases

The European Aviation Safety Agency (EASA) will require a documented safety risk assessment performed by the operator and a manual of operations, which lists the risk mitigation measures for all unmanned drones with 'specific' operation purposes (as per EASA A-NPA 2015-10).

The Federal Aviation Authority (FAA) requires a preflight assessment including risk mitigation actions so that small unmanned aircraft will pose no undue hazard to other aircraft, people, or property in the event of a loss of control or other safety hazards (as per FAA NPRM RIN 2120–AJ60).

Part I – Safety Hazard Identification:

Occurrences such as near misses or latent conditions, which led or could have led to drone operational flight safety harm, will be identified.

Part II – Safety Risk Assessment:

All identified hazards will be assessed, according to the operational risks severity and operational risk probability.

Part III – Safety Risk Mitigation:

According to the operational risk acceptance level, risk mitigation action will be defined.

Part IV – Safety Documentation:

Not only the results but also the whole UAS safety risk assessment process should be documented to ensure a continuous safety assurance.

Part I - Safety Hazard Identification

Definition of safety hazards

With the first phase of the UAS safety risk assessment, we shall collect and identify operational drone safety hazards separated into "active failures" and "latent conditions", both of which occur or might occur during the flight operations.

Active failures are actions – including errors and violations – that have an immediate effect. Generally, they are viewed as unsafe acts. Active failures are generally associated with front-line personnel (pilots, air traffic controllers, engineers, and so on).

Latent conditions are those that exist in the UAV system well before a damaging outcome is experienced. Initially, these latent conditions are not perceived as harmful, but could become evident once the system defenses are breached People removed in time and space from the event generally create these conditions.

List of UAV safety hazards:
(10 examples)

- High loss of altitude
- Loss of control
- Loss of transmission
- Collision with manned, unmanned aircraft or buildings, power lines
- Partial failure or loss of navigation systems
- Severe weather or climatic events
- Existence of corrosion
- Pilot unfamiliar with area
- Rotor failures
- Take-off and landing incidents as under-shooting or overrunning

Safety hazards identification methodologies

Reactive: This methodology involves analysis of past outcomes or events. Hazards are identified through investigation of safety occurrences. Incidents and accidents are clear indicators of system deficiencies; therefore, they can be used to determine the hazards that contributed either to the event or to the latent.

Proactive: This methodology involves an analysis of existing or real-time situations during drone operation

Predictive: This methodology involving data gathering is used to identify possible negative future outcomes or events during drone operation, analyzing system processes and the environment, to identify potential future hazards, and to initiate mitigating actions (e.g. FMEA).

Examples of safety hazard identification sources

Following methods can be used to identify safety hazards:

- Flight Operations Data Analysis (FODA)
- Flight Reports
- Maintenance Reports
- Safety (& Quality) Audits / Assessments
- Voluntary reporting of Incident/accidents/near misses
- Mandatory accident reporting to the competent authority
- Brainstorm acc. to Failure Mode Effects Analysis (FMEA)
- Surveys

The identified safety hazards must be run through a root-cause analysis to identify the safety hazards causes and their potential consequences. The potential outcome shall be assessed according to their risks in the next phase, the UAS safety risk assessment.

> A safety risk assessment is the fundament of safe drone operation and an instrument for continuous improvement.

Part II – Safety Risk Assessment

The second phase, the UAS risk assessment, measures the projected probability and severity of the consequences of the identified safety hazards of drone operation. This phase presents the fundamentals of safety risk management.

What is a risk?

Generally, a hazard has the same condition, which will be transformed into a risk when an action is exposed. The risk is the only parameter that can influence the condition of the hazard. A risk is the futuristic impact of a hazard.

Figure 2: risk exposure

Safety risk probability

The safety risk probability is defined as the likelihood or frequency that the consequence of safety hazard might occur.
All scenarios should be taken into consideration. The probability must be categorized into criteria such as numbers. These numbers should be assigned to each probability level. The following figure displays a common used five level probability table. It is possible to extend the safety risk probability to 6, 10, or 15 values.

Likelihood	Detail ("customized example")	Value
Frequently	Likely to occur many times or has occurred frequently ("five times during operation")	5
Occasional	Likely to occur sometimes or has occurred infrequently ("Every second operation")	4
Remote	Unlikely to occur, but possible or has occurred rarely ("I know it from some events")	3
Improbable	Very unlikely to occur or not known to have occurred ("it happened once and I heard about it from other operator")	2
Extremely improbable	Almost inconceivable that the event will occur ("never happend")	1

Figure 3: UAV safety risk probability

UAV safety risk severity

The safety risk severity is defined as the extent of harm that might reasonably occur as an outcome of the identified safety hazard. The severity assessment can be based on injuries (persons) and/or damages (Drones and buildings, power lines, or the cost dimension).

