Bowtie分析方法與應用

Introduction to Bowtie Analysis and Application

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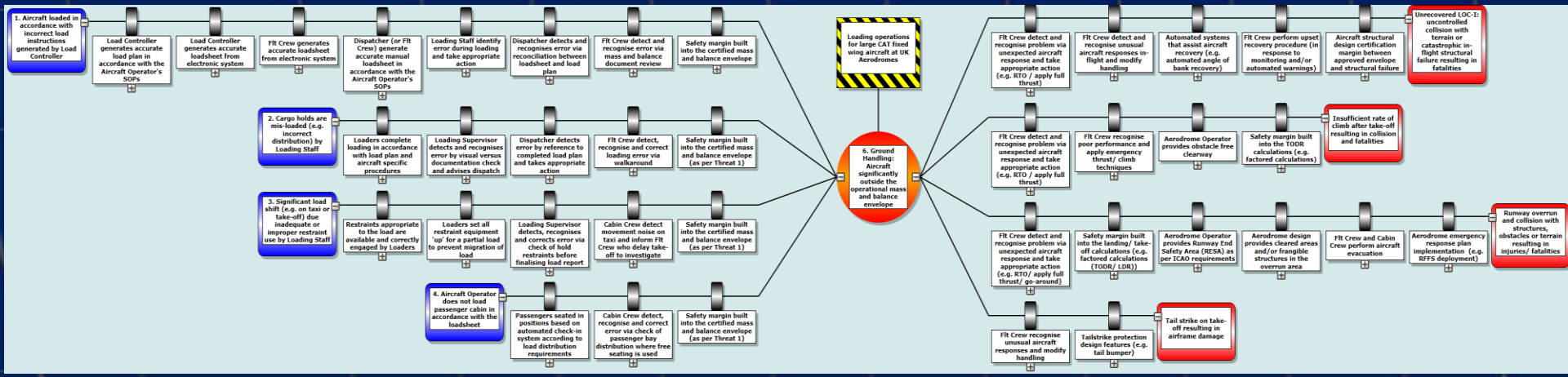
簡報大綱

① Bowtie分析方法概述
② Bowtie組成要素
③ Bowtie之應用
④ 結語

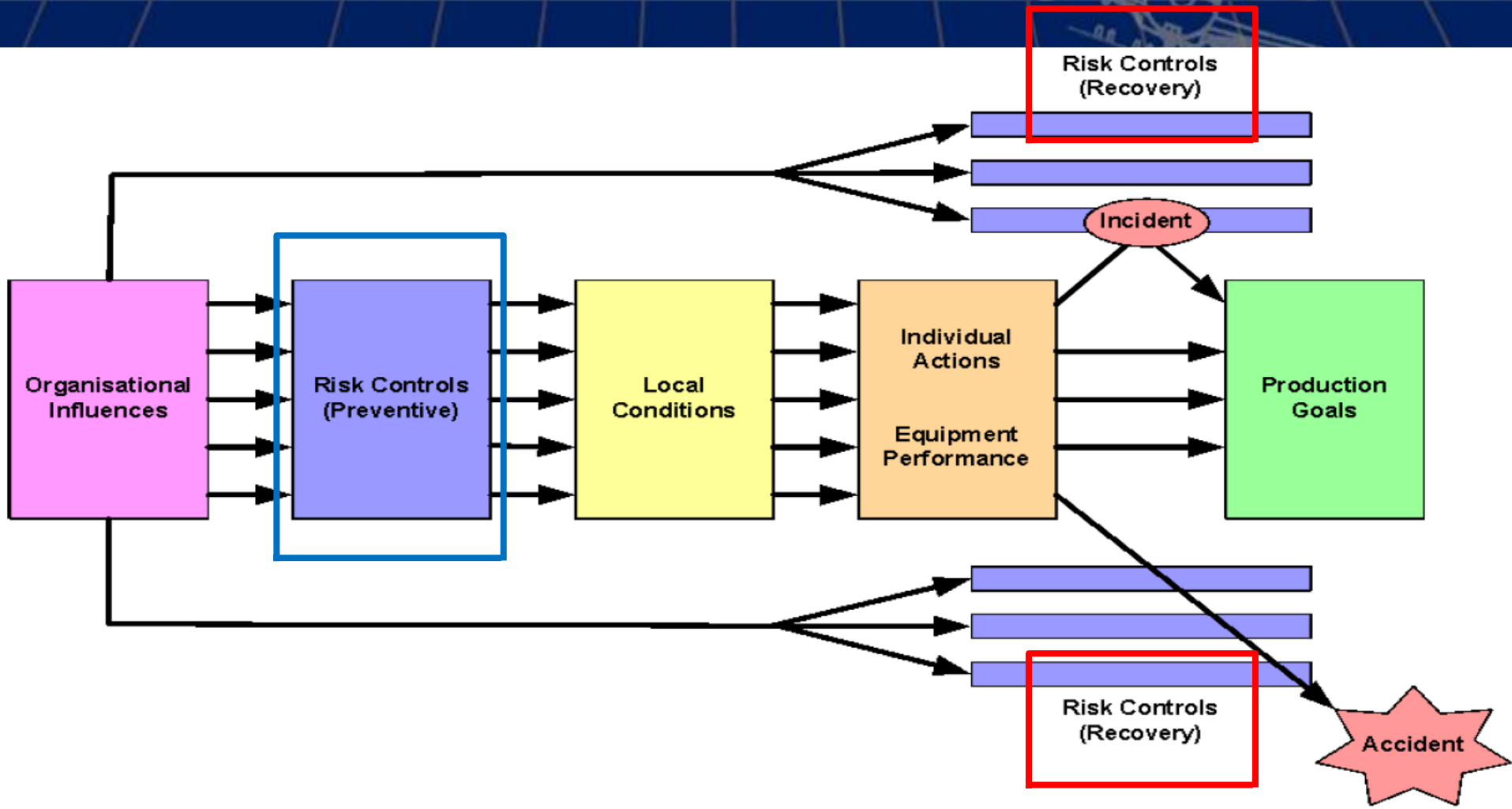
① Bowtie分析方法概述

A barrier-based approach to risk

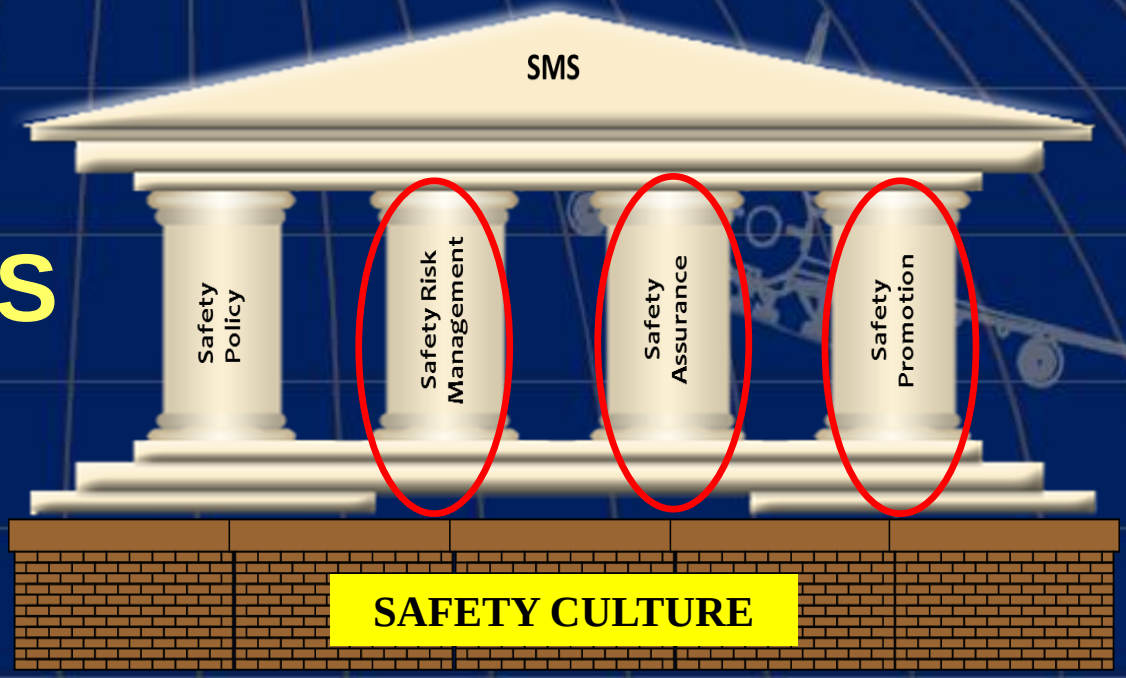
- 簡化版之fault & event tree methodologies
- Reason's model之延伸；強調以安全風險控管措施(barrier/ control)為基礎之分析方法
- 系統化分析方法，協助分析與管理安全風險
- 始於1990年代石油化學產業，後來亦推廣於國防工業、醫療產業、金融業與航空業



