A risk-based framework for assessment of runway incursion events

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Current classification of runway incursion events

Towards a risk-based approach for assessment of runway incursion events

Steps in the risk-based approach
1. Mapping of events to scenarios
2. Assessing probabilities of scenarios
3. Assessing collision probabilities of scenarios
4. Assessing consequences of a collision
5. Combination and evaluation of risk results

Discussion
Runway incursion

Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft (ICAO)
Safety management of runway operations

Airport infrastructure
ATC/airline procedures
Alerting systems
Safety promotion

runway operations

Normal operations
Runway incursions

safety management
Severity categories for classifying runway incursion incidents

ICAO recommends to classify the severity of runway incursion incidents as follows (ICAO Doc 9870, 2007)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A serious incident in which a collision was narrowly avoided</td>
</tr>
<tr>
<td>B</td>
<td>An incident in which separation decreases and a significant potential for collision exists, which may result in a time-critical corrective/evasive response to avoid a collision</td>
</tr>
<tr>
<td>C</td>
<td>An incident characterized by ample time and/or distance to avoid a collision</td>
</tr>
<tr>
<td>D</td>
<td>An incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and takeoff of aircraft but with no immediate safety consequences</td>
</tr>
<tr>
<td>E</td>
<td>Insufficient information or inconclusive or conflicting evidence precludes a severity assessment</td>
</tr>
</tbody>
</table>
Determining runway incursion severity categories

Severity classification is typically done by an assessment team:
- Narratives
- Radar and R/T data, if available
- Dependent on the interpretation of the assessment team

Recommended factors in classifying runway incursions (ICAO Doc 9870):
- Proximity of the aircraft and/or vehicle
- Geometry of the encounter
- Evasive of corrective action
- Available reaction time
- Environmental conditions, weather, visibility and surface conditions
- Factors that affect system performance
Severity classification example 1
Centennial, 2009

Occurrence
- Good visibility (VC1)
- C172 on final approach 17L
- L8 and AR11 holding short of 17L
- L8 pilot reported ready for departure
- GC told L8 pilot that he is no. 1 for departure and to monitor frequency
- L8 entered without clearance
- C172 flew over nose of L8 with about 50 ft vertical and landed normally 1,000 ft down runway

Severity (FAA): A
Severity classification example 2
Cleveland-Hopkins Intl, 2008

Occurrence
- Good visibility (VC1)
- Canadair CRJ2 on final approach 24L
- Dehavilland DH8A to taxi out via Lima, Romeo, hold of 24L
- Correct read back of DH8A
- DH8A did not hold short
- CRJ2 initiated go around on his own
- CR2J flew over DH8A with 200 ft vertical separation
- DH8A was 104 ft from runway center

Severity (FAA): B
Occurrence
- Good visibility (VC1)
- Luscombe SP18 on final approach 27R
- Piper PA28A instructed to taxi to 27R via Romeo and to contact local control
- PA28A entered 27R without clearance
- SP18 was issued a go-around at 0.25 mile final

Severity (FAA): C
Severity classification example 4
Long Island Mac Arthur Airport, 2010

Occurrence
- Good visibility (VC1)
- Cessna C172 on final approach 33R
- Bellanca BL17 instructed to hold short of 33R
- Pilot BL17 read back correctly
- BL17 crossed 33 R at Hotel without clearance
- C172 was issued a go-around at 0.25 mile final

Severity (FAA): C
Severity classification example 5
Nashville Intl, 2009

Occurrence
- Good visibility (VC1)
- Cessna C182 was issued IFR clearance and taxi instructions to 20C
- C182 entered 20C without clearance
- C182 departed without clearance
- No conflicts reported

Severity (FAA): D
Severities of runway incursion events in US NAS

Events/year

<table>
<thead>
<tr>
<th>Severity</th>
<th>Events/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1045</td>
</tr>
<tr>
<td>D</td>
<td>619</td>
</tr>
<tr>
<td>C</td>
<td>413</td>
</tr>
<tr>
<td>B</td>
<td>6.7</td>
</tr>
<tr>
<td>A</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Distribution of closest horizontal distance in RI events
Horizontal and vertical closest distance in A & B runway incursion events
Discussion of severity classification of runway incursions

Strongly based on the outcome (closest distance) of runway incursion events

Outcome depends on uncontrolled random circumstances
  ● Similar types of errors lead to different severity labels

