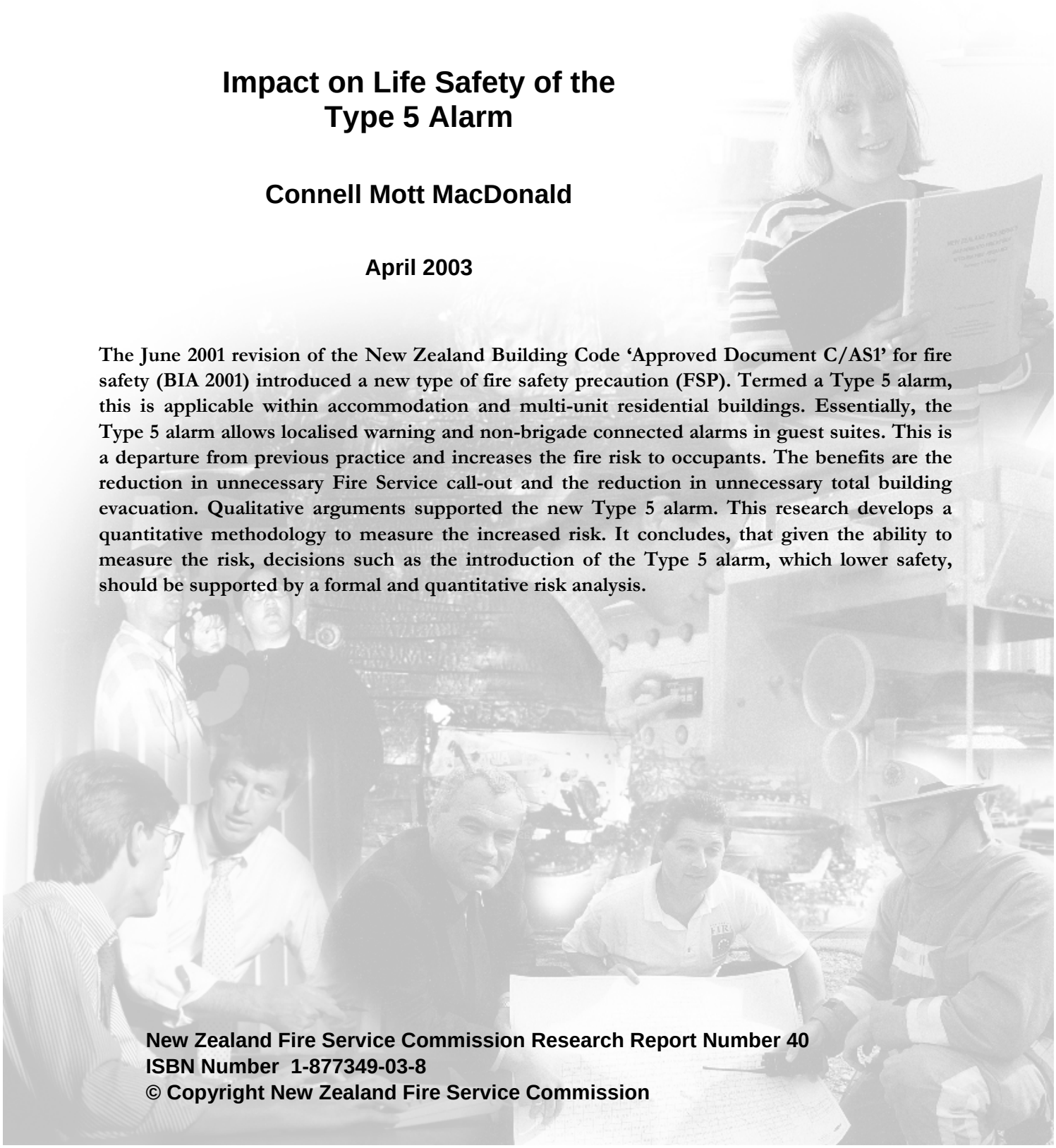
Fire Research Report

Impact on Life Safety of the Type 5 Alarm

Connell Mott MacDonald

April 2003

The June 2001 revision of the New Zealand Building Code 'Approved Document C/AS1' for fire safety (BIA 2001) introduced a new type of fire safety precaution (FSP). Termed a Type 5 alarm, this is applicable within accommodation and multi-unit residential buildings. Essentially, the Type 5 alarm allows localised warning and non-brigade connected alarms in guest suites. This is a departure from previous practice and increases the fire risk to occupants. The benefits are the reduction in unnecessary Fire Service call-out and the reduction in unnecessary total building evacuation. Qualitative arguments supported the new Type 5 alarm. This research develops a quantitative methodology to measure the increased risk. It concludes, that given the ability to measure the risk, decisions such as the introduction of the Type 5 alarm, which lower safety, should be supported by a formal and quantitative risk analysis.



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Abstract

The June 2001 revision of the New Zealand Building Code 'Approved Document C/AS1' for fire safety (BIA 2001) introduced a new type of fire safety precaution (FSP). Termed a Type 5 alarm, this is applicable within accommodation and multi-unit residential buildings. Essentially, the Type 5 alarm allows localised warning and non-brigade connected alarms in guest suites. This is a departure from previous practice and increases the fire risk to occupants. The benefits are the reduction in unnecessary Fire Service call-out and the reduction in unnecessary total building evacuation. Qualitative arguments supported the new Type 5 alarm. This research develops a quantitative methodology to measure the increased risk. It concludes, that given the ability to measure the risk, decisions such as the introduction of the Type 5 alarm, which lower safety, should be supported by a formal and quantitative risk analysis.

Executive summary

Introduction
Type 5 alarm

The June 2001 revision of the New Zealand Building Code 'Approved Document C/AS1' for fire safety (BIA 2001) introduced a new type of fire safety precaution. Termed a Type 5 alarm, this is applicable within accommodation and multi-unit residential buildings. Essentially, the Type 5 alarm allows localised warning and non-brigade connected alarms in guest suites. This is a departure from previous practice and increases the fire risk to occupants. The benefits are the reduction in unnecessary Fire Service call-out and the reduction in unnecessary building evacuation.

Motivation for research
Decision making tool

Qualitative arguments supported the new Type 5 alarm. This research demonstrates that a quantitative approach is available to assist in such decision making. This project contributes to a key research priority identified by the New Zealand Fire Service Commission: the cost-benefit study to support legislative change to improve fire safety.

Methodology
Event tree analysis

The methodology is based on an event tree analysis. Four event trees are developed that can be applied to most accommodation buildings with a Type 5 alarm. These event trees are paired; the Type 4 and 4e, ("e" denotes the Type 5 variation) and the Type 7 and 7e systems. Non-safe outcomes on each event tree are characterised by generic models comprising of limit state equations of escape time margin. The event trees and limit state equations are populated with probability distributions. The former gained from NZ fire incident statistics and the latter based on Swedish research. A fictitious but exemplar case study is then developed to provide a magnitude for the consequences. The analysis is run using Monte Carlo simulation for each event tree. The Type 4 risk profile is calibrated and the complete analysis model re-run. The measure of risk for the complimentary event trees are compared to quantify the increase in life safety. Because the fire origin is assumed in a guest room, which is the point of differentiation of the Type 5, the risk measures are not complete for the whole building but only the subset that will affect a Type 5.

Results

The case study results in the following mean individual fire risks (to life):

- 9.8×10^{-6} (Type 4) and 12.0×10^{-6} (Type 4e), increase 2.2×10^{-6}
- 1.3×10^{-7} (Type 7) and 1.5×10^{-7} (Type 7e), increase 0.2×10^{-7}

Conclusions

This research does not comment on the magnitude of the increased risk, as risk evaluation is the domain of the policy maker. However, this research does conclude, that given the ability to measure the risk, decisions such as the introduction of the Type 5 alarm which lower safety, should be supported by a formal and quantitative risk analysis. This research also concludes, that even allowing for sprinkler failure, the risk to life in sprinkler-protected buildings is typically two magnitudes of order better than in non-sprinklered buildings. Therefore, future research using multiple case studies may give consideration to the cost-benefit of fire safety systems incorporating fire sprinklers without the necessity of smoke alarm systems in corridors, assuming that alarms are required in guest rooms to detect smouldering fires. Future research may also incorporate a sub-model for fire barrier failure as a function of time, to allow for meaningful societal risk calculations.

Definitions

Consequence outcome of an event. Note: There may be one or more consequences, expressed positively or negatively, quantitatively or qualitatively. (ISO/PDTS 16732)

Consequence model a term used in this research to describe the limit state equation for escape time margin associated with the event tree path synonymous with outcome scenario.

Event tree a depiction of temporal, causal sequences of events, built around a single initiating condition. Note: A fire scenario in an event tree is given by a time-sequence path from the initiating condition through a succession of intervening events to an end-event (ISO/PDTS 16732). In this research the end event is termed the outcome scenario.

Event tree analysis a technique which describes the possible range and sequence of the outcomes which may arise from an initiating event. (AS/NZS 4360:1999)

Expected loss of life (ELL) a term used in this research to describe the probability of loss of life for a given outcome scenario.

Fire hazard potential for injury and/or damage from fire (from ISO 13943:2000, Fire safety – vocabulary). Note: In the context of fire risk assessment, "fire hazard" may be understood either as a measure of consequence, using the term "potential" in a quantitative sense, or as a physical object or condition with the potential to affect the probability or consequences of certain fire scenarios (ISO/PDTS 16732).