- The worst foreseeable situation should be taken into account.
- The severity must be categorized in quantifiable criteria such numbers.
- These numbers should be assigned to each probability level.

The following figure displays a typical five level severity table

Severity	Customized Detail	Value
Catastrophic	Death to people; Drone, equipment or buildings destroyed	E
Hazardous	Serious injury to persons; major equipment or buildings damage	D
Major	Injury to persons; Further operation not possible without major adjustments	C
Minor	Minor incident to persons; Minor effect on system performance	B
Negligible	No injury to persons; Minor consequences on system	A

Figure 4: UAV safety risk severity

Additionally risk assessors often use the "probability of detection" as a third dimension of the risk assessment (comparing to risk severity and probability). This dimension is commonly required in the product development, and it involves natural or technical safety barriers.

UAV safety risk acceptance

The third step in the UAV safety risk assessment process is to determine the safety risks that require actions.
The safety risk acceptance indicates the combined results of the safety risk probability and safety risk severity assessments. The respective assessment combination is presented in the safety risk assessment matrix shown in the following figures.

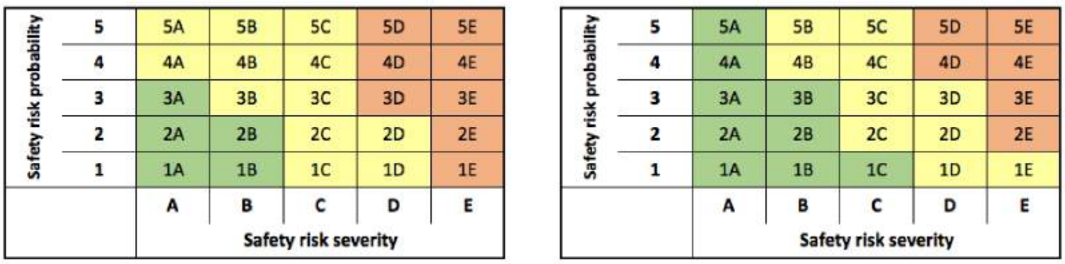

Figure 5: Customized UAV safety risk assessment matrices

This UAS safety risk matrix can be customized according to the UAS Company's business or safety policy.

The corrective and preventive actions should be recorded in a UAV safety risk map to enable the assignment of persons, which shall be responsible for actions, and due dates.

The combination of risk probability and severity indicates following:

- The safety risk acceptance level
  1. Red is not acceptable
  2. Yellow is tolerable but requires risk mitigation
  3. Green is an acceptable level
- The UAS safety risk index (SRI) can be used as an Indicator for statistical data acquisition and for a "before/after comparison" to measure the efficiency of a UAV safety risk management.

Then, the UAS safety risk matrix must be exported to a safety risk acceptance matrix to determine the required actions that will mitigate the unacceptable and tolerable safety risks to an acceptable status.

Part III - Safety Risk Mitigation

The UAV safety risk mitigation explains the approach to react to unacceptable or tolerable UAV safety risks. It is a systematic reduction of the risk severity and the probability of its occurrence.

Acceptance level	Assessed UAS safety risk index (SRI)	Recommended actions
Unacceptable	3D, 4D, 5D, 1E, 2E, 3E, 4E, 5E	Immediate mitigation action and escalation is required; An operation stop should be considered
Tolerable	4A, 5A, 3B 4B, 5B, 1C, 2C, 3C, 4C, 5C, 1D, 2D	The safety risk shall be mitigated as low as reasonable practicable and should be approved
Acceptable	3D, 4D, 5D, 1E, 2E, 3E, 4E, 5E	No actions required

Figure 6: UAV safety risk acceptance matrix

The UAV safety risk acceptance matrix provides information about the required actions for the strategies of risk mitigation:

- Unacceptable - the probability and/or severity of the consequence is intolerable. Major mitigation or redesign of the system is necessary to reduce the probability or the severity of the consequences of the safety hazard to an acceptable level.