Reason's Model



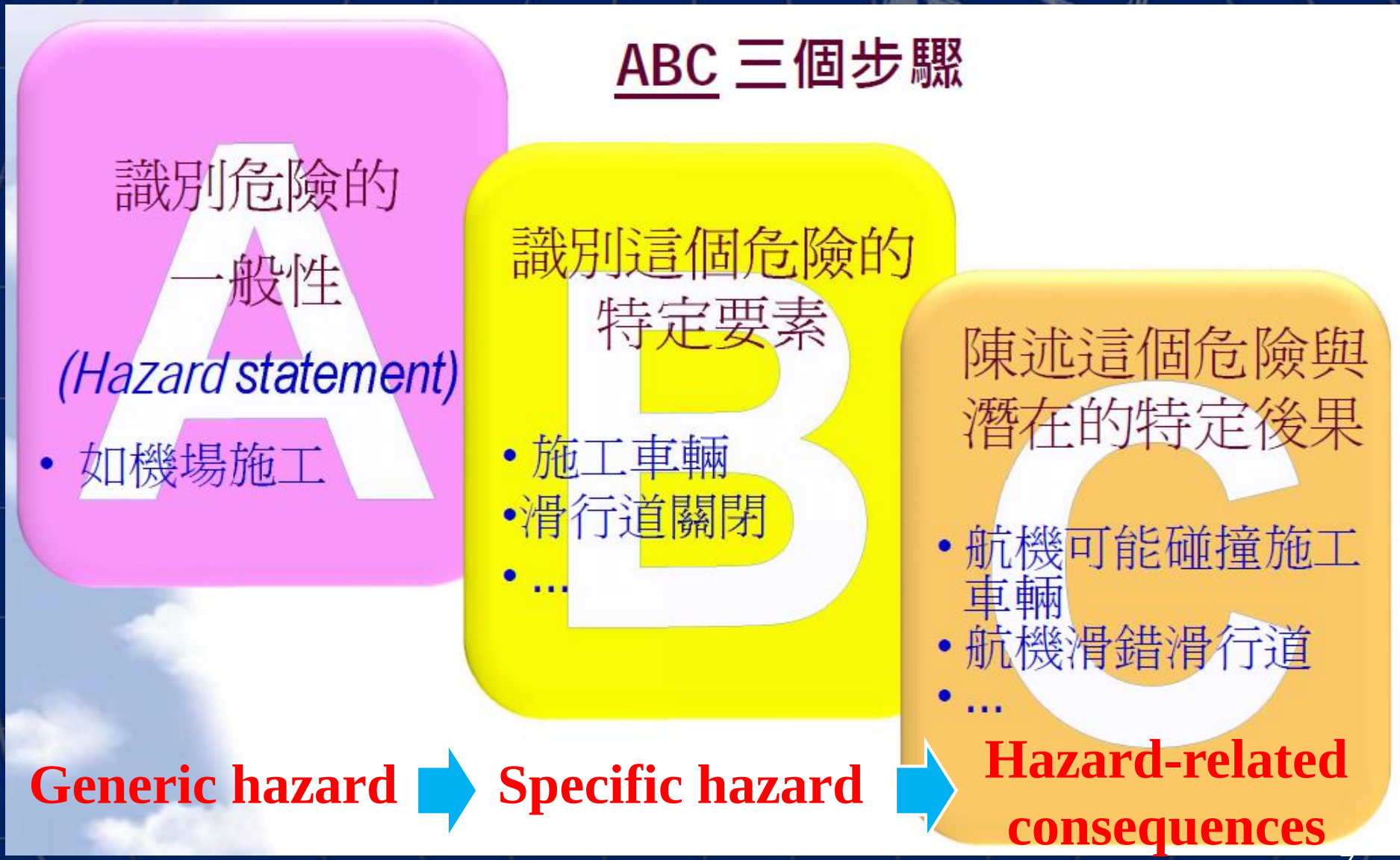
Bowtie and SMS



- 安全風險管理：Hazard analysis, Risk assessment & management
- 安全確保：SPI之識別與監控
- 安全推廣：Risk communication
- 2013年ICAO安全管理手冊第三版亦導入Bowtie

② Bowtie組成要素

Hazard Analysis



模式左側

消除Threat之措施

或

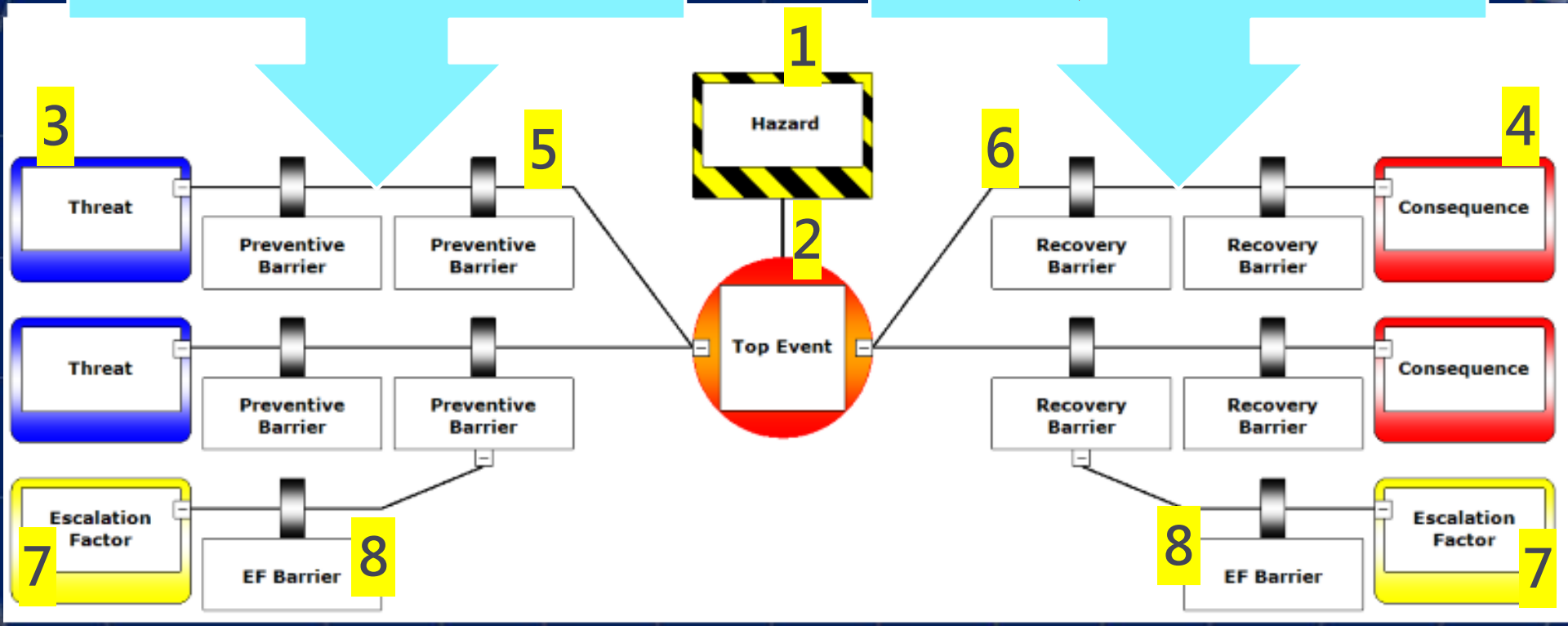
預防Threat致Top Event發生

模式右側

降低Top Event發展為Consequence之機率

或

降低嚴重性



Bowtie亦分析Barriers(or Controls)可能失效的原因(Escalation Factors)，以及如何對其管理(Escalation Factor Controls)

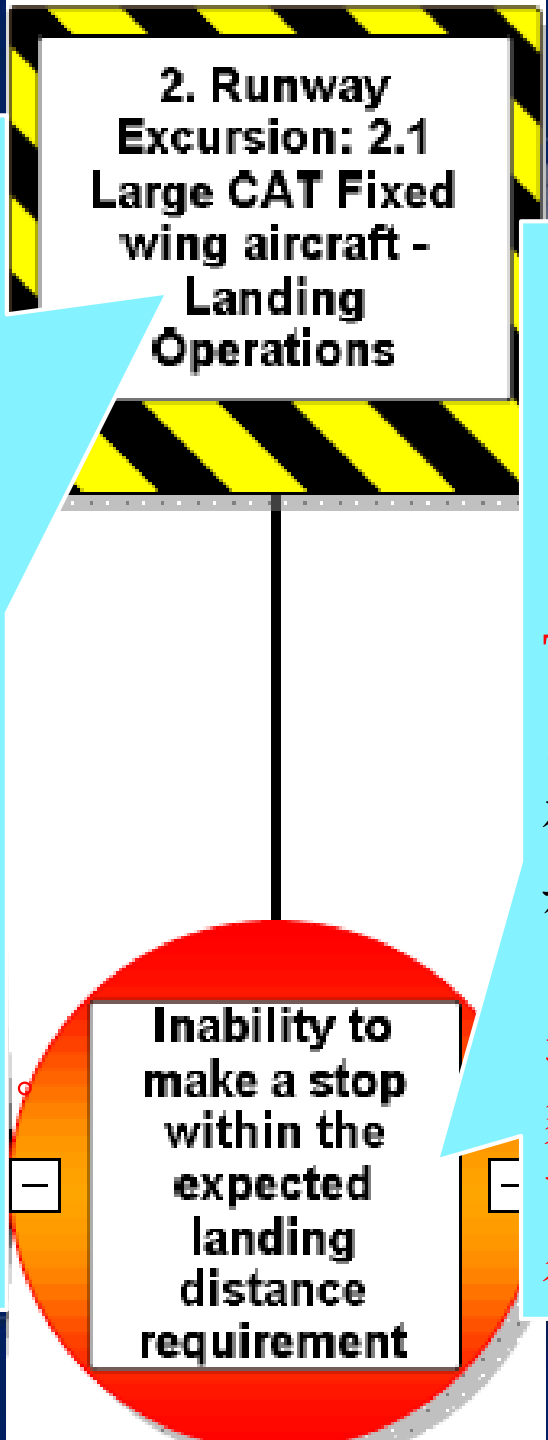
Hazard:

Anything which is a source of potential loss, injury, damage, or reduction of ability.