Fire risk (a) When defined as risk of an event or scenario, the combination of the probability of that event or scenario and its consequence. (b) When defined as risk of a design, the combination of the probabilities and consequences of all events or scenarios associated with the design.

Note 1: The general mathematical formulation of a combination of the probabilities and consequences of all scenarios associated with a design is:

Risk = $\sum f$ (probability, consequence of a given scenario), for all scenarios
(from ISO/TR 13387-1:1999, Fire safety engineering).

The two most frequently used specific mathematical formulations are:

Risk = $\sum$ (probability x consequence of a given scenario), for all scenarios (from ISO/TR 13387:1999, Fire safety engineering; and ISO 13943: 2000, Fire safety – vocabulary).

Risk = $\sum$ (probability of a given scenario), for all scenarios where the consequences exceed the specified safety threshold (from ISO/TR 13387:1999, Fire safety engineering).

Note 2: "Fire risk" requires a scenario structure and an explicit decision on the treatment of every scenario. If calculations are performed on only a small number of scenarios, then either all other scenarios must be shown to be represented by the ones analysed, or the ones not represented must be shown to be excluded from the definition of risk being used (e.g., risk against fires with a single point of origin, as a definition that would explicitly exclude fires that are started at several different points).

Note 3: Fire risk does not require explicit observation or mathematical calculation but can be done, in whole or in part, non-quantitatively and/or through the use of subjective estimates (e.g., engineering judgement).

Note 4: The choice of the function linking probability and consequence can be used to capture risk aversion. For example, if the consequence value is raised to a power greater than one before being multiplied by probability, this will quantify the common belief that a fixed value outcome is less preferred as the expected value of a risky situation than as the certain outcome of a risk-free situation. (ISO/PDTS 16732)

Limit state a state beyond which the structure no longer satisfies the design performance requirements (from ISO 2394:1998, General principles on reliability for structures). Note: In the context of fire risk assessment, a "limit state" defines a threshold or limiting value on a consequence severity scale, usually in the context of a time-sequence state description of the fire scenario. This means the structure can return to a state that does not exceed the limit state. The "limit state" concept can be applied to designed objects other than structures. (ISO/PDTS 16732)

Monte Carlo a process of sampling from the universe of fire scenarios and other system conditions, in order to produce a manageable calculation burden when closed-form analysis is not possible. Note: "Monte Carlo" simulation is not a type of probabilistic model but is rather a numerical calculation procedure for sampling-based analysis using a probabilistic model. The use of Monte Carlo methods does not eliminate the need to define and justify the relevant probability distribution functions and does not provide a rationale for the default usage of any simple standard distributions (e.g., uniform, normal).

Outcome scenario a term used in this research to describe the limit state equation for escape time margin associated with the event tree path and synonymous with consequence model.

Positive alarm sequence An automatic sequence that results in an alarm signal, even when manually delayed for investigation (NFPA 72:2002 'National Fire Alarm Code') – similar to some Type 5 alarm applications where monitored staffing stations have time delays.

Reliability probability that a unit will perform a required function for given conditions and for a given period of time (from ISO 921: 1997, Nuclear energy – vocabulary). Note: Reliability applies to the performance of any building or product design feature whose performance can influence the course of fire development, thereby contributing to the specification of the fire scenario that occurs and the risk consequences associated with that scenario. It is also possible that the design feature performance is better described by a range of partial successes or partial failures. This requires a more general and flexible definition than the one given above. (ISO/PDTS 16732)

Risk (see also fire risk) the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood. (AS/NZS 4360:1999)

Risk analysis a systematic use of available information to determine how often specified events may occur and the magnitude of their consequences. (AS/NZS 4360:1999)

Risk assessment the overall process of risk analysis and risk evaluation. (AS/NZS 4360:1999)

Risk evaluation the process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria. (AS/NZS 4360:1999)

Risk, individual a measure of fire risk limited to consequences experienced by a particular individual or entity. Note: For example, if the fire risk measure is probability of an unwanted consequence, such as death, then individual risk would be an estimate, typically expressed as events per unit time, of the probability of that unwanted consequence for a specific individual. The risk measure may be expressed as conditional on exposure to the hazard, such as being at a hazardous location. Individual risk is independent of the number of persons affected. Contrast with "risk, societal." (ISO/PDTS 16732)

Risk, tolerable In the risk evaluation phase of a risk assessment, risks that satisfy defined tolerability criteria and so do not form a basis for required change to a design proposal. (ISO/PDTS 16732)

Risk, societal a measure of fire risk combining consequences experienced by every affected person and group. Note 1: Combining consequences to all affected parties will also affect the overall probability of an incident. It will equal the sum of the individual risks of all affected individuals but can be expressed as a rate relative to the number of affected or exposed people, in which case it will be in a form directly comparable to the component individual risk measures. (ISO/PDTS 16732)

Sensitivity a measure of the degree to which a small perturbation of a system will create a large change in system status. Note: In a fire risk assessment, analysis of "sensitivity" of the calculation to small variations in each of the variables, parameters, and relationships provides information useful in setting priorities for a subsequent analysis of "uncertainty," by focusing attention on those variations most likely to change the conclusion of the analysis. (ISO/PDTS 16732)

Theoretical annual loss of life (TALL) a term used in this research as the sum of ELL across all scenarios and assuming 100% building occupancy rate.

Type 4 Alarm an automatic fire alarm system with smoke detectors and manual call points. (BIA 2001)

Type 4e Alarm an automatic fire alarm system with smoke detectors and manual call points. A Type 5 Alarm is permitted as an alternative alarm system within firecells containing sleeping accommodation. (BIA 2001)

Type 5 Alarm an automatic fire alarm system with modified smoke/heat detection and manual call points. A variation of the Type 4 and Type 7 Alarm systems permitting part of the smoke detection component to comprise only a local alarm. (BIA 2001)

Type 7 Alarm an automatic fire sprinkler system with smoke detectors and manual call points. (BIA 2001)

Type 7e Alarm an automatic fire sprinkler system with smoke detectors and manual call points. A Type 5 Alarm is permitted as an alternative alarm system within firecells containing sleeping accommodation. (BIA 2001)

Uncertainty a quantification of the systematic and random error. (ISO/PDTS 16732)

Variability a quantification of the probability distribution function for a variable, parameter, or condition. (ISO/PDTS 16732)

CHAPTER 1: Introduction

1.1 Preamble

The June 2001 revision of the New Zealand Building Code 'Approved Document C/AS1' for fire safety (BIA 2001) introduced a new type of fire safety precaution (FSP). Termed a Type 5 alarm, this is applicable within accommodation and multi-unit residential buildings. Essentially, the Type 5 alarm allows localised warning and non-brigade connected alarms in guest suites. This is a departure from previous practice and increases the fire risk to occupants. The benefits are the reduction in unnecessary Fire Service call-out and the reduction in unnecessary total building evacuation.. Qualitative arguments supported the new Type 5 alarm. This research demonstrates that a quantitative approach is available to assist in such decision making.

1.2 Motivation for research

This project contributes to a key research priority identified by the New Zealand Fire Service Commission: the cost-benefit study to support legislative change to improve fire safety.

New Zealand's Building Act 1991 similarly imposes a cost-benefit test for all proposed changes to fire safety requirements. In the case of the changes leading to the introduction of the Type 5 alarm the cost-benefit test was qualitatively based.

Understanding and assessing the benefits of new or proposed requirements should involve a sound appreciation of the risks associated with competing priorities. The benefits include the reduced frequency of unnecessary fire service call-out and the reduced frequency of unnecessary total building evacuation. The increased risk is dealt with subjectively. This research develops an objective technique for analysing the increased risk.

The methodology has a wider application as a decision making tool, than the specific example provided.

1.3 Risk management

Risk analysis and risk evaluation are sub-components of risk assessment, which itself is a sub-component of a risk management process. A good overview description of the risk management process applied to engineering risk is given by Keey (2000). The risk management process described below, is reproduced from the joint Australia and New Zealand Standard on Risk Management AS/NZS4360:1999 (SNZ 1999).

Descriptions of risk analysis, risk evaluation and risk assessment are included in the definitions section and are sourced from AS/NZS 4360 (SNZ 1999). Because these are key terms in this research, the definitions are repeated here.

- *Risk analysis* a systematic use of available information to determine how often specified events may occur and the magnitude of their consequences

- *Risk evaluation* the process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria

- *Risk assessment* the overall process of risk analysis and risk evaluation.

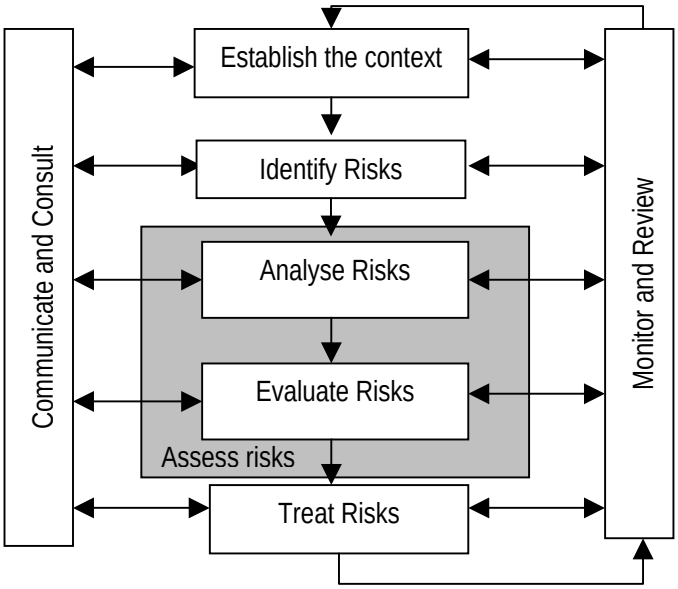

Figure 1: Risk management overview, reproduced from AS/NZS

1.4 The Type 5 alarm

Where an automatic fire alarm system is required by the Acceptable Solution C/AS1 in buildings with accommodation or residential purpose groups, the system is either a Type 4e alarm or Type 7e alarm, that is; automatic smoke detectors or fire sprinklers and automatic smoke detectors. The annotated "e" allows that "a Type 5 is permitted as an alternative alarm system within firecells containing sleeping accommodation".

