Risk-informed Airport Fire Engineering Solutions for Operational Continuity

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ABSTRACT

Traditionally new airport terminal buildings have been designed to provide life safety of occupants and protection to the building and contents. Airport operational continuity is also essential for passenger safety and airport efficiency. This paper presents a risk model for the quantification of airport false alarm evacuation disruption and a parametric study to investigate the influence of terminal building area and the benefits of a range of false alarm preventative and mitigation measures.

INTRODUCTION

Traditionally, airports were small simple low-rise (one or two storey structures) with a gross floor area in the order of around 10,000m^2. As the demand for civil air transport increased, so did the size of Passenger Terminal Buildings (PTB). Figure 1 shows the increase in floor area of a major international hub airport against time.

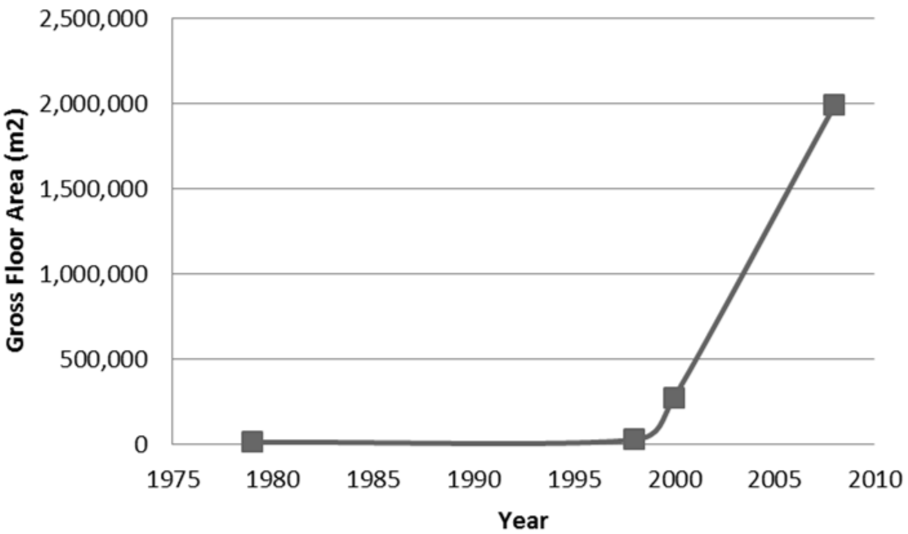

Figure 1: Major international airport floor areas against time

AIRPORT FIRE SAFETY DESIGN

With these increases in size, airport fire safety standards and fire engineering approaches were developed, including:

1. NFPA 415[1], and;
2. Fire Safety Engineering.

NFPA 415 (with other supporting NFPA standards) provides a comprehensive set of prescriptive guidance which addresses life safety and property protection.

The fire safety design solution for public areas in NFPA 415 generally comprises:

- Automatic Fire Detection in high hazard areas not continuously occupied;
- Sprinklers throughout;
- Smoke extraction from atria;
- Compartmentation (such as fire shutters), and;
- Total evacuation to assembly areas outside the building.

Many large airport PTBs adopt a zonal horizontal evacuation, although this is not the default evacuation strategy in NFPA 101[2] which is cited by NFPA 415.

In conjunction with NFPA 415, or other codes, the fire engineering approach has also been applied widely in the in large airport PTBs around the world, with the approach being used more widely as improved fire engineering analysis methods have become available. An example of a fire engineering of airports is the 'Cabin and Islands' approach developed by Beever [3].

The fire engineering approach generally comprises:

- Automatic Fire Detection in back of house areas;
- Sprinklers in fire load areas (not in low fire load areas with high ceilings);
- Local smoke extraction from retail units/food outlets;
- No compartmentation of the high open plan main space, and;
- Zonal and sub-zonal horizontal evacuation.

Many large international airports adopt a combination of these two approaches. Whilst both approaches have benefits for the mission continuity of the airport, neither explicitly considers operational interruption due to fires or false alarms.

Similarly, the literature regarding airport evacuation tends to concentrate on the prediction of total egress time as part of a fire engineering study of airport fire safety [4, 5 & 6].