- Tolerable level - the consequence and/or likelihood is of concern; measures to mitigate the risk to a reasonably low level should be sought for. This risk can be tolerated if the risk is understood and if it has an endorsement within the organization.
- Acceptable level - the consequence is very unlikely or not severe enough to be of concern. The risk is tolerable and the safety objective has been met. However, consideration should be given to reduce the risk further to a reasonably practical level.

UAV safety risk mitigation actions can be separated into two dimensions:

- Corrective actions - Actions with an immediate effect for the safety hazard
- Preventive actions - Actions that have a long-term effect on the safety hazard to mitigate the risk to an acceptable level.

DRONEII.COM **UAS operational safety risk map**

	Safety hazard identification					Safety risk assessment				Safety risk mitigation			
ID	Safety item or hazard	Element	Root cause	Worst consequence	Type of finding	Severity	Probability	RPN	Risk level	Corrective action (CA)	Preventive action (PA)	Responsible	Due date for PA
1	Lack of power	Technical	Baterry	Harm to people	Minor	Catastrophical	Remote	3B	Tolerable	Change battery	Review power system	Tom	13. Dez. 15
2	Under-shooting or overruning during take-off	Pilot/People	GPS	Harm to people	Major	Major	Occasional	5D	Unacceptable	Keep people way from take-off area	System calibration	Tom	19. Dez. 15
3	Camera failure	Technical	Transmitter	No stream	Negligible	Major	Remote	3A	Acceptable	-	Train pilot to stay in connection	Jane	-

Figure 7: UAV safety risk map

The UAV safety risk mitigation describes the last step of a UAV safety risk assessment. The question, if a continuous review of UAS safety risks and a safety performance increase is necessary, is obsolete. UAV safety risk documentation and documented risk management procedures are required and are described in the following paragraphs.

Part IV: Safety Documentation

Not only UAV risk mitigation exercises need to be documented, but also the ambition of continuous improvement and a transparent organization need a documented risk management process.
Additionally a safety risk database – which shall be used as an evidence for required pre-flight checks or as a basis for UAS operation manuals – should be established.
Recommendations:

- Set up an UAS safety risk database including safety hazards and mitigation actions
- Establish a risk monitoring procedure
- Establish voluntary and mandatory reporting systems
- Establish a safety culture

A risk management process example is displayed in the following figure:

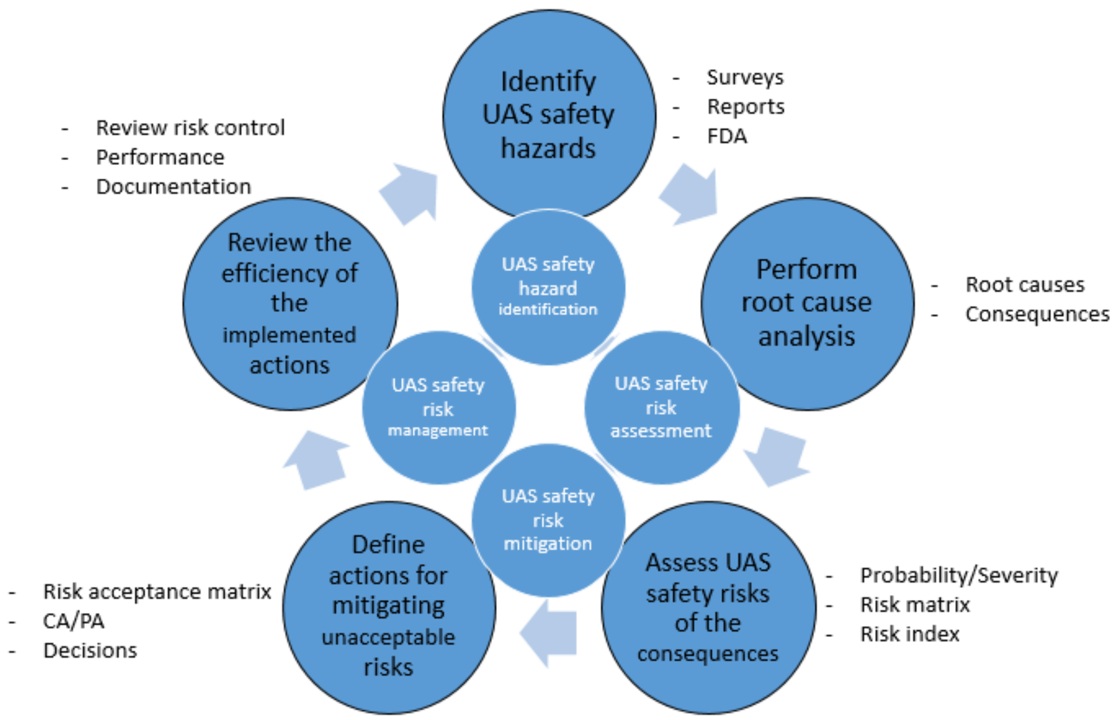

Figure 8 UAV safety risk management process

Case Study

Pilot Todd has the order to accompany a street cycle race with his 7kg quadcopter DII-11 to support a local television company with great action videos of the final kilometers.
The race route is crowded with people. He keeps the required distance of 5 meters between the vehicle and the crowd and the racers, according to the one-time flight permission requirements. Suddenly, during the flight operation, strong wind comes up and pushes the quad close to the power lines, which runs parallel to the race route.
Todd is an experienced pilot, so he can react accordingly and stabilize the quad so that an accident does not occur. He stops operation and lands the quad at a safe distance because an accident could prevent him from flying again in future.
This is a typical "near-miss" situation during flight operation. To ensure that this occurrence never recurs and/or an equivalent hazard never occurs, a UAS risk assessment should be performed using the four-phase-risk-model described above.

Part I: Safety hazard identification:

1. Todd reports this event to the nominated safety manager of his drone operation company. In this case, the hazard identification source is a flight or voluntary reporting. The hazard identification methodology has a reactive character.
2. The risk assessor starts the safety hazard identification with the root cause analysis. The following hazard documentation method can be used.

	Safety hazard identification								
ID	Safety item or hazard	Description	Date of event	Operational stage	Safety hazard category	Root cause ID	Root cause	Root cause category	consequences
1	Near miss of powerllines	During the The DII-11 operation the vehicle, caused by upcoming wind, had almost contact with a power line. The pilot who was in visual contact with the drone was able to avoid the contact by manoevring it out of the danger zone.	1.12.2015	Cruising	Active failure	1.1	The pilot was not familiar with the area	Human factors	Harm to people; Damage of drone; damage of infrastructure (high costs)
						1.2	Documented distance to power lines to close	Documen-tation	Harm to people; Damage of drone; damage of infrastructure (high costs)
						1.3	GPS stabilizer defect	Technical	Harm to people; Damage of drone; damage of infrastructure (high costs)

Figure 1: Safety hazard identification and root cause analysis

The risk assessor (and/or his team) noted one safety hazard (the event itself) and assigned three root causes. In addition, he categorized the root causes and listed the potential consequences of the hazard. He separated the consequences into three items, because different root causes have obviously different outcomes.

Part II: Safety risk assessment:

1.) The risk assessor and/or his team now assess the probability and severity of the potential consequences. The result should be discussed at least between two persons, because they will provide guidance for further actions. In conflict situation, always choose the worse:

				Safety risk assessment			
Root cause ID	Root cause	Root cause category	consequences	Probability	Severity	RPN	Risk level
1.1	The pilot was not familiar with the area	Human factors	Harm to people; Damage of drone; damage of infrastructure (high costs)	Improbable	Hazardous	**2D**	**Tolerable**
1.2	Documented distance to power lines to close	Documen-tation	Harm to people; Damage of drone; damage of infrastructure (high costs)	Occasional	Hazardous	**4D**	**Unacceptable**
1.3	GPS stabilizer defect	Technical	Harm to people; Damage of drone; damage of infrastructure (high costs)	Extremely Improbable	Hazardous	**1D**	**Tolerable**

Figure 2: UAS safety risk assessment

2.) See the result in the risk matrix of a risk sensible company:

Safety risk probability		A	B	C	D	E
	5	5A	5B	5C	5D	5E
	4	4A	4B	4C	4D 1.2	4E
	3	3A	3B	3C	3D	3E
	2	2A	2B	2C	2D 1.1	2E
	1	1A	1B	1C	1D 1.3	1E
		A	B	C	D	E
		Safety risk severity				

Figure 3: UAS risk matrix

Part III: Safety risk mitigation

1.) Then, the risk assessor must transfer the results to the risk acceptance matrix. The risk acceptance matrix has to be defined before proceeding with the assessment, and the management should approve it.