The Type 5 is described in Appendix A of C/AS1as follows:

> *A variation of the Type 4 and Type 7 alarm systems permitting part of the smoke detection component to comprise only a local alarm*
>
> *The local alarm system, activated by the presence of smoke, has audible alerting devices to warn only the firecell occupants and the building management, where such management exists. Examples of such management situations are motels, hotels or multi-unit residential accommodation in a retirement village.*
>
> *The local alarm component of a Type 5 system:*
>
> *a) Is restricted to single firecells containing sleeping accommodation being household units in purpose group SR or individual suites in purpose group SA. The local alarm system shall not be extended to other areas such as exitways or common spaces which shall retain a Type 4 smoke detection system, and*
>
> *b) Shall be permitted only where an automatic fire detection and alarm system activated by heat detectors (part of the main fire alarm system) is also installed in sleeping firecells which do not already have an automatic sprinkler system.*

The Type 5 description is followed by the comment:

> *The local smoke alarm provides the necessary early fire warning for the firecell occupants. If the firecell is unoccupied or if the occupants fail to respond to the local alarm and there is*

a developing fire, the automatic alarm activated by either heat detectors or sprinklers will alert the Fire Service and occupants in the building.

The small increase in risk, due to the brief delay between activation of the local smoke alarm and activation of the automatic alarm, is more than compensated for by avoiding Fire Service call out and total building evacuation in the event of a false alarm in one firecell.

This last paragraph is particularly relevant to this research which puts a measure to "*the small increase in risk*".

Fire alarm installations are subject to the Standard NZS4512 'Fire alarm systems in buildings' (SNZ 1997). However, the Standard does not specifically cater for the new Type 5 alarm leading to ambiguous installation practice. The Standard is currently undergoing a significant revision and in its current form DZ4512 (SNZ 2002) appears to more specifically address and define the installation practice for the Type 5 alarm.

1.5 Event tree analysis

The risk analysis of the impact of the Type 5 alarm is done using event tree analysis. Event tree analysis is a technique which describes the possible range and sequence of the outcomes which may arise from an initiating event. A simple example of an event tree is described by Figure 2, which is reproduced from Frantzich's work (Frantzich 1997).

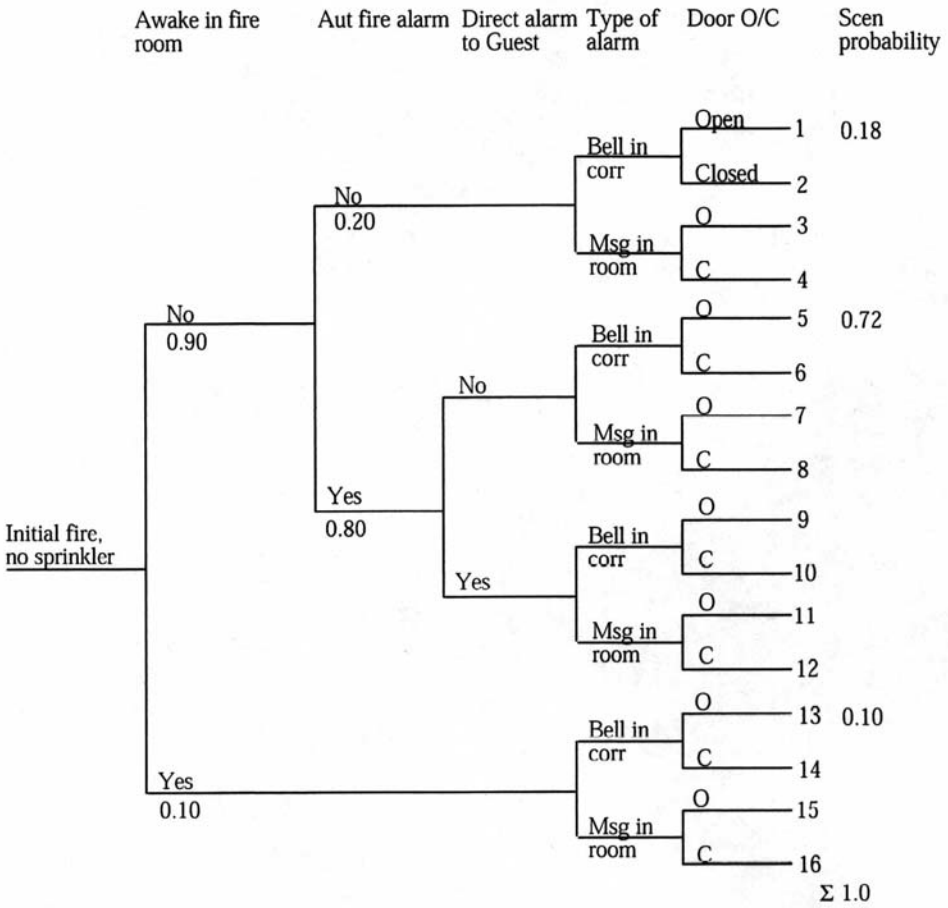

Figure 2: Example Event Tree, reproduced from Frantzich (1997)

Complementary pairs of event trees are developed for the Type 4 and 4e alarms and the Type 7 and 7e. The event trees are appended. A theoretical annual loss of life (TALL) is calculated for each event tree. The complementary pairs are compared to determine the increase in risk, measured in loss of life, of the Type 5 alarm.

The initiating event is a fire in an accommodation building followed by a second event determining whether the origin is a guest room or suite, ie; the point of difference of a type fire alarm. If the fire is not in a guest room of suite then a 'safe' result is returned, which is a misnomer because it is more correct that the result is not of significance to the Type 5. For this reason, the risk calculation is not for a whole building, but for a hotel building where the guest room is the location of origin‡. Therefore, in interpreting the results during risk assessment, care is taken to discuss the relative or differential increase in TALL between the complementary event trees rather than absolute risks.

Probabilities and consequences are assigned to the event tree. Each is discussed in detail in the following chapters. Uncertainty, error and indeterminacy are treated by assigning distributions to each of the variables. Risk is calculated across the event tree by using Monte Carlo Simulation.

‡ To give this some context: From US data (NFPA 1999), 30 of 38 of hotel fire deaths between 1992 to 1996 are from the guest room being the room of origin.)

CHAPTER 2: Probabilities

2.1 Fire incidence

Fire incidence data in accommodation§ buildings is a particularly important statistic as it is the starting point of the event tree analysis and the final risk-calculation result is linearly proportional to this value. Due to its importance, NZ data is checked against several international sources. In this research fire incidence is report per annum and per 100 occupants. This does not, at this stage, factor occupancy rates. These appear latter in the analysis.

New Zealand data

NZ fire data is gained from the NZFS Fire Incidence Reporting System database (FIRS) which is published in a user friendly format as the Emergency Incident Statistics (EIS) book (NZFS 2001). A useful discussion of the limitations of such FIRS-based data can be found in 'Source of Uncertainty' in Chen (2001).The EIS fire incident data is manipulated by relating it to accommodation capacity, to provide a rate ie fires per year per capacity. This is necessary for the incidence to be a function of building size.

Accommodation capacity data is gained from Statistics New Zealand (2002). Full (100%) occupancy is assumed. This is necessary to calculate first the theoretical annual loss of life (TALL) from which the expected loss of life (ELL) will later be calculated, based on actual occupancy rates. The capacity data is taken from the period June to May to match the NZFS EIS reporting period.

The fire frequency data was first reduced to include buildings likely to have a Type 5 Alarm ie; flats > 20 Units, boarding houses, hotels, motels and lodges. It was further reduced, ie the value appearing in parenthesis in Table 1, to the subset of those buildings likely to be categorised as 'guest' rooms in the Statistics NZ survey, ie they exclude flats and apartments but include hotels, motels and lodges, this is necessary to match and marry the data with rooms numbers to gain a rate per capacity. The Statistics New Zealand data has also been reduced to exclude caravan parks, camping grounds and home-stays.

Year	No. of fires	No. of beds (10^3)	Incidence (p.a. & 100 cap.)
1997	218 (102)	52.4*	0.19
1998	253 (127)	55.1	0.23
1999	224 (88)	59.5	0.15
2000	229 (88)	62.3	0.14
2001	187 (99)	65.0	0.15
		μ =	0.17
		σ =	0.034

Table 1: NZ fire incident data for accommodation buildings

Notes to Table 1:

- (*) assumed value, in this case extrapolated from least squares fit of other four years' data, the correlation is excellent, as expected for such a large sample as accommodation capacity with low annual change, the correlation coefficient, r = 99% (and r^2 = 98%)
- The corporate year 1996/97 is referred to as 1997 etc
- The results are reported to two or three significant figures, anything more detailed implies false accuracy

§ ie; non-domestic residential such as hotels, motels, hostels and large multi-unit residential apartments

USA data

The NFPA (1999) data is the most comprehensive reviewed in terms of numbers and location of fires in the building types of interest. Unfortunately, it doesn't relate the number of fire starts to the number of total buildings; Hotels, Motels and Apartments or Hotel rooms, from which an incidence probability could be gained. However, international hotel industry data is available from Mintel (1998), including room numbers. This can be used to approximate an incident probability. The Mintel data is for the period 1990 to 1997 whereas the NFPA fire data is 1985 to 1996. Therefore, the period 1990 to 1996 is matched for the purposes of calculating an incidence statistic with an average number of rooms per Hotel assumed at the 1995 value.