AIRPORT FALSE ALARMS AND OPERATIONAL CONTINUITY

As well as life safety and property protection, mission continuity is critical for airport operations, false alarm evacuation disruptions cause:

- Slips, trips, falls and aggravate health conditions;
- Delays to passengers and missed connections;
- Compensation;
- Financial losses, and;
- Air traffic management challenges/risks.

To help reduce the number of false alarm evacuations, a number of approaches can be adopted including [1, 2 & 3]:

- No fire detection in public areas;
- A Positive Alarm Sequence (with an 180s investigation period);
- Evacuation zones;
- Horizontal evacuation;
- Sub-evacuation zoning, and/or;
- A 300s investigation period.

However, it is not clear which of these approaches is most effective or how many of them are needed for any particular airport PTB. Therefore an airport false alarm evacuation disruption risk model was developed.

Airport false alarm disruption risk model

Comprehensive quantification of the risks of disruption would require a significant amount of information and distributions of many variables and so is generally not undertaken. However, it is possible to gain some insight into airport false alarm evacuation business continuity risks with a simpler risk model:

$$R_d = F_d \, . \, C_d \tag{1}$$

Where: R_d = Risk (passenger.hours per year);
F_d = Frequency of false alarm evacuation (per year), and;
C_d = Consequences (passenger.hours).

$$F_d = F_a \, . \, P_e \tag{2}$$

Where: F_a = Frequency of false alarm evacuations (per year), and;
P_e = Probability of failure of false alarm activation investigation.

The Frequency of false alarm evacuations due to detector activations can be approximated by:

$$F_a = A \, . \, N_{afd}" \, . \, F_{fa} \tag{3}$$

Where: A = Area of the PTB (m^2);
N_{afd}" = Number of automatic fire detectors (per m^2), and;
F_{fa} = Frequency of false alarm activations (per detector year)

This model addresses false alarm evacuations from automatic fire detector activations and so does not address manual fire alarm call point false alarms or sprinkler flow false alarms (which experience shows are generally much lower than false alarms from automatic fire detection systems).

Therefore, from equations (2) and (3) it can be seen that:

$$F_d \propto A \tag{4}$$

The consequences of disruption are proportional to the number of passengers disrupted and the extent of the delay in terms of time (measured in passenger.hours).

$$C_d = N_p \, . \, t_d \tag{5}$$

Where: N_p = the number of passengers disrupted, and;
t_d = the time of the delay (hours).

From NFPA 101 (based on its occupancy) the number of people in an airport/evacuation zones is proportional to its area:

$$N_p \propto \frac{A}{N_{ez}} \tag{6}$$

Where: N_{ez} = the number of evacuation zones.

Similarly, the time of the delay may be proportional to the distance travelled during the evacuation. The distance travelled will depend on the size of the building (or smoke zone). Some people will be near the exit and not have far to walk to and from an assembly point/adjacent compartment/smoke zone. Others will be deep in the building/compartment/smoke zone and have much further to walk.

Therefore, the return travel distance will vary from nearly nothing to some distance depending on the dimensions of the building/compartment/smoke zone/assembly area locations. Therefore:

$$t_d \propto d_t \propto E_s \sqrt{\frac{A}{N_{ez}}} \tag{7}$$

Where: d_t = the distance travelled (m), and;
E_s = is a function of the geometry & evacuation strategy (0.5 for horizontal and 1.5 for vertical).

Therefore, from equations (5), (6) and (7):

$$C_d \propto \frac{A^{3/2}}{N_{ez}^{3/2}} \tag{8}$$

Therefore, it can be seen from equations (1), (4) and (8) that the risk of false alarm disruption is:

$$R_d \propto F_d.C_d \propto A^{5/2}$$

Therefore, if false alarm evacuation preventative or mitigation measures were taken, the risk of disruption would increase to the power of 2.5 of the airport's area.

Multiple evacuation zones has the effect of reducing the individual frequency by the number of evacuation zones, but then this frequency would then need to be multiplied by the number of evacuation zones, so the number of evacuation zones has no impact on the frequency of disruption. However, it will reduce the consequence of disruption in terms of the number of people and the time of disruption from equations (1), (4) and (8):

$$R_d \propto \frac{A^{5/2}}{N_{ez}^{3/2}}$$

Application of risk model

This airport disruption risk model has been quantified and validated against a number of large international airports in a number of different countries. The model was then used to parametrically quantify the baseline risk (i.e. no preventative or mitigation measures) for a range of different airport sizes (See Table 1).