Acceptance level	Assessed UAS safety risk index (SRI)	Recommended actions
Unacceptable	3D, 4D, 5D, 1E, 2E, 3E, 4E, 5E	Immediate mitigation action and escalation is required; An operation stop should be considered
Tolerable	4A, 5A, 3B 4B, 5B, 1C, 2C, 3C, 4C, 5C, 1D, 2D	The safety risk shall be mitigated as low as reasonable practicable and should be approved
Acceptable	3D, 4D, 5D, 1E, 2E, 3E, 4E, 5E	No actions required

Figure 4: UAS Safety risk acceptance matrix

2.) The risk assessor defines following corrective and preventive actions:

				Safety risk mitigation			
Root cause ID	Root cause	RPN	Risk level	Corrective action (CA)	Resp	Preventive action (PA)	Resp
1.1	The pilot was not familiar with the area	2D	Tolerable	The responsible pilot shall be trained about the required pre-flight preparation procedure	Flight Trainer	A checklist for area fitness shall be included intot he flight preparation	Quality Engineer
1.2	Documented distance to power lines to close	4D	Unacceptable	All pilots shall be informed immediately that the distance is not docmuented correctly. Distance shall be extended by 2 meters	Chief-Pilot	Distance parameter shall be evaluated and adjusted accordingly	Flight engineer
1.3	GPS stabilizer defect	1D	Tolerable	GPS system shall be calibrated according to wind parameter...	Flight enginer	The efficiency of the pdated system shall be checked frequently; procedure update	Quality engineer

Figure 5: UAS risk mitigation actions

3.) Always assign a person or a role to the specific action to ensure a proper implementation.

Part IV: Safety risk documentation:

1.) The risk assessor assigns the appropriate date to the corrective and preventive actions to include a kind of quality gate to the risk assessment. This procedure is known as risk management. The risk management requires a documented risk assessment, a regular review of the assessed risks, and a check of the actions efficiency.

Safety risk mitigation				Documentation and Management				
Corrective action (CA)	Resp	Preventive action (PA)	Resp	Due date CA	Due date PA	Re-assessment due at	To be reported to the authority	To be included into the Management report
The responsible pilot shall be trained about the required pre-flight preparation procedure	Flight Trainer	A checklist for area fitness shall be included intot he flight preparation	Quality Engineer	15.12.2015	31.12.2015	N/A	Yes	Yes
All pilots shall be informed immediately that the distance is not docmuented correctly. Distance shall be extended by 2 meters	Chief-Pilot	Distance parameter shall be evaluated and adjusted accordingly	Flight engineer	2.12.2015	05.12.2015	10.12.2015		
GPS system shall be calibrated according to wind parameter...	Flight enginer	The efficiency of the pdated system shall be checked frequently; procedure update	Quality engineer	1.01.2016	31.01.2016	N/A		

Figure 6: UAS risk management

2.) The risk assessor uses a UAS safety risk map in which he describes all the UAS flight hazards including the respective risk assessment results. He presents this map, including defined risk indicator every month, to the CEO who requires this information for strategy meetings. The UAS safety risk map can have the layout as shown above:

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UAS safety risk map

	Safety hazard identification									Safety risk assessment			
ID	Safety item or hazard	Description	Date of event	Operational stage	Safety hazard category	Root cause ID	Root cause	Root cause category	consequences	Probability	Severity	RPN	Risk level
1	Near miss of powerlines	During the The DII-11 operation the vehicle, caused by upcoming wind, had almost contact with a power line. The pilot who was in visual contact with the drone was able to avoid the contact by manoevring it out of the danger zone.	1.12.2015	Cruising	Active failure	1.1	The pilot was not familiar with the area	Human factors	Harm to people; Damage of drone; damage of infrastructure (high costs)	Improbable	Hazardous	2D	Tolerable
						1.2	Documented distance to power lines to close	Documen-tation	Harm to people; Damage of drone; damage of infrastructure (high costs)	Occasional	Hazardous	4D	Unacceptable
						1.3	GPS stabilizer defect	Technical	Harm to people; Damage of drone; damage of infrastructure (high costs)	Extremely Improbable	Hazardous	1D	Tolerable

Figure 7: Extract of the UAS safety risk map

Based on this UAS risk assessment Todd and the risk assessor feel well prepared for further operations. They plan to collect all the safety data and to include the risk management process into the UAS flight manual, which is required by the authorities in charge.

About

Drone Industry Insights (www.droneii.com) is a market research and analytics company based in Hamburg, Germany. We provide insights, competitive intelligence and market data for the commercial drone industry. Our consulting services range from operational issues up to cooperate strategy solutions.

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