描述一個飛航環境中正常的、不一定能夠或應該被消除的:

- 狀況(機尾亂流)
- 物體(施工車輛)
- 活動(航機進場作業)

決定分析的規模與背景。一個Hazard可對應多個Top Event。



Top Event:

A point in time which describes the release or loss of control over a hazard.

The undesired safety state.

飛機起飛時遭遇機尾亂流

施工車輛誤入運作中跑道

航機進場時與無人機接近

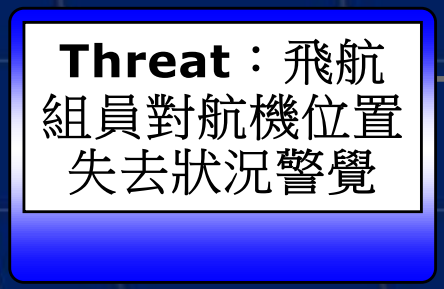
適當的Top Event係指能夠讓分析者可識別多重的可能的原因(Threats)與後果(Consequences)


1. Flt Crew land significantly outside the touchdown criteria (zone or speed)
Commonly exposed
Also see RI bowtie 4.3
2. Flt Crew land within the touchdown criteria but LDR calculations are incorrect or no longer valid
Commonly exposed
3. Unanticipated technical failure of the aircraft's stopping devices on landing
Commonly exposed
4. Incorrect or no deployment of the aircraft's stopping devices by the Flt Crew
Commonly exposed
2. Runway Excursion: 2.1 Large CAT Fixed wing aircraft - Landing Operations
Inability to make a stop within the expected landing distance requirement
Runway overrun and collision with structures, obstacles or terrain resulting in injuries/ fatalities
Threat:(相互獨立/重要者置上)
A possible direct cause that will potentially release a hazard by producing a top event.
管制員未提供適當航機隔離
施工車輛進入跑道前未獲許可
無人機操作人位監控載具位置
Consequence:
(失事/重大意外)
A potential event resulting from the release of a hazard, which directly results in loss or damage.
應使用與航機運作相關聯之用語，如衝出跑道。
Consequence是event，不單是outcome(severity)，但可合併，如航機衝出跑道後撞擊維修人孔蓋，起落架折斷。

Example One


Hazard:機場附近之地障


Top event:
航機進場過程中與地障隔離不足

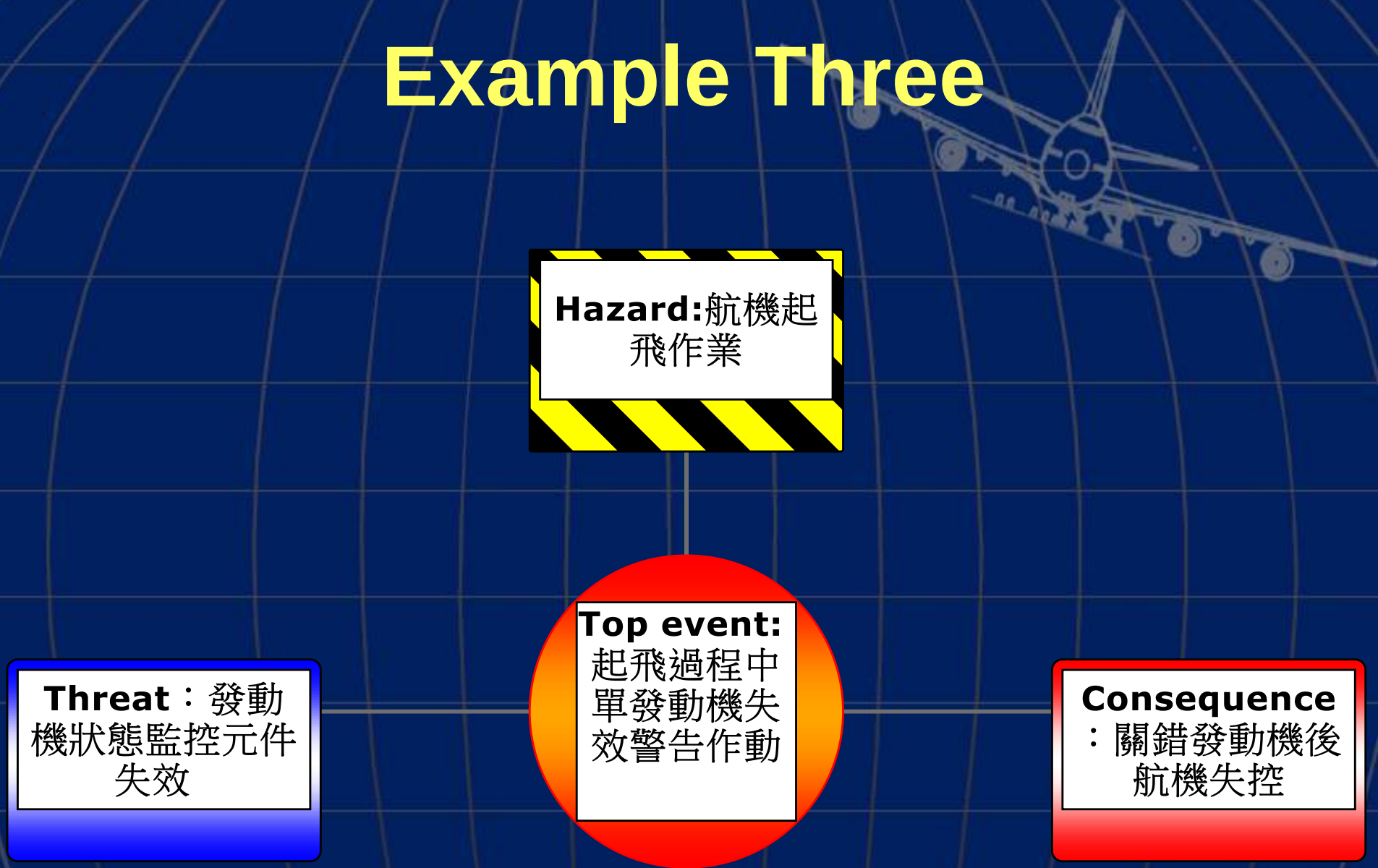

Threat：飛航組員對航機位置失去狀況警覺


Consequence：航機撞擊地障

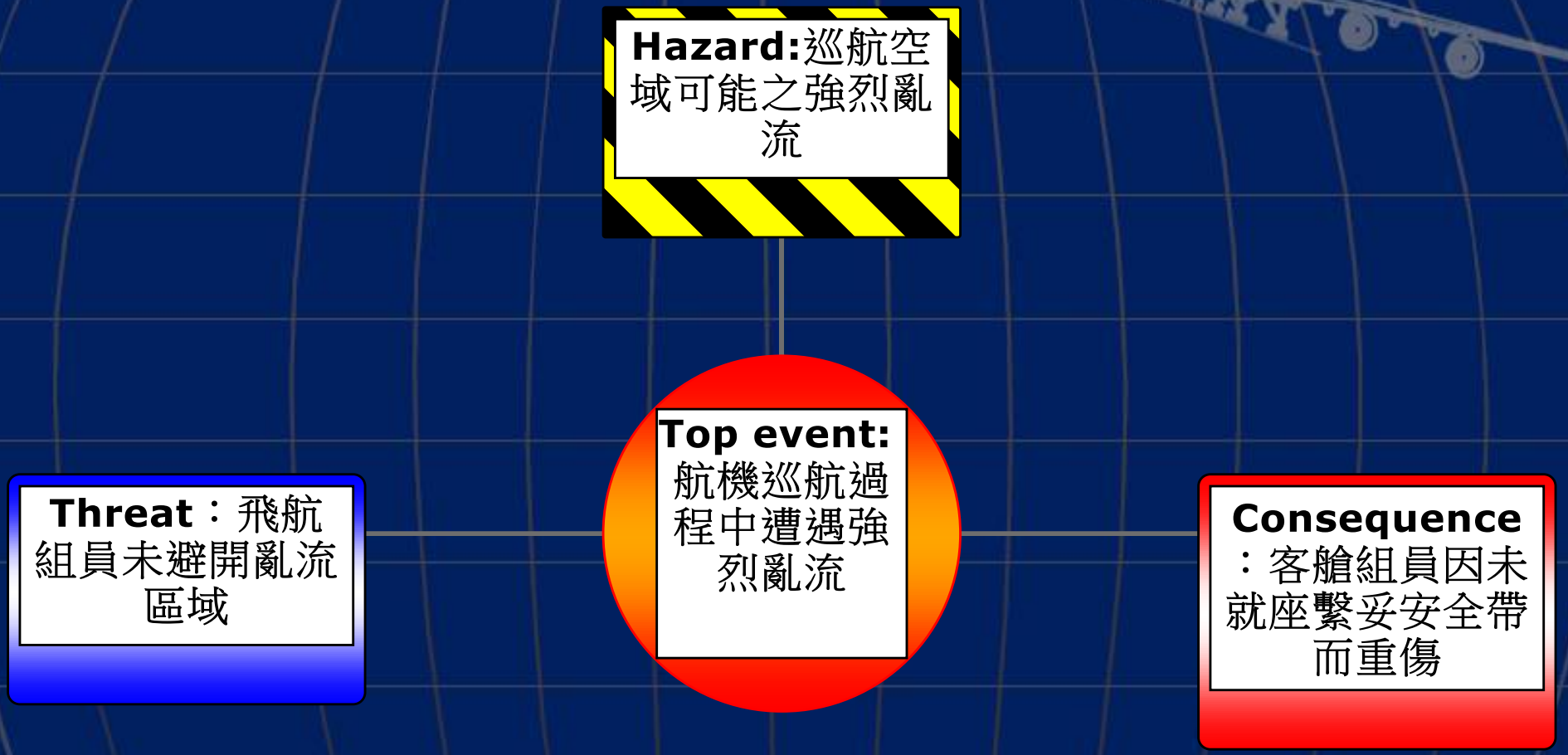
Example Two


Hazard:UAV活動
Top event: UAV闖入離到場航道
Threat：UAV操作人未能確實監控航機位置
Consequence：UAV與民航機空中相撞