Year	No. of fires	No. of rooms ($\times 10^3$)	Incidence (p.a. & 100 occ's)
1985	1,800	--	--
1986	1,600	--	--
1987	1,500	--	--
1988	1,800	--	--
1989	1,600	--	--
1990	1,600	3,033	0.053
1991	1,300	3,057	0.043
1992	1,300	3,080	0.042
1993	1,000	3,080	0.032
1994	900	3,175	0.028
1995	1,000	3,225	0.031
1996	1,100	3,275	0.034
1997	--	3,323	--
		μ =	0.038
		σ =	*0.0080*

Table 2: USA fire incident data for accommodation buildings

Notes to Table 2:

- The Mintel data doesn't report number of rooms in 1991, a value was linearly interpolated on the basis that the figures for 1990, 1992 & 1993 were reasonably constant (< 1% difference)
- The Mintel average number of rooms per Hotel / Motel is gathered from the major chains only. It may be assumed then that the figure may be lower, however the Mintel figure is used as it produces a conservative result of a higher incidence rate per Hotel / Motel

Swedish data

Frantzich (1997) bases probability of guest room fire starts, on limited data of hotel fires in the Swedish city of Helsingborg over a period of seven years. In this period, there were five fires for a total of 1431 hotel rooms. This is represented as a probability of 0.05 fires per year, per 100 hotel rooms. An important note about this data set is that the five fires were five fires that the Fire Service attended. It was reasoned that this approximated well to the actual number of fires on the basis that most Hotels in Helsingborg have brigade-connected automatic fire alarms. This leads to the simplifying assumption that if there is a fire using this probability, then it is a fire that has grown beyond the incipient stage, which is useful for a later event.

Period (years)	No. of fires	No. of rooms	Incidence p.a. & 100 occ's
7	5	1,431	0.050

Table 3: Swedish fire incident data for accommodation buildings

British Data

Annex B to the draft British Standard DD240 ,1:1997 (BSI 1997) is an informative annex entitled 'Selected data for use in probabilistic risk assessment'. As the title suggests, it has a variety of data useful to quantitative risk assessment. Tables B1 to B3 of the Annex provide data for probability of fire starts by occupancy. Disappointingly, accommodation buildings are not included. The closest occupancy type is 'Dwellings' which are at an incidence rate of 3.0×10^{-3} per occupancy per year. This research does not attempt to correlate these statistics to accommodation.

Alternatively, the Fire Protection Association (Scoones 1994) report fire starts in hotels and other accommodation buildings as an annual figure from 1998 to 1992. As with the USA data, the Mintel data is matched to derive incident statistics as per Table 4.

Year	No. of fires	No. of rooms ($\times 10^3$)	P(Incidence) (p.a. & 100 occ's)
1988	1,872	497*	0.38
1989	2,188	497*	0.44
1990	1,900	497	0.38
1991	1,752	468**	0.37
1992	1,805	438	0.41
		μ =	0.40
		σ =	*0.025*

Table 4: British fire incident data for accommodation buildings

Notes to Table 4:
- (*) assumed values
- (**) interpolated value(s)

Summary

The data is summarised in Table 5.

Source country	P(Incidence) Per annum and per 100 occupants
New Zealand	0.170
USA	0.038
Swedish	0.050
British	0.400
	μ = 0.1645

Table 5: International fire incident data for Accommodation buildings

Notes to Table 5:
- The Swedish data, given such a low sample size, returned a mean result very similar to the USA data
- The UK data is a magnitude of order higher than the USA and Swedish data
- The NZ data is somewhere between the UK and US data

NZ statistics are based on a smaller sample size than either the US or UK data sets, however they are clearly of the most relevance to this research. It had originally been intended to supplement the NZ statistic with international data to increase confidence (by increasing sample size). However, it is clear that there are some regional differences and so since the NZ data is within a magnitude of order of comparable countries, this research will use the NZ mean incidence, albeit adjusted for uncertainty.

Table 1 presents a mean and standard deviation of NZ fire incidence. The deviation is a representation of annual variability in the data rather than a representation inclusive of uncertainty.

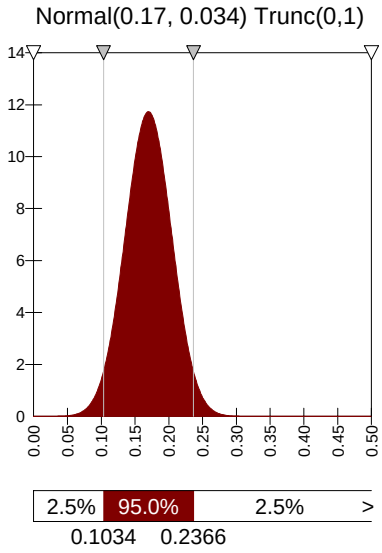

Figure 3: Probability distribution for fire incidence (per annum per 100 occupants)

2.2 Fire location (guest room / suite)

This event determines the fire location in terms of guest room / suite or not. It determines whether the automatic alarm is via a Type 5 or conventional Type 4 or 7 ie if the fire origin is elsewhere than in a hotel or apartment sleeping area, then by definition the alarm will be 'global', rather than 'accommodation local'. Fires elsewhere than in a Type 5 Alarm zone are not of interest to this research. Because of this, it is important to note, that the risk profiles ultimately generated in this analysis are not complete building risk profiles, ie the TALL and ELL will be not only for (say) a hotel fire, but a hotel fire conditional upon a guest room / suite fire origin. The source for this data is the Emergency Incident Statistics book (NZFS 2001).

EIS reports bedrooms as accounting for an average 11.3% of residential fires over the five year reporting period. These figures are reported annually in Column (4) of Table 6 below, so that annual variations can be reported as a standard deviation. This data must be interpreted with care, since by far the largest proportion of residential fires are domestic single unit households (83% five year mean) rather than accommodation fires where a Type 5 alarm is expected to be present. Therefore it is assumed that a domestic bedroom location correlates to an accommodation bedroom / suite fire. Consider Column (5), a proportion of fires were unrecorded. The figures are adjusted pro-rata allowing for this origin-unrecorded blank in FIRS. Consider Column (6), by far the largest single location contributor is the kitchen (28.2% five year mean) and in some accommodation cases, the kitchen will be in the Type 5 Alarm zone, especially in NZ motels and accommodation bed-sits. This is why the term suite is also used. Therefore, given that 11% (five year mean) of residential fires are in accommodation buildings of interest we qualitatively assume that 10% of this stock will have kitchens in the Type 5 Alarm zone, leading to an adjustment of 1.1% to bedroom / suite fire location.

Year (1)	Bedroom / suite fires (2)	All origins (3)	% bedroom / suite (4)	Adjusted % Unrecorded (5)	Adjusted % cooking (6)	P(bedroom / suite) (7)
1997	632	4,762	13.3	+ 1.7	+ 1.1	0.161
1998	596	4,863	12.3	+ 1.7	+ 1.1	0.151
1999	487	4,484	10.8	+ 1.6	+ 1.1	0.135
2000	428	4,564	9.4	+ 1.2	+ 1.1	0.117
2001	423	3,973	10.6	+ 1.9	+ 1.1	0.136
					μ =	0.140
					σ =	*0.015*

Table 6: Fire location data

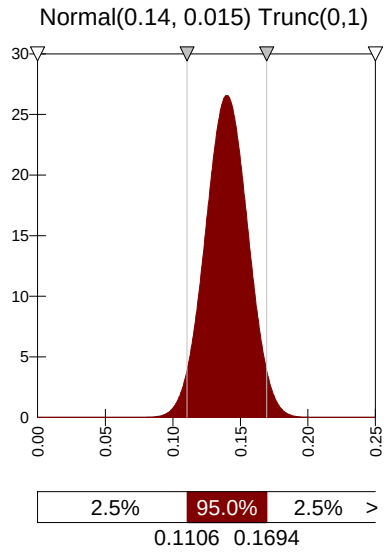

Figure 4: Probability distribution for fire located in bedroom / suite

2.3 Fire growth beyond incipient stage

This event determines whether the fire grows beyond the incipient phase to potentially life threatening and assumes that incipient fires in themselves are not life threatening. Because the fire incidence statistic is based on fires attended by the fire service and excludes false alarms, the probability of fires not growing beyond an incipient stage approaches zero, or rather the probability that the fire does grow beyond incipient stage is almost unity. However, to allow for variability, it is assumed that 2% of fire events, that were not false alarms and that were attended and recorded by the fire service, would not have grown beyond the incipient stage.