Statistics: few A & B events, many C & D events
  ● Lessons from C & D events may be undervalued in safety management
  ● Possibly overreacting to A & B events

Current severity classification does not structure reasons of runway incursions, nor does it evaluate their risk implications
Current classification of runway incursion events

Towards a risk-based approach for assessment of runway incursion events

Steps in the risk-based approach
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Conclusions
On the notion of risk

Risk is assessed by probability and severity of future occurrences

Risk is about uncertain and undesired future occurrences

There is no risk in the outcomes of runway incursion events
Runway incursion scenario as basis of a risk-based approach

A runway incursion scenario describes the start of a runway incursion event

The choice of a runway incursion scenario does not depend on the outcomes of runway incursion events
More scenarios......

(a) Start of runway incursion event

(b) Start of runway incursion event

(c) Start of runway incursion event
## Conflicts between two physical entities on a runway including at least one aircraft

<table>
<thead>
<tr>
<th>Type</th>
<th>Descriptor</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>Runway configuration</td>
<td>Single / Intersecting</td>
</tr>
<tr>
<td>Main</td>
<td>Entity type</td>
<td>Aircraft / Vehicle / Person / Helicopter</td>
</tr>
<tr>
<td>Main</td>
<td>Operation</td>
<td>Takeoff / Land / Taxi / Other</td>
</tr>
<tr>
<td>Main</td>
<td>Intent of human operator</td>
<td>Cross / Lineup / Taxi along taxiway / Stop &amp; hold short / Takeoff / Land / Any</td>
</tr>
<tr>
<td>Main</td>
<td>Runway incursion initiator</td>
<td>Entity 1 / Entity 2</td>
</tr>
<tr>
<td>Main</td>
<td>Encounter direction</td>
<td>Same / Opposite / Intersect</td>
</tr>
<tr>
<td>Main</td>
<td>Encounter relative position</td>
<td>In front / Behind</td>
</tr>
<tr>
<td>Sub</td>
<td>Location on runway</td>
<td>Start / Middle / End</td>
</tr>
<tr>
<td>Sub</td>
<td>Size of entities</td>
<td>Small / Large / Heavy</td>
</tr>
<tr>
<td>Sub</td>
<td>Visibility condition</td>
<td>VC1 / VC2 / VC3&amp;4</td>
</tr>
<tr>
<td>Sub</td>
<td>Runway hold distance</td>
<td>Small / Medium / Large</td>
</tr>
</tbody>
</table>
Scenario selection example 1
Centennial, 2009

Main scenario indicators
- Configuration: *single runway*
- Entity types: (1) *aircraft* / (2) *aircraft*
- Operations: (1) *land* / (2) *taxi*
- Intents: (1) *land* / (2) *line-up*
- Initiator: *entity 2*
- Encounter: *intersect, in front*

Subcase indicators
- Location: *runway start*
- Sizes: (1) *small* / (2) *small*
- Visibility: *VC1*
- Runway hold distance: *medium*
Scenario selection example 2
Cleveland-Hopkins Intl, 2008

Main scenario indicators
- Configuration: *single runway*
- Entity types: (1) *aircraft* / (2) *aircraft*
- Operations: (1) *land* / (2) *taxi*
- Intents: (1) *land* / (2) *cross or taxi along taxiway*
- Initiator: *entity 2*
- Encounter: *intersect, in front*

Subcase indicators
- Location: *runway start*
- Sizes: (1) *large* / (2) *large*
- Visibility: *VC1*
- Runway hold distance: *large*
Mapping of RI events to scenarios

- None: 1.3%
- One: 68% (31% C, 37% B)
- Multiple: 31% (12% C, 19% B)

Years: 2004-2010
Current classification of runway incursion events

Towards a risk-based approach for assessment of runway incursion events

Steps in the risk-based approach
1. Map events to scenarios
2. Assess probabilities of scenarios
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5. Combine and evaluate risk results

Conclusions
- Step 1 -
Map event to scenarios

User

Runway incursion event

Select indicators

Possible scenarios

Assess scenario probabilities

Data

(Optional)

Conditional probabilities of scenarios

P(S_{i,j}^{RI} | E_{q,t \leq t_0}^{RI})