Example Three



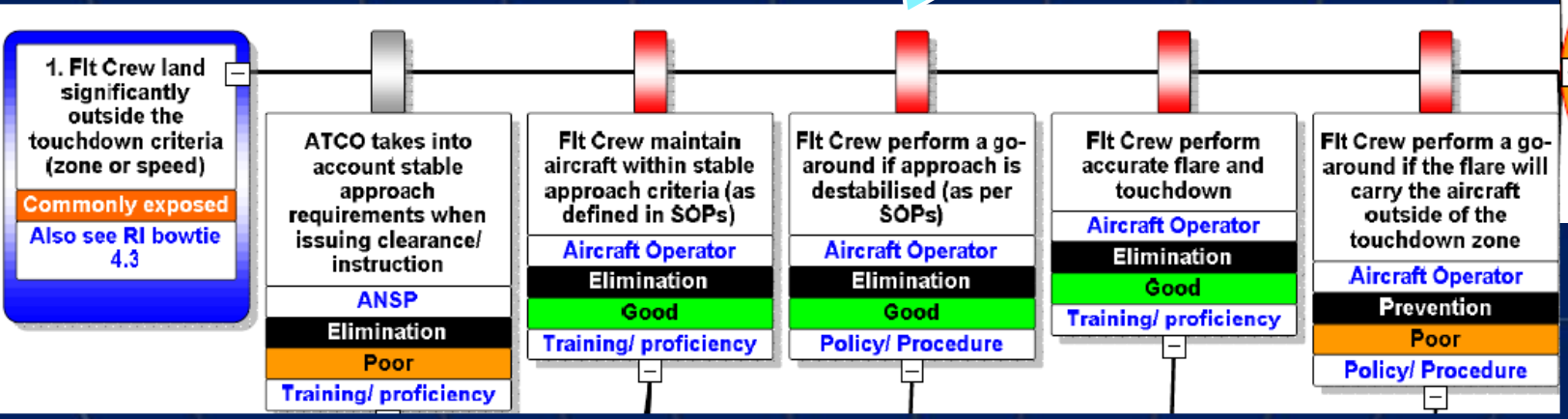
Example Four



Prevention Control:

Any measure taken which acts against some undesirable force or intention, in order to maintain a desired state.

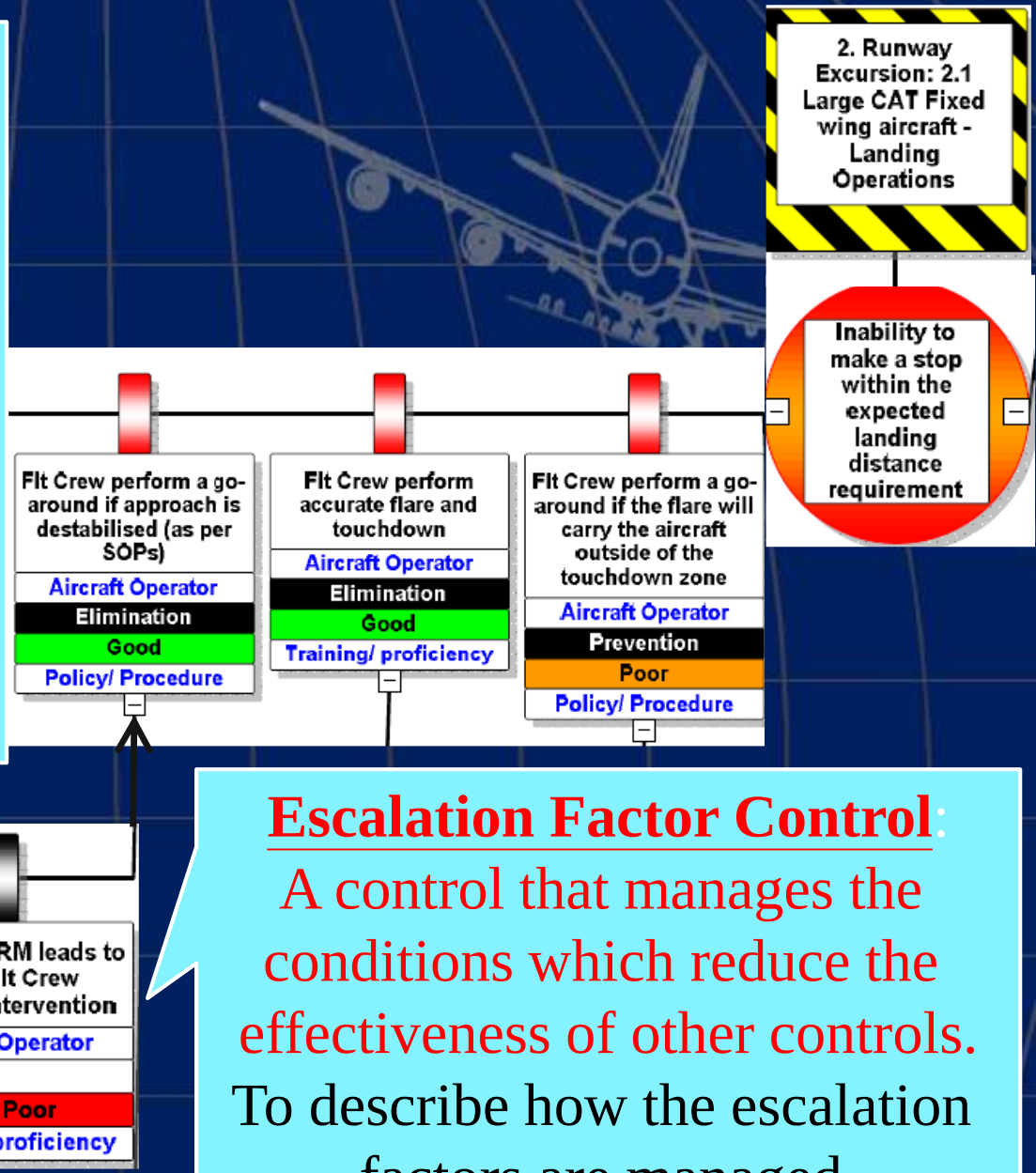
- 設法消除Threat發生
- 緩解Threat導致Top Event發生
- 應具體明確



Escalation Factors:

A condition that leads to increased risk by reducing the effectiveness of controls.

An escalation factor cannot directly cause the top event or consequence.