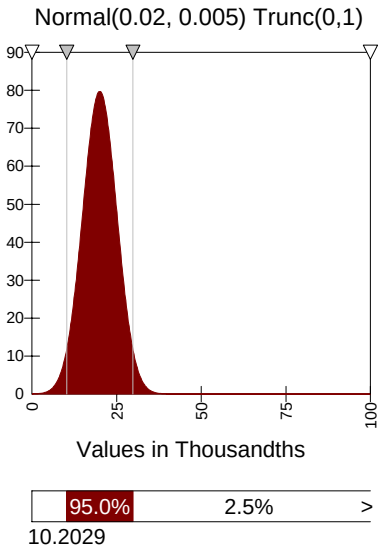

Figure 5: Probability distribution for fire not growing beyond incipient stage

2.4 Occupant awake

This event is concerned with whether an occupant is awake, yes and no states lead to different parameters in the consequence model, most notably in the occupant reaction time. In determining this probability a simplifying assumption is made that if the time of fire event is between certain hours then the occupant is awake (06:00-21:59), or else they are asleep (22:00 – 05:59). The source for NZ data is the Emergency Incident Statistics book (NZFS 2001). The results are summarised in Table 7. The probability is determined from 'all structure' fires. Unfortunately residential fires (or better still, accommodation fires) are not distinguished in the EIS.

Year (1)	Fires 22:00-05:59 (2)	Fires 06:00-21:59 (3)	P(awake) (4)
1997	1,498	5,627	0.790
1998	1,487	5,625	0.791
1999	1,385	5,158	0.788
2000	1,399	5,282	0.791
2001	1,182	4,432	0.789
		μ =	0.790
		σ =	0.001

Table 7: Occupant awake

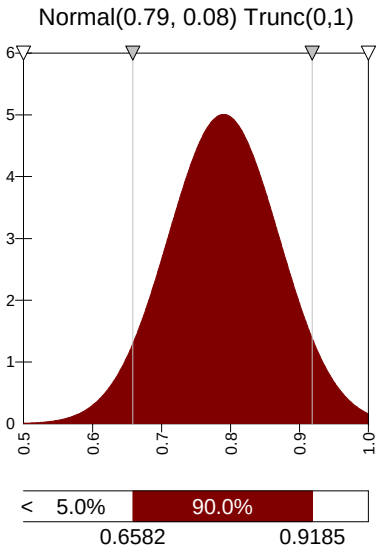

Figure 6: Probability distribution for occupant awake

2.5 Manual suppression

This event is concerned with whether the fire is manually controlled prior to it becoming life threatening. This event differs between whether the occupant is awake or asleep. Here the data is poor. The only directly relevant reference found was from 1968 where Chandler (1968) reports, of hotel fires, that 53% are 'tackled' by occupants before Fire Service attendance and 'nearly half' of these are extinguished before Fire Service attendance. Assume 'nearly half' refers to 25% of hotel fires and that this is applicable now, as it was in 1968. To further simplify, assume that this refers to occupants that were awake and unawake occupants do not manually suppress the fire.

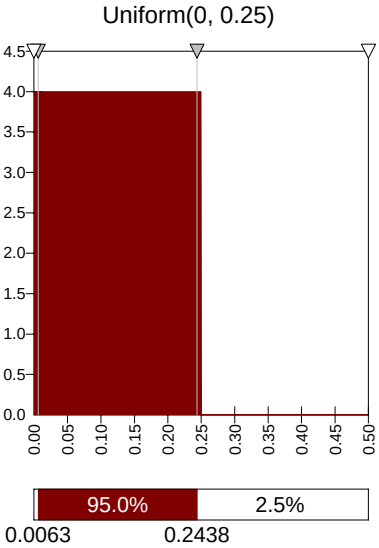

Figure 7: Probability distribution for manual suppression if occupant awake

2.6 Automatic suppression

This event is concerned with whether the fire is automatically controlled prior to it becoming life threatening. Effectively, for the building type of interest, it amounts to whether a sprinkler system is present or not.

It is assumed that if there is an automatic fire sprinkler system, and if it is effective, then the fire will not be life threatening. This is justified by the fact that there's been only one reported fatality in NZ in a sprinkler-protected building and the circumstances were unique enough for that fatality to be deemed statistically insignificant. This is not to say that sprinklers are 100% effective, for there is a probability of failure, in which case they are present but ineffective. If sprinklers are not present, then it is assumed that there is no automatic suppression, and the event tree directs towards a life threatening scenario since earlier events have dealt with incipient non-growing fires and manual suppression.

In the case where sprinklers are present, Marryat (1988) reports sprinkler reliability at 99.5%. This is very high, by international terms, where reliability is reported from 81.3% to 99.5% (Budnick 2001). However, the high value is assumed suitable rounded down to 99%, as NZ has an effective regime of installing, commissioning and maintaining systems.

With the standard deviation being (deliberately) set as the difference between the mean and 100%, so that the distribution is slightly distorted, as shown in Figure 8. Assume also, that p(automatic suppression: no sprinklers) is 0.

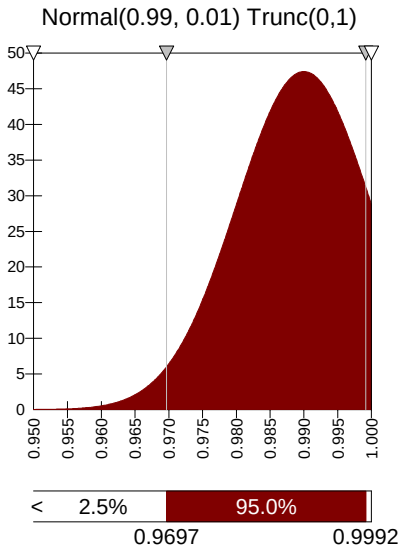

Figure 8: Probability distribution for automatic suppression if sprinklers installed

2.7 Automatic alarm

This event is concerned with unawake occupants receiving an automatic smoke alarm, and sets up the next event which is the key point of difference of the Type 5 alarm. Unlike the previous events, (sprinklers) there will be smoke detectors present in all Type 5 Alarm buildings. The probability of this event is taken as the reliability, ie 1 – p(failure), of smoke detectors. A reliability of 90% is used, from British Fire Service data (BSI 1997).

Assume that p(automatic alarm: smoke detectors) is characterised by a normal distribution with mean of 0.90 and standard deviation of 0.02. This distribution is shown as Figure 9.

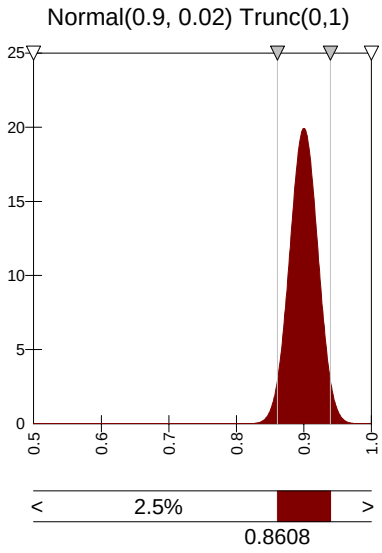

Figure 9: Probability distribution for automatic alarm reliability

2.8 Alarm direct to all occupants

This is the key event in differentiating between Type 5 Alarms and conventional Type 4 or 7. It is a binary event, if there's a Type 5 present the probability is p(0,1) if it's a Type 4 or 7 its p(1,0). This event is not concerned about the probability, but the consequences change, ie it directs the analysis to consequence scenarios with delayed alarm times.

2.9 Fire spread: confined to room and spread beyond room

These two events relate to fire spread; horizontal and vertical fire spread. As with the preceding event, these events are concerned with directing or weighting the analysis towards varying consequences. Unlike the preceding event, they are based on statistics rather than being a binary event. In this case the NZ data is not used. The EIS data (NZFS 2001) is considered to be too skewed or shifted (from what this study is interested in) by the high proportion of domestic, single-storey structures. EIS data for horizontal fire spread from room to room or from the structure to ancillary structures is not necessarily representative of the accommodation structure model, in which firecells are significantly more compartmented. Instead, more purpose-specific fire and smoke spread data is found in the NFPA Report (NFPA 1995)] with the results for the period 1992 to 1996 reported in Table 8. The USA-based data for hotels and motels is used, rather than including apartment buildings, on the basis that their definition of a hotel / motel room is more likely to represent the NZ accommodation firecell. The number of fire and fatalities are reported. It is interesting that these do not correlate linearly, for example when fires spread beyond the floor of origin there is a disproportionate level of fatalities. Upon consideration, this is an expected result, as multiple-level fires usually corresponds to unsafe egress from upper levels. In this analysis the probabilities of fire rather than fatalities is used, on the basis that the consequence models will deal with fatalities.

	Confined to room of origin		Beyond room but confined to floor		Beyond floor of origin	
Fires	4,680	87.6 %	200	3.8%	460	8.6%
Fatalities	14	36.8%	2	5.3%	22	57.9%

Table 8: Extent of flame and smoke damage

Assume that p(fire spread confined to room of origin) is characterised by a normal distribution with mean of 0.876 and standard deviation of 0.044 (arbitrarily set). Similarly, assume that p(fire spread

confined floor of origin: fire spread beyond room of origin) is characterised by a normal distribution with mean of 0.303 and standard deviation of 0.1 (arbitrarily set). These distribution are shown as Figure 8 and Figure 9 respectively.