Case No.	Case description	Public area of PTB (m2)	Number of Evacuatio Zones	Evacuation Strategy (1.5 = Vert) (0.5 = Hori)	Probability of failure of alarm investigatio	Frequency of fire alarm (/year)	Consequence of disruption (PAX.mins /evacuation)	Reputation risk of disruption (pax.h/year)
0	1960's PTB Single Storey/No AFD	10,000	1	0.5	1	0.7	4,167	49
1	1960's Passenger Terminal Building	10,000	1	1.5	1	14	12,500	2,917
2	1970's PTB Vertical Evacuation Strategy	20,000	1	1.5	1	28	35,355	16,499
3	1980's PTB Vertical Evacuation Strategy	50,000	1	1.5	1	70	139,754	163,047
4	1990's PTB Vertical Evacuation Strategy	100,000	1	1.5	1	140	395,285	922,331
5	2000's PTB Vertical Evacuation Strategy	200,000	1	1.5	1	280	1,118,034	5,217,492
6	2010's PTB Vertical Evacuation Strategy	500,000	1	1.5	1	700	4,419,417	51,559,869

Table 1: Increase in Reputation risk of disruption as a function of airport terminal building area

Table 2 indicates the effectiveness of a number of preventative and mitigation measures when gradually combined from cases 7 to 14.

Case No.	Case description	Public area of PTB (m2)	Number of Evacuatio Zones	Evacuation Strategy (1.5 = Vert) (0.5 = Hori)	Probability of failure of alarm investigatio	Frequency of fire alarm (/year)	Consequence of disruption (PAX.mins /evacuation)	Reputation risk of disruption (pax.h/year)
7	2010's PTB Two floors	500,000	2	1.5	1	700	1,562,500	18,229,167
8	2010's PTB No AFD in occupied areas	500,000	2	1.5	1	350	1,562,500	9,114,583
9	2010's PTB Positive Alarm Sequence	500,000	2	1.5	0.1	350	1,562,500	911,458
10	2010's PTB Evacuation Zones	500,000	10	1.5	0.1	350	139,754	81,523
11	2010's PTB Horizontal Evacuation	500,000	10	0.5	0.1	350	46,585	27,174
12	2010's PTB Smaller evacaution zone	500,000	20	0.5	0.1	350	16,470	9,608
13	2010's PTB Cabin concept	500,000	40	0.5	0.1	350	5,823	3,397
14	2010's PTB 300 second investigation period	500,000	40	0.5	0.01	350	5,823	340

Table 2: Decrease in Reputation risk of disruption as a function of the combination of a number of preventative and mitigation measures

DISCUSSION AND CONCLUSIONS

The main conclusions and discussion points from the paper are:

1. Airport operating experience shows that there is an increase of operational interruption and reputation risk with an increase in airport terminal building size.
2. An airport false alarm evacuation disruption risk model indicates that baseline risk is proportional to the area to the power of 2.5. For a large international hub terminal building, this represents a significant level of risk.
3. Although the annual expected passenger disruption for cases 5 and 6 are significant, they are not inconsistent with one evacuation simulation of 39,140 passengers which was predicted to take 3,541s [6]. In addition, the disruption time also includes the time to re-occupy the terminal building.
4. The airport false alarm evacuation disruption risk model shows that the number of evacuation zones reduces the risk to the power of -1.5 of the number of evacuation zones. Therefore, simply increasing the number of evacuation zones to limit the area affected is unlikely to fully compensate for the increase in reputation risk. This is because the frequency of disruption is not affected by the number of evacuation zones.
5. A generic parametric study of increasing PTB areas shows the significant potential extent of the increase of false alarm disruption risk. The parametric study also shows the potential benefits for a range of false alarm disruption preventative and mitigation measures used in combination.
6. The more detailed sub-zone level version of the airport false alarm evacuation disruption risk model can be used to quantify the risks and options for a specific airport. For exceptionally large international hub airports, additional false alarm evacuation preventative and mitigation measures should be considered to reduce the risk of disruption to as low as practicable.

REFERENCES

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