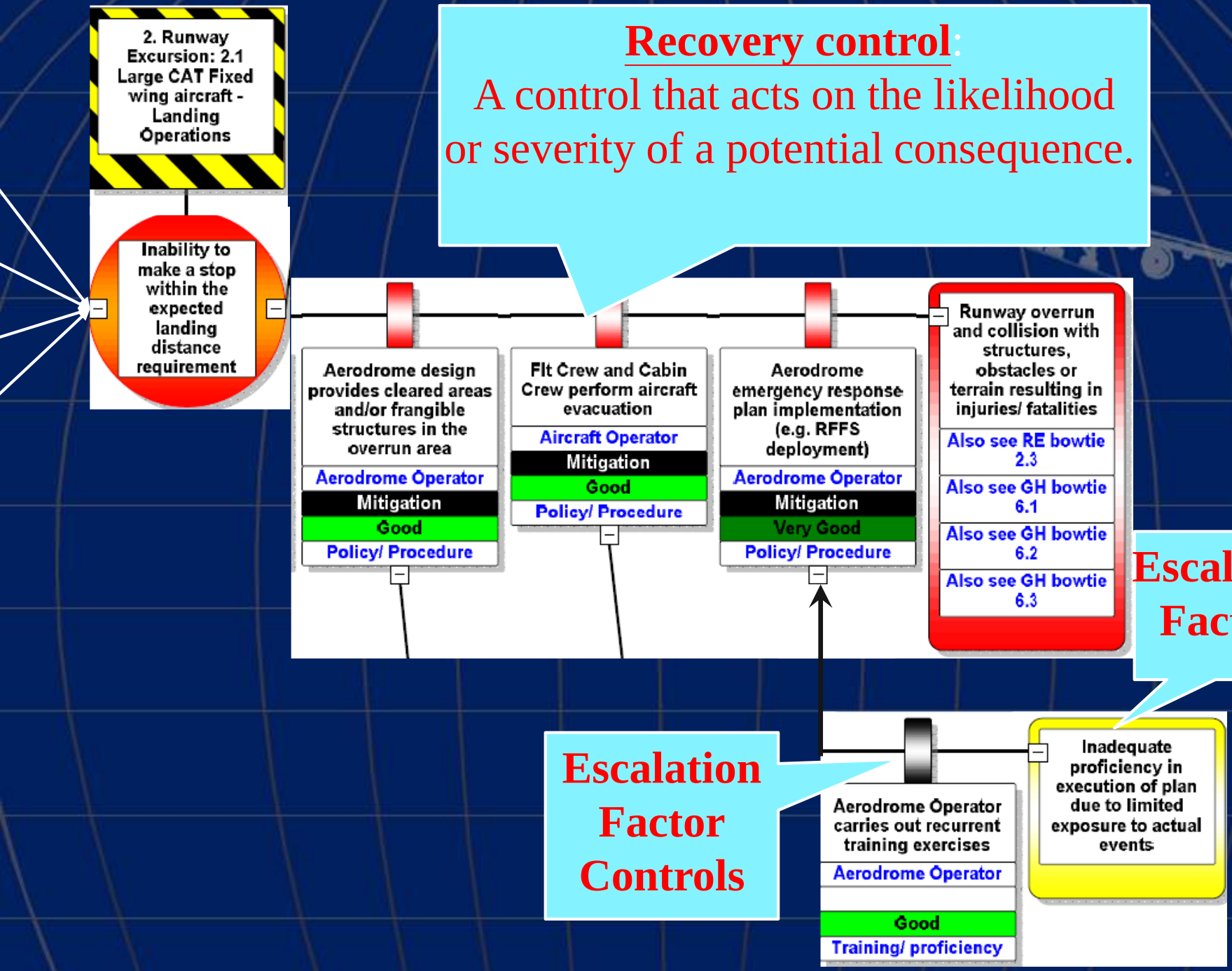


Escalation Factor Control:

A control that manages the conditions which reduce the effectiveness of other controls.

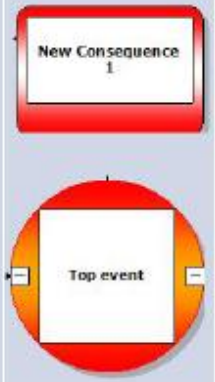
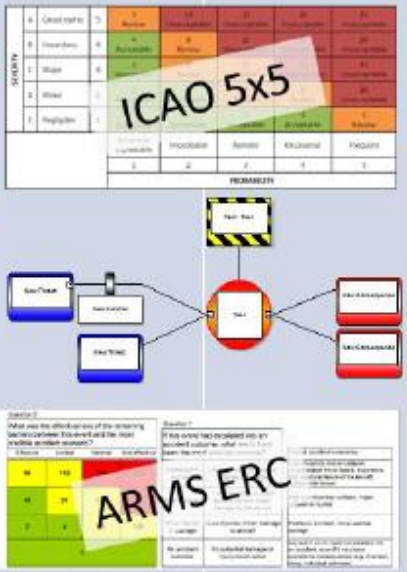
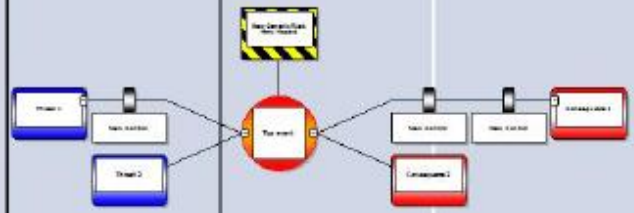
To describe how the escalation factors are managed.

Recovery control:
A control that acts on the likelihood or severity of a potential consequence.




3
Threat01:飛航組員操作航機於顯著超過跑道著陸區外始觸地
5
Prevention control:飛航組員依規定於不穩定進場情況下執行重飛
1
Hazard:衝偏出跑道:固定翼航空器進場落地作業
7
Escalation Factor：飛航組員因注意力侷限、個人、組織壓力或其他人為績效因素而不願意重飛
8
Escalation factor control:有效的CRM使得其他飛航組員下達重飛
2
Top event:航機落地後未能於跑道上煞停
6
Recovery control:機場依ICAO標準提供跑道地帶安全區
4
Consequence:航機衝出跑道撞擊障礙物、建物或地障後人員傷亡與航機受損
8
Escalation factor control:跑道端外設置EMAS
7
Escalation Factor；機場地形限縮跑道安全地帶之設置
3
Threat02:飛航組員未能正確計算所需落地距離
3
Threat03:航機減速裝備非預期故障

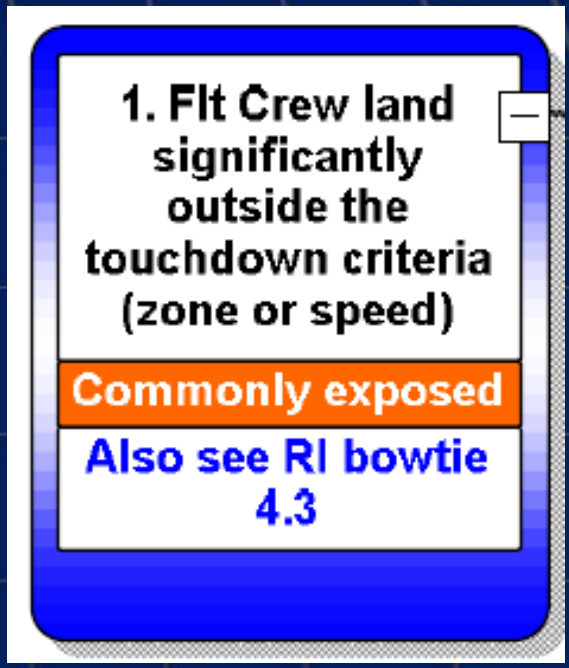
Using bowtie within risk matrix and hazard register

Hazard	Outcome	Severity of Outcome	Likelihood	Risk	Mitigation	Severity of outcome	Likelihood	Risk
List of bowtie threats 	The worst credible outcome linked to the particular threat via the top event within the bowtie 	Using ICAO (5x5) or ARMS (ERC) matrix considering the severity of the outcome 	Considering the barriers/controls within the appropriate bowtie - how likely is the threat to cause the outcome?	Calculate the score based on the chosen matrix	If the score is unacceptable and requires mitigation, refer to the bowtie for possible changes to the system – remember to consider transfer of risk which is easily identifiable on a bowtie 	Consider the effectiveness of the new or improved mitigations (controls) for reducing the severity of the outcome	Consider the effectiveness of the new or improved mitigations (controls) for likelihood of the threat escalating into the outcome	Calculate the new risk score based on the new or improved mitigations
				Inherent Risk				*Residual Risk*

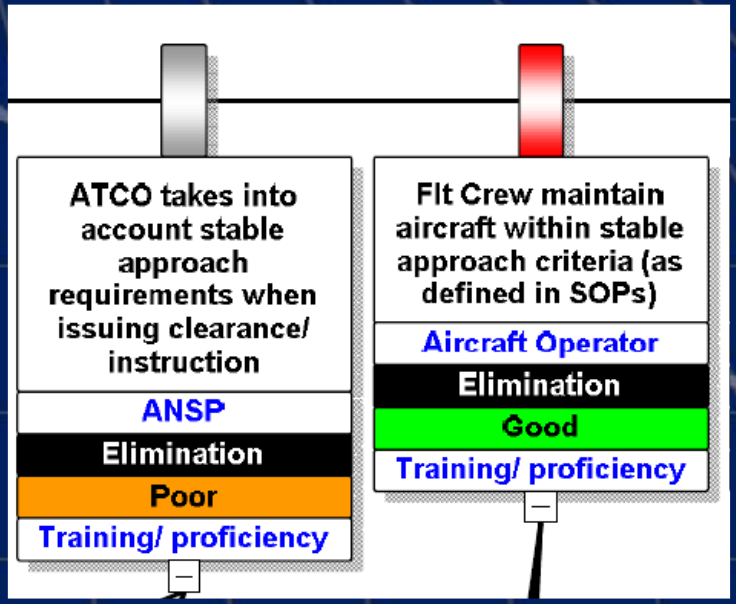
Identify Safety Risk Priorities

- 對於bowtie組成要素賦予給多的管理資訊，以作為後續資源分配或優先順序決策之參考，例如：

Threat exposure: constantly exposed, commonly exposed, limited exposed.



Identify Safety Risk Priorities



Control ownership: A/C operator, aerodrome, ANSP

Control type: policy/procedure, training/ proficiency, engineered devices

Control function: elimination, prevention/ reduction, mitigation.