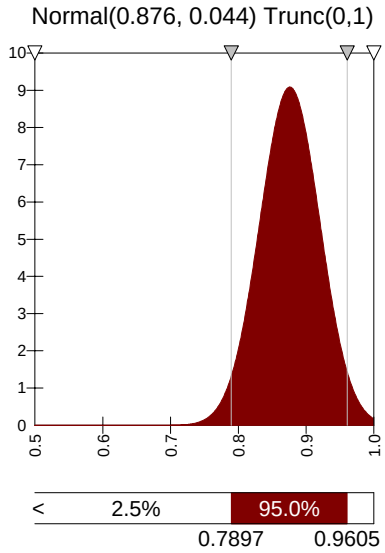

Figure 10: Probability distribution for fire spread confined to room of origin

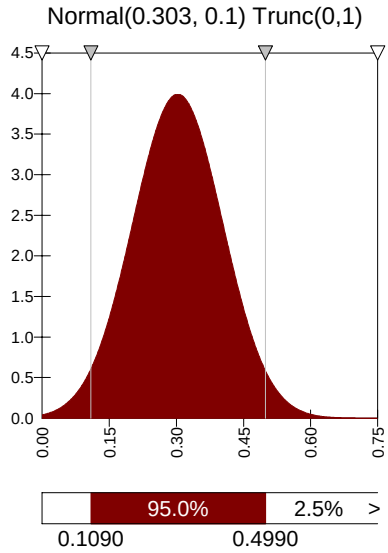

Figure 11: Probability distribution for fire spread confined to floor of origin given that its spread beyond the room of origin.

2.10 Summary of event tree probabilities

Event	Statistic	Dist. Type	Mean	Std Dev	Units
1	p(incident)	Normal	0.17	0.034	Fires / yr / 100 ppl
2	p(located in bedroom / suite)	Normal	0.14	0.015	Dimensionless
3	p(incipient only)	Normal	0.02	0.005	Dimensionless
4	p(occupant awake)	Normal	0.79	0.08	Dimensionless
5a	p(manual suppression: awake)	Uniform	0.125	0.072	Dimensionless
5b	p(manual suppression: not awake)	--	0	N/a	Dimensionless
6a	p(automatic suppression: sprinklers)	Normal	0.99	0.01	Dimensionless
6b	p(automatic suppression: no sprinklers)	--	0	N/a	Dimensionless
7	p(automatic alarm)	Normal	0.90	0.02	Dimensionless
8a	p(alarm direct to all occupants: Type 5)	Binary	0	N/a	Dimensionless
8b	p(alarm direct to all occupants: not Type 5)	Binary	1	N/a	Dimensionless
9	p(fire limited to room of origin)	Normal	0.876	0.044	Dimensionless
10	p(fire limited to floor: spread beyond room)	Normal	0.303	0.100	Dimensionless

Table 9: Summary of event probabilities

CHAPTER 3: Consequences

3.1 Outcome scenarios (consequences)

Each event tree branch terminates at an outcome, as outcomes may differ in consequence within an event tree these are termed outcome scenarios. An outcome scenario is the point where a particular consequence can be generally described by the events leading up to it. For example one outcome is a life threatening bedroom / suite fire, while the occupants sleep in a non-sprinkler protected building, with fire spread confined to the room / firecell of origin. Depending on the geometry of the building and other specific details the magnitude of that outcome (ie the consequence) needs to be determined to calculate the risk.

In this research the calculation of the magnitude of an outcome is termed consequence modelling, and it is done following the methodology of Frantzich [1997]. In this work, a limit state function is derived for each outcome expressing the escape time margin. The consequence is the product of the probability of a negative escape time margin multiplied by the maximum** number of occupants.

3.2 General equation

Limit State Function

Starting with the limit state function, G the escape time margin is calculated by:

$$G = ASET - RSET \qquad \text{Equation 1}$$

G	Escape time margin (s)
$ASET$	Available safe egress time (s)
$RSET$	Required safe egress time (s)

The limit state function *G*, is based on a classical deterministic approach to egress. A negative escape time margin equates to a loss, and a positive escape time margin equates to a safe state. This form of equation may be found, with differing notation, in many national design guidelines such as the New Zealand Fire Engineering Design Guide (Buchanan 2001) and the Australian Fire Engineering Guidelines (Warren Centre 1996). The deterministic approach is converted to a risk-based approach by assigning probability distributions to the random and calculated variables within the limit state function. There is therefore a probability of a loss and a probability of safety.

ASET and RSET

The ASET is calculated as a function of fire growth, using a mathematical model that Frantzich (1997) developed from a regression analysis of results of the computer model CFAST (Peacock et al 1993). CFAST has since been superseded by FAST (Peacock et al 2000). However, the changes do not alter the regression algorithm.

$$ASET = S \cdot U_S \qquad \text{Equation 2}$$

S	Time to untenable conditions, calculated (s)
U_s	Uncertainty factor applied to *S*, characterised by the distribution *Normal (1.35,0.11)*

The RSET is itself, composed of some basic variables.

** The maximum occupant load leads to the TALL, this is then adjusted for actual occupancy rates to gain an ELL.

$$RSET = t_d + t_i + t_r + t_e$$ Equation 3

t_d Detection time, calculated or random variable (s)
t_i Investigation time (from Frantzich) or delayed alarm if Type 5, random variable (s)
t_r Occupant response time, random variable (s)
t_e Occupant movement time, random variable, (s)

The general equation is derived by substituting into Equation 1 for Equation 4.

$$G = S \cdot U_s - \left(t_d + t_i + t_r + t_e\right)$$ Equation 4

3.3 Case study

For the analysis to produce meaningful risk profiles, basic details of building geometry must be assumed. An example building layout is therefore chosen, from the case study Hotel building used by Frantzich (1997). The following description is based on text in Frantzich's report, but modified to suit the Type 5 scenario rather than the 'positive alarm sequence' used in Sweden.

Frantzich's Hotel case study

The calculations are based around one floor in a multi-level hotel. It is assumed that the occupants can evacuate without any assistance from other occupants or the hotel staff. Following alarm, the occupant responds to the alarm signal and after a period, begin evacuation.

Each guest room has a floor area of 6.0 m x 5.0 m and a height to the ceiling of 2.4 m. The room has a window, 0.9 m x 0.9 m, to the outside and a door, 2.0 x 1.0 m leading to the corridor. Each room is a separate firecell. The door to the corridor is a fire doorset with a closing device. The door is assumed to open into the guest room. Even if the door is fire rated some leakage is assumed. Leakage openings of 2.0 x 0.005 m at the side and 1.0 m x 0.010 m under the door are assumed for the CFAST simulations. The window is assumed to have a leak opening to the outside of 0.9 m x 0.01 m. The corridor length is 30 m. The corridor is 3 m wide and 2.5 m high. The number of guest rooms per floor is 12 rooms. The walls and ceiling are covered by gypsum sheets applied on non-combustible material and the floor is constructed of concrete. The NZBC requirement for corridor ventilation is assumed not to be present nor are subdividing corridor smoke control doorsets.

In both ends of the corridor it is assumed that safe path staircases, lead to a safe place. The doors leading to the staircases are assumed to be closed. They will, however, be opened during evacuation, letting smoke and people out to the staircase. To simulate this, these doors will be kept open during the whole simulation with an area of 2.0 m x 0.100 m. This is an engineering assumption which also makes the fire calculations easier. The staircases are assumed to be a place of safety.

It is further assumed that there is one occupant in each room and that no queuing occurs at the staircases leading to the ground floor. When the individual risk is calculated the number of occupants on the floor is irrelevant as the safety is affecting the last person to leave the location of interest. However, in terms of societal risk, that is based on the risk of multiple affected people, the number must be part of the calculation. As the number of occupants on the floor is low, it is assumed that the arrival rate at the staircases is one occupant every four seconds. This rate is determined by the distance between the rooms and not by the flow capacity at the doorway. This information is needed to calculate the number of occupants not yet in safety when the corridor escape time margin is less than zero.

The limit state function described by Equation 4, is not appropriate in considering vertical fire spread beyond the floor of origin. Instead an approximation of the consequence of vertical fire spread is developed based on an 'escalation model'. Frantzich's hotel case study must be expanded to include a

number of storeys. The escalation model is a function of the location of the fire (floor of origin) and the number of occupants threatened, above that floor. This is treated as an outcome scenario variable developed in the following section.

3.4 Outcome scenario variables

Alarm type

The consequence scenarios, ie the specific consequence equations, are of the form of Equation 4. However, the variables will differ as a function of alarm type. For this research, four distinct event trees are necessary, two pairs of two. The first pair relate to Type 4 and Type 4e (ie Type 5) Alarms, and the second pair relate to the Type 7 and Type 7e (ie Type 5 with sprinklers). The risk profiles are then compared of the Type 4 versus Type 4e and Type 7 versus Type 7e to determine the relative change in level of risk, measured in ELL.

Time to untenable conditions

The time to untenable conditions depends on whether the scenario is considering the occupant in the room of origin, on the floor of origin or elsewhere in the building. This latter is not dealt with using classical ASET versus RSET calculations and is more statistically-based.

Frantzich (1997) develops a relationship, based on a regression analysis of multiple CFAST simulations, for the time to untenable conditions as a function of fire growth rate, assuming that the fire is characterised by the classical alpha-time-squared relationship, refer to Equation 5.

$$S = r \cdot \alpha^{-q} \qquad \text{Equation 5}$$

r, q Geometry-dependent constants (--)

Using the tenability parameters described in Table 10, the constants are determined for time to untenable conditions in the room ie Equation 6 relating to fires confined to the room of origin and conditions in the corridor ie Equation 7 relating to fires not confined to the room of origin.