Event E1

E_{RI}^{q,t \leq t_0}

P(S8 | E1) = 1

Event E2

P(S7 | E2) = 0.5

P(S10 | E2) = 0.5

S8

S7

S10

User Data (Optional)
- Step 2 – Assess probabilities of scenarios

\[ P(S_{i,j}^{RI} \mid E_{q,t \leq t_0}^{RI}) \]

\[ N^{AO} \]

\[ \frac{1}{N^{AO}} \sum_{q=1}^{N^{RI}} P(S_{i,j}^{RI} \mid E_{q,t \leq t_0}^{RI}) \quad \text{(per airport operation)} \]

\[ N^{AO} : \text{number of airport operations} \]

\[ N^{RI} : \text{number of runway incursions} \]
- Step 2 – Assess probabilities of scenarios

<table>
<thead>
<tr>
<th>Main scenario</th>
<th>Number of events</th>
<th>Cond. prob. given RI</th>
<th>Prob. / ap. op.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S7</strong> Aircraft lands and taxiing aircraft enters runway erroneously, while its pilots have the intent to cross the active runway and think they are allowed to do so</td>
<td>32</td>
<td>0.063</td>
<td>4.5E-07</td>
</tr>
<tr>
<td><strong>S9</strong> Aircraft lands and other aircraft lines up on the runway erroneously, while its pilots think they are allowed to lineup</td>
<td>29</td>
<td>0.077</td>
<td>5.5E-07</td>
</tr>
<tr>
<td><strong>S10</strong> Aircraft lands and taxiing aircraft enters runway erroneously, while its pilots have the intent to taxi over a normal taxiway or an inactive runway</td>
<td>34</td>
<td>0.066</td>
<td>4.7E-07</td>
</tr>
</tbody>
</table>

**Subcases**

- **Aircraft size**
  - Small: 62%
  - Large: 34%
  - Heavy: 4%

- **Visibility**
  - Clear: 98.3%
  - Cloudy: 0.9%
  - Rain: 0.3%
  - Snow: 0.6%
  - Unknown: 0.1%
- Step 3 -
Assess collision probabilities of scenarios

\[ S_{i,j}^{RI} \rightarrow \text{Collision risk model} \rightarrow P(E_{\text{coll}} \mid S_{i,j}^{RI}) \]

Agent-based dynamic risk modeling

- Stochastic dynamic models of humans, systems and environment, and their interactions

- Monte Carlo simulations up to the level of collisions provide conditional probabilities of a collision given a runway incursion scenario
Scenario S10: Aircraft lands and taxiing aircraft enters runway erroneously, while its pilots have the intent to taxi over a normal taxiway or an inactive runway

<table>
<thead>
<tr>
<th>Size landing aircraft</th>
<th>Size taxiing aircraft</th>
<th>Taxiway location</th>
<th>Visibility condition</th>
<th>Runway hold distance</th>
<th>Conditional collision risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Small</td>
<td>Middle</td>
<td>VC1</td>
<td>Small</td>
<td>1.90E-02</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Middle</td>
<td>VC1</td>
<td>Medium</td>
<td>8.60E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Middle</td>
<td>VC1</td>
<td>Large</td>
<td>3.00E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Middle</td>
<td>VC1</td>
<td>Small</td>
<td>2.50E-02</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Middle</td>
<td>VC1</td>
<td>Medium</td>
<td>1.30E-02</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Middle</td>
<td>VC1</td>
<td>Large</td>
<td>4.00E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Start</td>
<td>VC1</td>
<td>Medium</td>
<td>2.80E-02</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Middle</td>
<td>VC3/4</td>
<td>Medium</td>
<td>3.00E-02</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

243 subcase results
Scenario S9: Aircraft lands and other aircraft lines up on the runway erroneously, while its pilots think they are allowed to line-up

<table>
<thead>
<tr>
<th>Size landing aircraft</th>
<th>Size taxiing aircraft</th>
<th>Taxiway location</th>
<th>Visibility condition</th>
<th>Runway hold distance</th>
<th>Conditional collision risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC1</td>
<td>Small</td>
<td>3.00E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC1</td>
<td>Medium</td>
<td>8.30E-05</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC1</td>
<td>Large</td>
<td>1.00E-06</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC2</td>
<td>Small</td>
<td>8.60E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC2</td>
<td>Medium</td>
<td>4.30E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td>Start</td>
<td>VC2</td>
<td>Large</td>
<td>2.30E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Start</td>
<td>VC1</td>
<td>Small</td>
<td>4.00E-03</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>Start</td>
<td>VC1</td>
<td>Medium</td>
<td>1.50E-04</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
- Step 4 -
Assess consequences of a collision

\[ P(C_k^{\text{Hu}} \mid E^{\text{coll}}, S_{i,j}^{\text{RI}}) \]
\[ P(C_k^{\text{Ma}} \mid E^{\text{coll}}, S_{i,j}^{\text{RI}}) \]