Control effectiveness: very poor, poor, average, good

Control criticality: standard, critical

Bowtie分析方法之使用工具

- 繪圖軟體如Visio
- Excel工作表<ICAO SMM 3rd>
- 可使用專門之bowtie software- BowTie XP

③ Bowtie之應用

Significant Seven in UK

① Loss of Control
② Runway Excursion
③ CFIT
④ Runway Incursion
⑤ Airborne Conflict
⑥ Ground Handing
⑦ Fire

- Bowtie templates
- Bowtie webviewer

Significant Three in Taiwan

① Runway Excursion
② Loss of Control
③ CFIT

- AC 120-049 安全績效指標：各業者得以納為外部資訊，再依自己組織特性、營運型態及安全資料分析結果，訂定相應之指標據以管理
- SPI範例

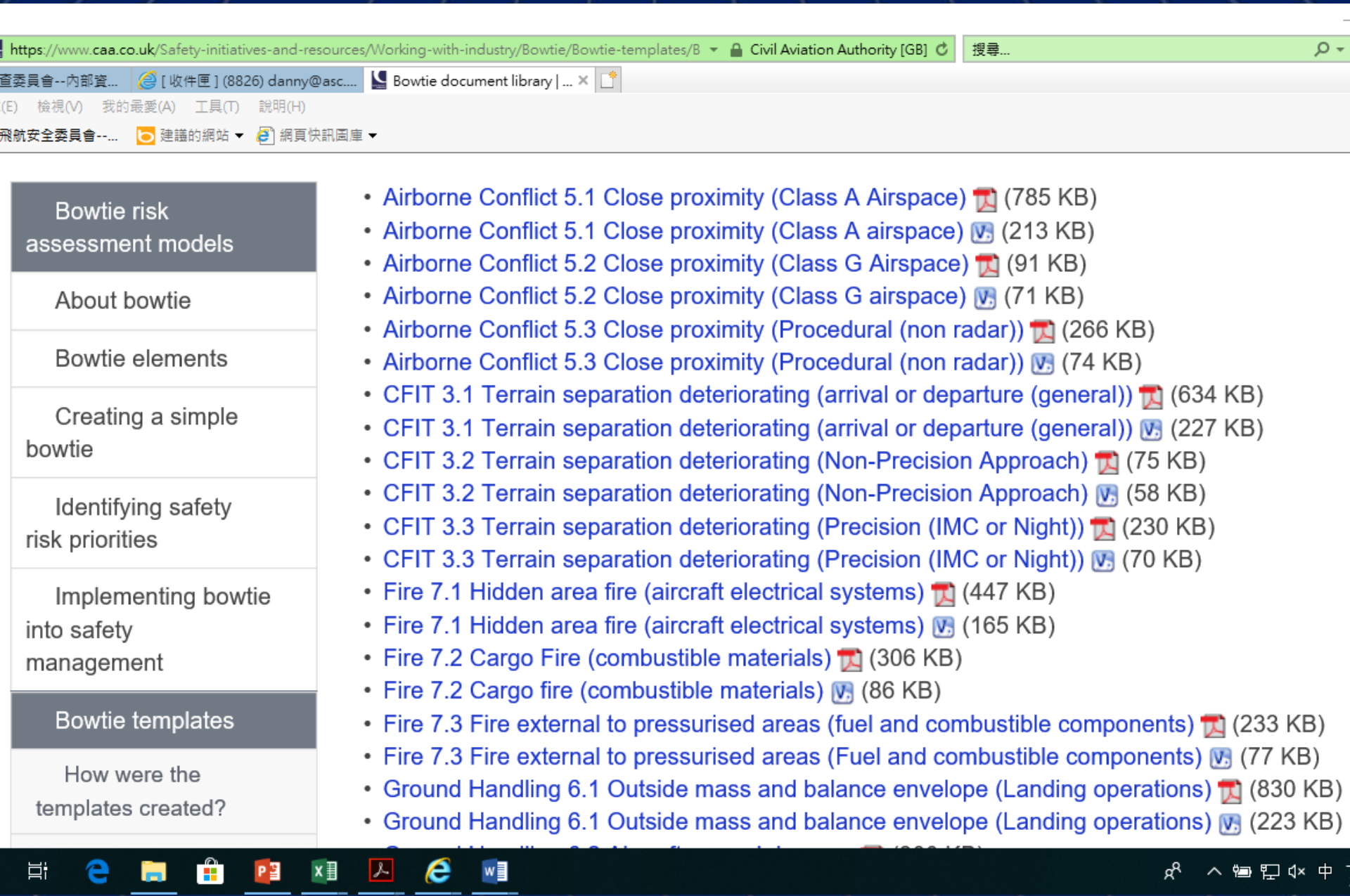
How were the bowtie templates created by the UKCAA

- UKCAA與航空公司、以及相關領域之專家，以專題研討會的方式，整體航空產業之觀點研討後產生。

- 每次專題研討會由1名bowtie導師主持，航空公司與相關領域專家6至8名參加。

How were the bowtie templates created by the UKCAA

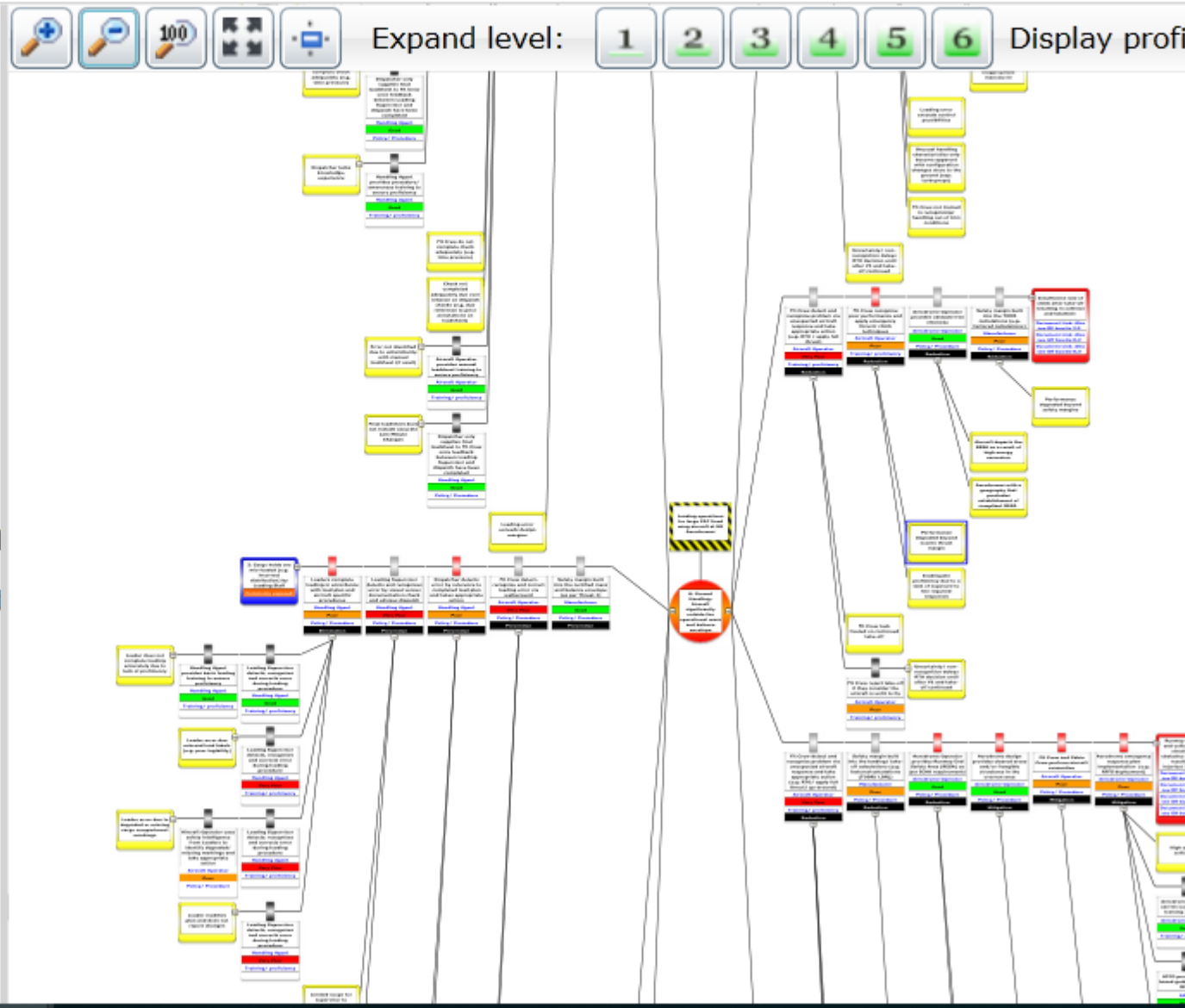
- 針對每個重大事故類型UKCAA皆發展出1個core bowtie與2個supplementary bowties，例如針對Runway Excursion：
  1. Inability to stop within distance (landing operations) <core bowtie>
  2. Loss of directional control (take-off and landing)
  3. Acceleration or take-off not as expected (take-off or departure)


https://www.caa.co.uk/Safety-initiatives-and-resources/Working-with-industry/Bowtie/Bowtie-templates/B
Civil Aviation Authority [GB]
搜尋...
Bowtie document library | ...
檢視(V)
我的最愛(A)
工具(T)
說明(H)
連結的網站
網頁快訊圖庫
Bowtie risk assessment models
About bowtie
Bowtie elements
Creating a simple bowtie
Identifying safety risk priorities
Implementing bowtie into safety management
Bowtie templates
How were the templates created?
• Airborne Conflict 5.1 Close proximity (Class A Airspace) (785 KB)
• Airborne Conflict 5.1 Close proximity (Class A airspace) (213 KB)
• Airborne Conflict 5.2 Close proximity (Class G Airspace) (91 KB)
• Airborne Conflict 5.2 Close proximity (Class G airspace) (71 KB)
• Airborne Conflict 5.3 Close proximity (Procedural (non radar)) (266 KB)
• Airborne Conflict 5.3 Close proximity (Procedural (non radar)) (74 KB)
• CFIT 3.1 Terrain separation deteriorating (arrival or departure (general)) (634 KB)
• CFIT 3.1 Terrain separation deteriorating (arrival or departure (general)) (227 KB)
• CFIT 3.2 Terrain separation deteriorating (Non-Precision Approach) (75 KB)
• CFIT 3.2 Terrain separation deteriorating (Non-Precision Approach) (58 KB)
• CFIT 3.3 Terrain separation deteriorating (Precision (IMC or Night)) (230 KB)
• CFIT 3.3 Terrain separation deteriorating (Precision (IMC or Night)) (70 KB)
• Fire 7.1 Hidden area fire (aircraft electrical systems) (447 KB)
• Fire 7.1 Hidden area fire (aircraft electrical systems) (165 KB)
• Fire 7.2 Cargo Fire (combustible materials) (306 KB)
• Fire 7.2 Cargo fire (combustible materials) (86 KB)
• Fire 7.3 Fire external to pressurised areas (fuel and combustible components) (233 KB)
• Fire 7.3 Fire external to pressurised areas (Fuel and combustible components) (77 KB)
• Ground Handling 6.1 Outside mass and balance envelope (Landing operations) (830 KB)
• Ground Handling 6.1 Outside mass and balance envelope (Landing operations) (223 KB)