Condition	Tenability Limit
Radiation	2.5 kW.m^{-2}
Smoke layer height (above floor)	1.5 m
Temperature in upper layer	100 C
Toxicity	0.5 FED

Table 10: Untenable Conditions

$$S = 10.6 \cdot \alpha^{-0.48} \qquad \text{Equation 6}$$

$$S = 55.9 \cdot \alpha^{-0.38} \qquad \text{Equation 7}$$

α Fire growth rate, characterised by the distribution *Lognormal (0.02,0.01)*[††], and
U_s is an uncertainty factor applied to *S*, characterised by the distribution *Normal (1.35,0.11)*

Detection time

Frantzich (1997) also develops a regression analysis, based on the routine DETACT-T2[‡‡] for the relationship of the time to automatic (smoke) detection as a function of fire growth rate (Equation 8).

[††] @RISK notation is adopted to abbreviate distribution descriptions. The values in parentheses describe first the mean and second the standard deviation, except in the case of a uniform distribution where the values describe the limits.

[‡‡] Contained with CFAST / FPETool suite of computer routines[Peacock 1993], [Peacock et al 2000]

Frantzich assumes probability distributions for time to detection if the occupant is intimate with fire and awake (Equation 9), or a third party manual detection if the first two conditions fail ie not detected automatically by the alarm or manually by the intimate occupant (Equation 10).

$$t_{d_1} = 20.6 \cdot \alpha^{-0.30} \quad \text{Equation 8}$$

$$t_{d_2} = Lognormal(15,3) \quad \text{Equation 9}$$

$$t_{d_3} = Uniform(120,300) \quad \text{Equation 10}$$

Where;

t_{d_1} Time to automatic smoke detection (s)

t_{d_2} Time to manual detection if awake and intimate with fire (s)

t_{d_3} Time to manual detection otherwise (s)

Investigation alarm – Type 5 Alarm delay time (key variable)

In Frantzich's (1997) work, the next variable is t_i, the investigation time that represents the 'positive alarm sequence'. That is, the situation where the local alarm activates in the room of origin and at a remote staff-attended monitor, allowing the staff time to investigate and activate a global alarm if necessary. This is characterised by the distribution *Lognormal(60,15)*. However, in the case of the Type 5 there is no investigation time, in so far as positive alarm sequence. Instead, there is a time delay between local and global alarms. This is the time between smoke and thermal activation (thermal inclusive of sprinklers). This is termed the 'Type 5 delay time' and is the key variable in the risk analysis. It is notated as Δt_d .

$$t_i = \Delta t_d = t_{d_4} - t_{d_1} \quad \text{Equation 11}$$

Δt_d Type 5 Alarm delay time (s)

t_{d_4} Time to automatic thermal (incl. sprinkler) detection (s)

The general equation (Equation 4) is revised as;

$$G = S \cdot U_s - \left(t_d + \Delta t_d + t_r + t_e\right) \quad \text{Equation 12}$$

The value of t_{d_4} is derived from a regression analysis of DETACT-T2 results. These results appear in Table 11 and Figure 12. The regression equation, as Equation 13 and the calculation of delay time as Equation 14.

$$t_{d_4} = 49.2\alpha^{-0.34} \quad \text{Equation 13}$$

$$\Delta t_d = 49.2\alpha^{-0.34} - 20.6 \cdot \alpha^{-0.30} \quad \text{Equation 14}$$

Fire growth	Alpha (kW.m^{-2})	Detection time Smoke (s), t_{d_1}	Detection time Thermal (s), t_{d_4}
Slow	0.0029	119	362
Medium	0.0117	78	218
Fast	0.0469	52	137
Ultra-fast	0.1876	34	88

Table 11: Detector activation, thermal alarm

Notes to Table 11

- Rather than set Δt_d as a discrete difference it is left in the form of Equation 13 to allow the growth rate distribution function to be modelled in the MCS.
- Assumed parameters for a typical hotel room and thermal detector (for simplicity assumed the same for Heat and Sprinkler element) are: height from fire to detector is 2.1 m (ie fire 300 mm above floor level), radius from fire centre to detector ~3.0 m, ambient temperature 17 C, activation temperature 68 C, thermal detector response time index 57 (m.s)$^{0.5}$

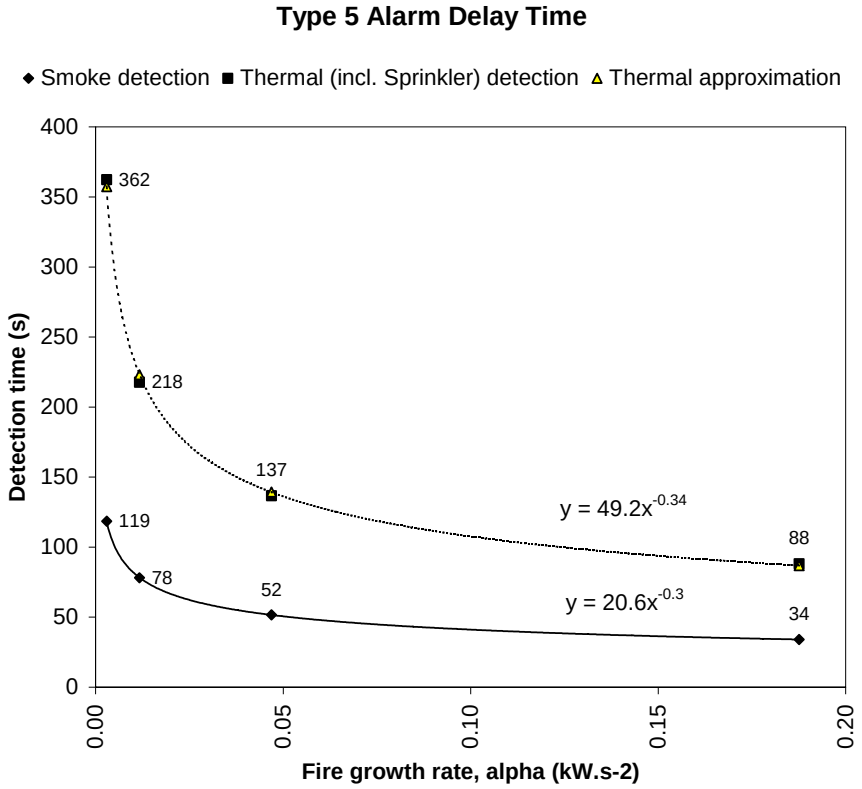

Figure 12: Type 5 Alarm, delay time

Response time

This is the time immediately following alarm and up to evacuation. This time is also commonly called pre-movement time. Depending on the outcome scenario, the occupant will be awake or asleep, and intimate or remote from the fire. Using Frantzich's (1997) statistics, in the room of origin, with the occupant awake the response time, is assumed to follow the distribution described by Equation 15. Otherwise, Equation 16.

$$t_{r_1} = Lognormal(15,3)$$ Equation 15

$$t_{r_2} = Lognormal(120,20)$$ Equation 16

t_{r_1} Response time for occupants awake and intimate with the fire (s)

t_{r_2} Response time otherwise (s)

Evacuation time

This is the travel time, both traversal and queuing. However, for such a low occupant load as a hotel guest floor with 30 occupants, queuing is assumed not to occur. Again, Frantzich's (1997) example is used.

$$t_e = Normal(20,3)$$ Equation 17

t_e Occupant movement time, in this case evacuation (movement) time to safe path stair (s)

Consequences

The limit state equation gives an escape time margin. The consequence is the probability of a negative escape time margin in the room multiplied by room occupancy (one) plus the probability of a negative escape time margin in the corridor multiplied by the floor's occupant load (twelve). Fire spread to other upper floors is treated separately, as described in the next section.

Escalation model

As described previously, Frantzich's case study must be expanded to consider the consequence of vertical fire spread beyond the floor of origin.

The first step is to determine a building height, in number of storey, for the case study hotel. The height should be representative of the NZ sample but should be tall enough to:

- be representative of building likely to have a Type 5 alarm, ie; single storey buildings are unlikely to require a Type 5
- allow for high consequence event in the risk profile[§§]

The NZ hospitality data (Statistics NZ 2002) provides NZ accommodation annual capacity and establishment number. The data has been reduced to exclude caravan parks, camping grounds and home-stays. From this data we can determine a mean number of beds. Refer to Table 12 below.

Year	No. of establishments	No. of beds ($x10^3$ per night)	Mean No. of beds per establishment
1998	2,210	55.1	24.9
1999	2,301	59.5	25.9
2000	2,364	62.3	26.4
2001	2,998	65.0	21.6
		μ =	25
		σ =	2

Table 12: NZ accommodation data

Notes to Table 12:

[§§] High consequences are balanced in risk profile by their probability, but it is important that high-consequence events are included in the first place

- The corporate year 1997/98 is referred to as 1998, etc
- The results are reported to two or three significant figures, anything more detailed implies false accuracy

The data in Table 12 indicates that the mean accommodation building in NZ has 25 bed capacity. Qualitatively, it can be assumed that the mean NZ structure is low rise, typically two storey. For the case study building, it is assumed an atypical case of four storeys of accommodation at 12 bedrooms per floor. Further assume an equal probability of fire incidence per floor. For example, there is a 25% chance that the L1 occupants are exposed, ie; a fire start on L1, 50% for L2 occupants, ie fire start L1 *or* L2 and so on. The consequence is assumed as the number of people exposed, which are 12 multiplied by the number of floors.

3.5 Specific equations

Scenario specific, limit state equations are developed and reported on the event trees in CHAPTER 4: 'Risk '.