Input from MC simulation collision data (Step 3):
- speed
- position
- aircraft size

<table>
<thead>
<tr>
<th>Human impact</th>
<th>Material impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Many fatalities</td>
<td>Hull loss</td>
</tr>
<tr>
<td>2 Some fatalities</td>
<td>Substantial damage</td>
</tr>
<tr>
<td>3 Serious injuries only</td>
<td>Minor damage</td>
</tr>
<tr>
<td>4 No serious injuries or fatalities</td>
<td>No damage</td>
</tr>
</tbody>
</table>
- Step 5 -
Combine and evaluate risk results

\[
P(S_{i,j}^{RI} \mid E_{q,i\leq t_0}^{RI})
\]

\[
P(S_{i,j}^{RI})
\]

\[
P(E_{coll}^{RI} \mid S_{i,j}^{RI})
\]

\[
P(C_{k}^{Hu} / C_{k}^{Ma} \mid E_{coll}^{RI}, S_{i,j}^{RI})
\]

**Single event risks**
- Probability of a collision given a RI event
- Probability of a collision consequence category given a RI event

**Aggregated risk (for multiple events)**
- Probability of collision due to RI scenarios
- Probability of collision consequence category due to RI scenarios

**Compare aggregated risk results with target levels of safety**
- Is the overall risk acceptable?
- What scenarios are the main contributors to the overall risk?
## Results for single events (examples)

<table>
<thead>
<tr>
<th>Event</th>
<th>Closest distance</th>
<th>Severity</th>
<th>Scenario</th>
<th>Collision risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 ft vertical</td>
<td>A</td>
<td>Small aircraft lands; small aircraft lines up erroneously; near runway start; medium distance hold-short line; VC1</td>
<td>3.0E-5</td>
</tr>
<tr>
<td>2</td>
<td>200 ft vertical</td>
<td>B</td>
<td>Large aircraft lands; large taxiing aircraft enters runway erroneously (crossing or being lost); near runway start; medium distance hold-short line; VC1</td>
<td>6.0E-3</td>
</tr>
<tr>
<td>3</td>
<td>0.25 mile horizontal</td>
<td>C</td>
<td>Small aircraft lands; small aircraft lines up erroneously; near runway middle; medium distance hold-short line; VC1</td>
<td>6.6E-6</td>
</tr>
<tr>
<td>4</td>
<td>0.25 mile horizontal</td>
<td>C</td>
<td>Small aircraft lands; small taxiing aircraft enters runway erroneously (crossing or being lost); near runway start; medium distance hold-short line</td>
<td>3.6E-3</td>
</tr>
</tbody>
</table>
Aggregated risk results (examples)

Probability of scenario

Probability of collision given scenario

Probability of collision and scenario
Contents

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Discussion
Risk-based framework

Not outcome-based (as current approach) but risk-based

The risk is evaluated in a consistent probabilistic framework

User only needs to specify possible scenarios
  ➢ Consistent risk evaluations
Feedback to safety management

Aggregated risk results provide key feedback for effective safety management of aerodrome operations

- What scenarios occur most frequently?
- What scenarios contribute most to safety risk?
  - Collision probabilities
  - Human & material consequence probabilities

Contrast with current A/B/C/D severity categories

- They merely indicate close encounters
- They do not structure reasons for runway incursions
- They do not provide risk-implied priorities of runway incursion types
Future steps

Evaluate and extend inventory of runway incursion scenarios
- Assess suitability of inventory with runway safety teams
- Possibly extend for availability of specific procedures / technical systems / aerodrome infrastructure
- Include events without a conflict (type D events)

Achieve risk results for all scenarios and subcases
- Extend agent-based dynamic risk models for other conflict configurations and types of agents
- Possibly use expert judgment and probabilistic graphical models for simple scenarios

Develop guidelines for integration in safety management
Questions / Discussion