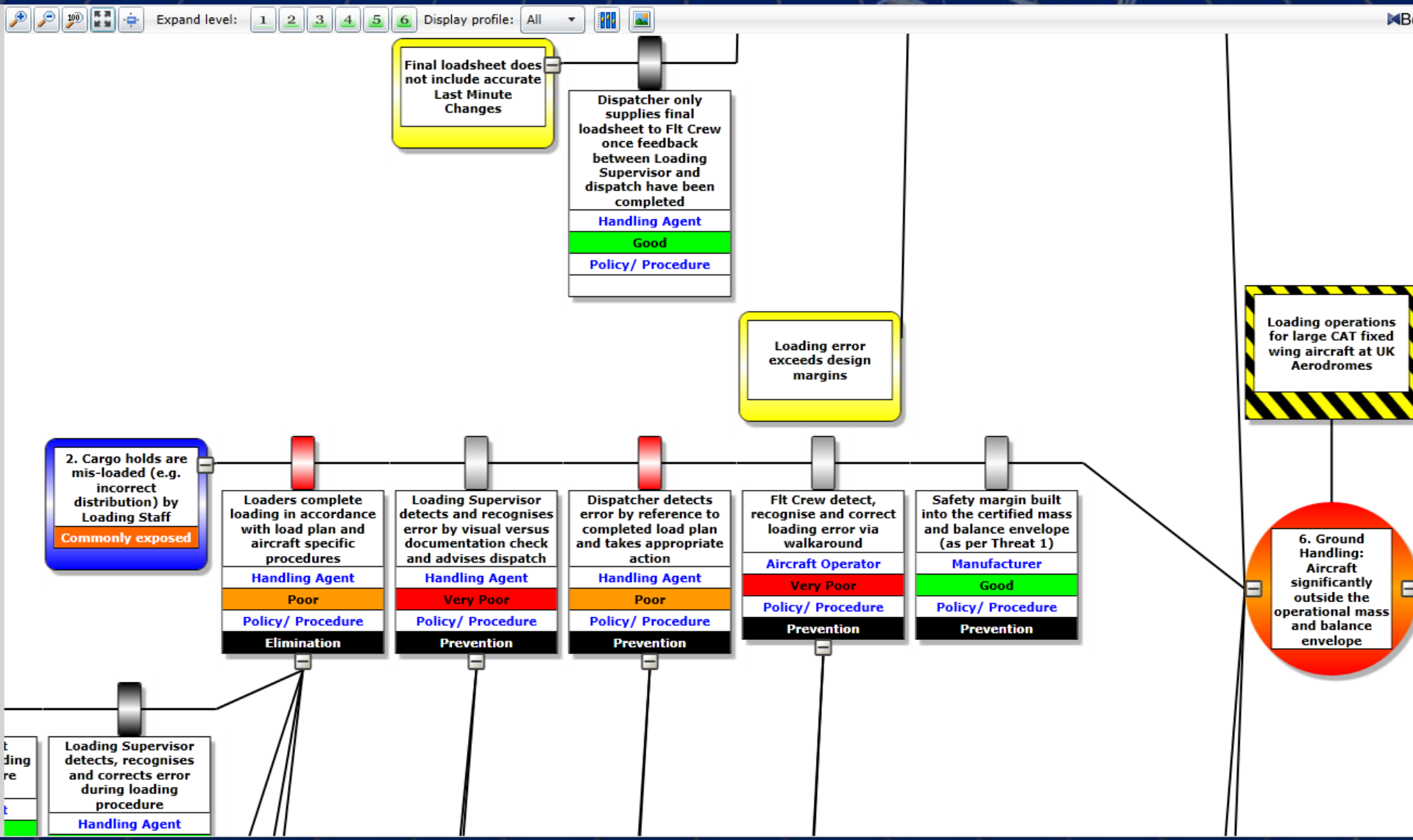
Current UK CAA Sig 7 Ver 11

- 1. Loss of Control
- 2. Runway Excursion
- 3. CFIT
- 4. Runway Incursion
- 5. Airborne Conflict
- 6. Ground Handling
  - 6.1 Loading operations
  - 6.2 Ground operations
  - 6.3 Cold weather condit
- 7. Fire
- 8. Umbrella

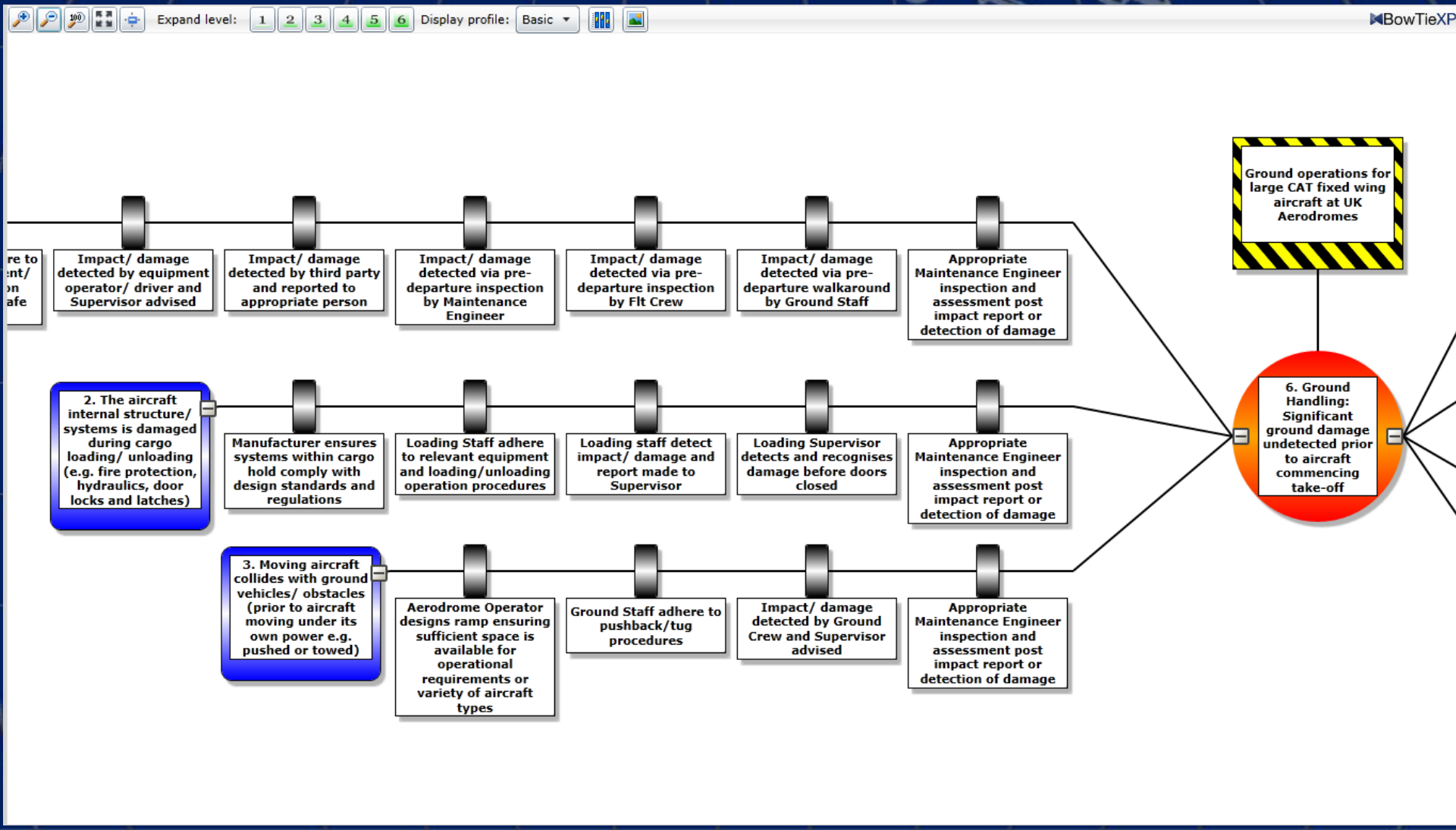
Expand level: 1 2 3 4 5 6 Display profi



Core Bowtie


Expand level: 1 2 3 4 5 6 Display profile: All
Final loadsheet does not include accurate Last Minute Changes
Dispatcher only supplies final loadsheet to Flt Crew once feedback between Loading Supervisor and dispatch have been completed
Handling Agent
Good
Policy/ Procedure
Loading error exceeds design margins
Loading operations for large CAT fixed wing aircraft at UK Aerodromes
2. Cargo holds are mis-loaded (e.g. incorrect distribution) by Loading Staff
Commonly exposed
Loaders complete loading in accordance with load plan and aircraft specific procedures
Handling Agent
Poor
Policy/ Procedure
Elimination
Loading Supervisor detects and recognises error by visual versus documentation check and advises dispatch
Handling Agent
Very Poor
Policy/ Procedure
Prevention
Dispatcher detects error by reference to completed load plan and takes appropriate action
Handling Agent
Poor
Policy/ Procedure
Prevention
Flt Crew detect, recognise and correct loading error via walkaround
Aircraft Operator
Very Poor
Policy/ Procedure
Prevention
Safety margin built into the certified mass and balance envelope (as per Threat 1)
Manufacturer
Good
Policy/ Procedure
Prevention
6. Ground Handling: Aircraft significantly outside the operational mass and balance envelope
Loading Supervisor detects, recognises and corrects error during loading procedure
Handling Agent

Supplementary Bowtie



Bowtie與日常安全管理功能之整合

- UKAAA建議航空業者以bowtie templates為基礎，發展自己的bowtie分析，並與日常的安全管理整合：

✓ 識別風險控管措施相關之作業並指派承辦的單位與人員，落實執行

✓ 針對風險控管措施與相關作業發展與實施自我督察計畫(barrier-based audits)

✓ 識別並整合與風險控管措施相關之安全資訊，例如：安全報告系統所獲某風險控管措施失效之報告

✓ 依據Bowtie分析結果，發展並監控相關安全績效指標

① Activity indicators: Prevention, Recovery, & Escalation factor controls

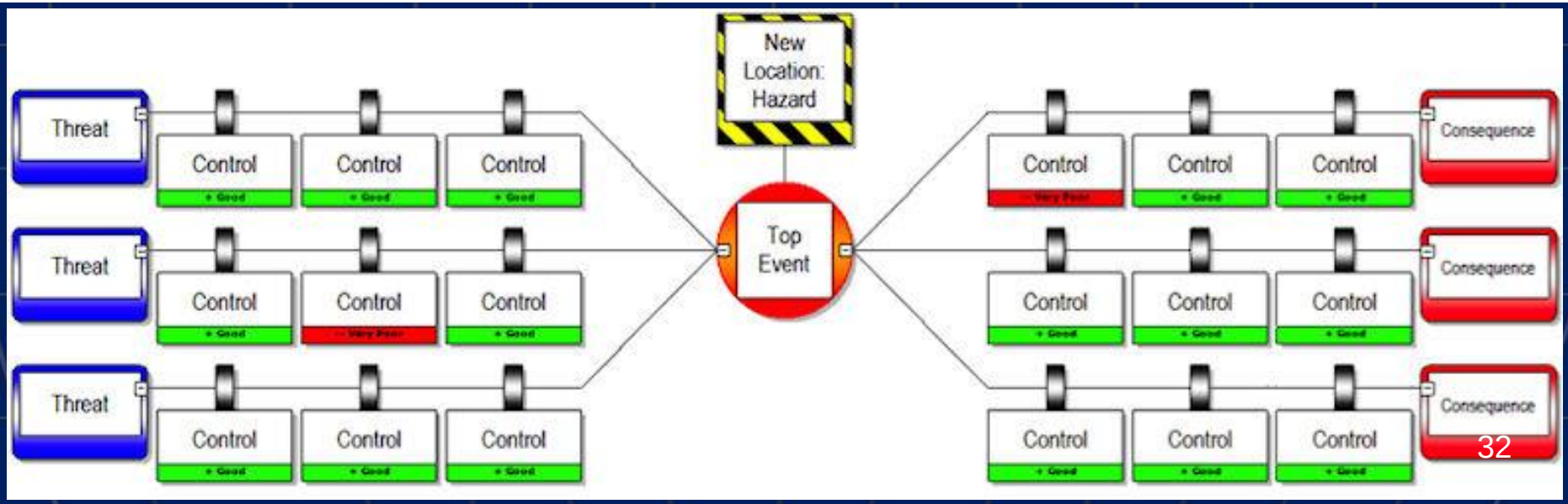
② Outcome indicators: Consequences, Top events, Threat, Escalation factors

Consolidated Barrier Strength Value (CBSV) Approach

- 藉由Bowtie分析安全危害控管措施之有效性，作為風險分析時可能性評估之依據

Sheet 6: Likelihood Table 7-Jan-14

Level	Descriptor	Likelihood Description
E	Certain/ frequent	Is expected to occur in most circumstances.
D	Likely/ occasional	Will probably occur at some time.
C	Possible/ remote	Might occur at some time.
B	Unlikely/ improbable	Could occur at some time.
A	Exceptional/	May occur only in exceptional circumstances.



Assess Likelihood Value of Risk Index

Step 1 - Assess Consolidated Barrier Strength Value (CBSV) of Unsafe Event (or Consequence) - Sht 6A

Step 2 - Derive Likelihood value of Unsafe Event (or Consequence) based on the CBSV obtained – Sht 6B

Sheet 6A - Barrier Strength Value To Likelihood Correlation

<<<

Table 1 - Barrier Strength Value (BSV)

Barrier Strength	Barrier Strength Description	Barrier Strength Value (BSV)
Poor	Weak, superficial or insignificant Barrier	1
Fair	Barely viable or adequate Barrier	2
Satisfactory	Reasonable or acceptable Barrier	3
Good	Effective, recognised and established Barrier	4
Excellent	Best or most robust Standard/ Regulation/ Practice	5

1

Table 2 - Consolidated Barrier Strength Value Assessment

Barrier Sequence #	Assessed BSV
1	2
2	4
3	3
4	3
5	2
6	1
7	
8	
	15
	12

3

<<< Consolidated BSV (# 1 to 6)

<<< Consolidated BSV (4 optimum barriers - # 2 to 5)

*Note to Consolidated BSV:

1. BSV summation of the actual number of barriers OR optimum number of barriers, whichever is the lesser.
2. Where actual number of barriers exceed the optimum number of barriers, select the barriers with the highest BSVs.

Table 3 - Optimum Number of Barriers

Severity Value of UE/ C	Severity Descriptor	Optimum Number of Barriers	Optimum CBSV*	Applicable CBSV-Likelihood Table
1	Insignificant	2	10	Table 4A
2	Minor	3	15	Table 4B
3	Moderate	4	20	Table 4C
4	Major	6	30	Table 4D
5	Catastrophic	8	40	Table 4E

2

*Note to Optimum CBSV: Optimum Number of Barriers multiply by 5 (highest BSV).

Table 4A: CBSV-Likelihood Correlation (Severity Value 1)

CBSV Range	Likelihood Value	Likelihood Descriptor
0-1	E	Certain/ frequent
2-3	D	Likely/ occasional
4-5	C	Possible/ remote
6-7	B	Unlikely/ improbable
8-10	A	Exceptional/ impossible

Table 4B: CBSV-Likelihood Correlation (Severity Value 2)

CBSV Range	Likelihood Value	Likelihood Descriptor
0-2	E	Certain/ frequent
3-5	D	Likely/ occasional
6-8	C	Possible/ remote
9-11	B	Unlikely/ improbable
12-15	A	Exceptional/ impossible

Table 4C: CBSV-Likelihood Correlation (Severity Value 3)

CBSV Range	Likelihood Value	Likelihood Descriptor
0-3	E	Certain/ frequent
4-7	D	Likely/ occasional
8-11	C	Possible/ remote
12-15	B	Unlikely/ improbable
16-20	A	Exceptional/ impossible

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Table 4D: CBSV-Likelihood Correlation (Severity Value 4)

CBSV Range	Likelihood Value	Likelihood Descriptor
0-5	E	Certain/ frequent
6-11	D	Likely/ occasional
12-17	C	Possible/ remote
18-23	B	Unlikely/ improbable
24-30	A	Exceptional/ impossible

Table 4E: CBSV-Likelihood Correlation (Severity Value 5)

CBSV Range	Likelihood Value	Likelihood Descriptor
0-7	E	Certain/ frequent
8-15	D	Likely/ occasional
16-23	C	Possible/ remote
24-31	B	Unlikely/ improbable
32-40	A	Exceptional/ impossible

Sheet 6: Likelihood Table

7-Jan-14

Level	Descriptor	Likelihood Description
E	Certain/ frequent	Is expected to occur in most circumstances.
D	Likely/ occasional	Will probably occur at some time.
C	Possible/ remote	Might occur at some time.
B	Unlikely/ improbable	Could occur at some time.
A	Exceptional/	May occur only in exceptional circumstances.

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④ 結語

結語

① Bowtie分析方法係ICAO所建議之安全風險管理方法，國外如英國、新加坡亦有應用的實例。

② 飛安會於本年度引進Bowtie分析軟體，後續將研究如何應用Bowtie分析方法於飛航事故調查，並視研究結果，於適當的機會與國內航空界分享。

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