CHAPTER 4: Risk analysis

4.1 Calculation of risk

The event trees are included as Appendix A. These are populated with event probabilities and outcome scenarios. The ELL is calculated for each scenario and then summed and divided by the total occupant load to provide the TALL. This is described by Equations 18 and 19.

$$ELL_i = P(SCEN_i) \cdot P(G < 0) \cdot N_i \quad \text{Equation 18}$$

$$ELL = \sum ELL_i \cdot (N/100) \quad \text{Equation 19}$$

$$TALL = ELL/N \quad \text{Equation 20}$$

The theoretical annual loss of life assumes 100% occupancy. A lower occupancy rate decreases the risk of a fatality overall. However, it simultaneously increases the probability to any specific individual occupant (refer also to the definition of individual risk). The net effect is assumed to be a constant individual risk. In this research, the risk measure is relative and so differing occupancy rates have negligible effect on the results.

The software @RISK (Palisade 2002) is an add-in to the spreadsheet package Microsoft Excel and contains a Monte Carlo Simulation engine. @RISK is used to model uncertainty and variability in the input variables and to generate the probability density functions required for Equation 18. @RISK is also used as a reporting tool to generate the graphs and tables included in this section. Two-step simulations were run for each event tree. The first step had $P(G<0)$ as the output. The second, had ELL_i, ELL and $TALL$ as the outputs, given $P(G<0)$. Each step and each simulation involved 100,000, samples using Latin Hyperbole sampling (LHS).

4.2 Pre-calibration results

Detailed pre-calibration results are included in Appendices B. Key probability and risk results are included in Table 13 and Table 14.

SCEN	Type 4		Type 4e		Type 7		Type 7e	
	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%
04	1.4 x 10^{-2}	1.0	1.4 x 10^{-2}	1.0	1.8 x 10^{-4}	1.0	1.8 x 10^{-4}	1.0
05	6.1 x 10^{-4}	1.6	6.1 x 10^{-4}	1.6	7.8 x 10^{-6}	1.6	7.8 x 10^{-6}	1.6
06	1.4 x 10^{-3}	0.2	1.4 x 10^{-3}	0.2	1.8 x 10^{-5}	0.2	1.8 x 10^{-5}	0.2
09	3.9 x 10^{-3}	100	--	--	5.0 x 10^{-5}	100	--	--
10	1.7 x 10^{-4}	3.0	--	--	2.1 x 10^{-6}	3.0	--	--
11	3.8 x 10^{-4}	0.3	--	--	4.9 x 10^{-6}	0.3	--	--
12	--	--	3.9 x 10^{-3}	100	--	--	5.0 x 10^{-5}	100
13	--	--	1.7 x 10^{-4}	34	--	--	2.1 x 10^{-6}	34
14	--	--	3.8 x 10^{-4}	3	--	--	4.9 x 10^{-6}	3
15	4.3 x 10^{-4}	100	4.3 x 10^{-4}	100	5.5 x 10^{-6}	100	5.5 x 10^{-6}	100
16	1.9 x 10^{-5}	48	1.9 x 10^{-5}	48	2.4 x 10^{-7}	48	2.4 x 10^{-7}	48
17	4.3 x 10^{-5}	5	4.3 x 10^{-5}	5	5.5 x 10^{-7}	5	5.5 x 10^{-7}	5

Table 13: Probability data, pre-calibration

Comparing the P(G < 0) SCEN 10 with SCEN 13 illustrates the impact of the Type 5 Alarm in terms of the increased likelihood of a negative escape time margin. These are not yet 'risk' profiles, as they must yet be weighted by P(SCEN) and consequence data.

TYPE	ELL	TALL
TYPE 4	2.4×10^{-3}	4.9×10^{-5}
TYPE 4e	2.8×10^{-3}	5.9×10^{-5}
TYPE 7	3.0×10^{-5}	6.2×10^{-7}
TYPE 7e	3.6×10^{-5}	7.6×10^{-7}

Table 14: Risk profiles, pre-calibration

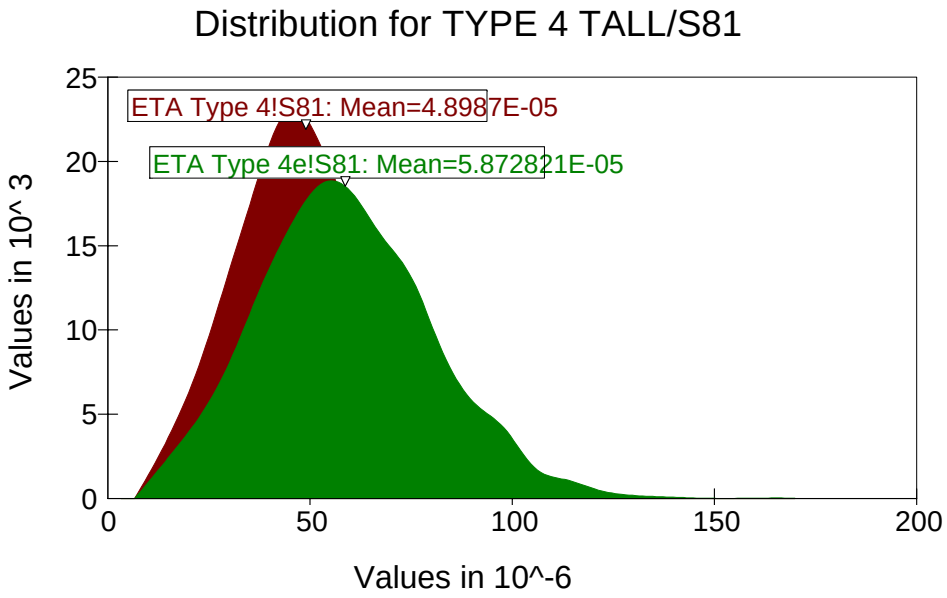

Figure 13: Case study probability density functions of TALL, comparing Types 4 and 4e

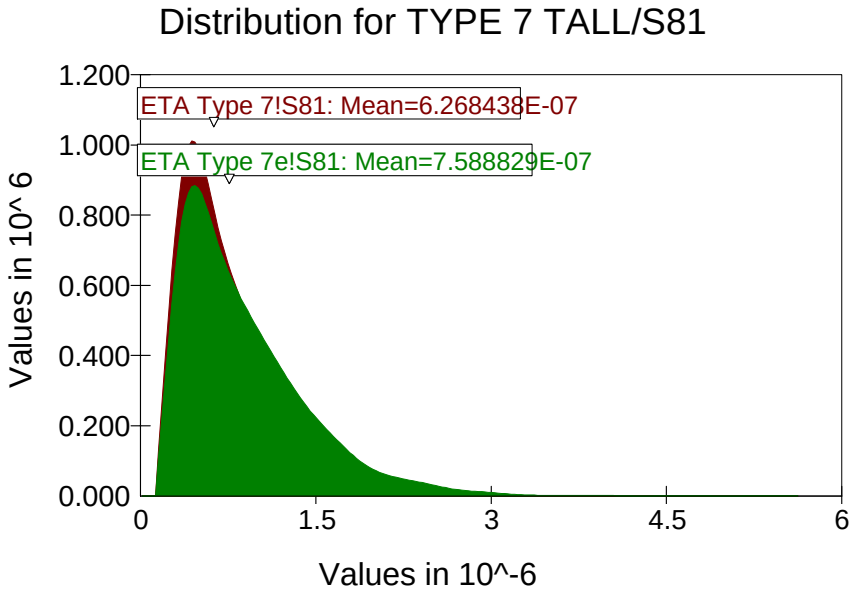

Figure 14: Case study probability density functions of TALL, comparing Types 7 and 7e

The relative increase in TALL between the Type 4 and 4e, and the Type 7 and 7e is the impact of the Type 5 alarm, about 20% in each case. The results require validation.

4.3 Model validation

Assume the tolerable level of individual risk in a Hotel is ~1 x 10^{-5} deaths per annum (refer to CHAPTER 5: 'Risk assessment'). Assume also, that the BIA Acceptable Solution C/AS1'Fire Safety' (BIA 2002) provides for a tolerable level of risk. Given this, it follows that the TALL for the Type 4 in the case study should have been less than 1 x 10^{-5}.

From the USA data (NFPA 1999), for the period 1992 to 1996, 30 of 38 Hotel and Motel fire fatalities (civilian) were from fires originating in the bedroom. Based on this statistic, the TALL for the case study with a Type 4 alarm should have been ~ 8 x 10^{-6}. The calculated value of ~ 5 x 10^{-5} is therefore almost a magnitude of order high. This indicates that the model requires calibration in terms of the absolute value of TALL. A value calibrated for the Type 4 alarm will also automatically calibrate the other alarms. It should be noted that this research is a risk relative exercise, ie the difference in TALL between the Type 4 and 4e and similarly the Type 7 and 7e. It is desirable but not essential that the absolute TALL values are correct to any more than a magnitude of order, to be able to comment on the impact of the Type 5 alarm.

In terms of the relationship between the Type 4 and 4e data with their Type 7 and 7e pairings, the relative difference is two magnitudes of order. This is an expected result given the assigned mean 99% reliability of the automatic fire sprinkler system.

4.4 Model sensitivity

Figure 15 is a sensitivity analysis generated by @RISK for the case study with a Type 4. This, and the other sensitivity analyses are included in Appendix B. It can be seen that the TALL for a guest room fatality, is most sensitive to the probability that an occupant is awake, the probability that the location of origin is a guest room and the probability that there is a fire start. If the correlation is negative, this means that an increased probability of that variable decreases the TALL. If the correlation is positive, the reverse holds.

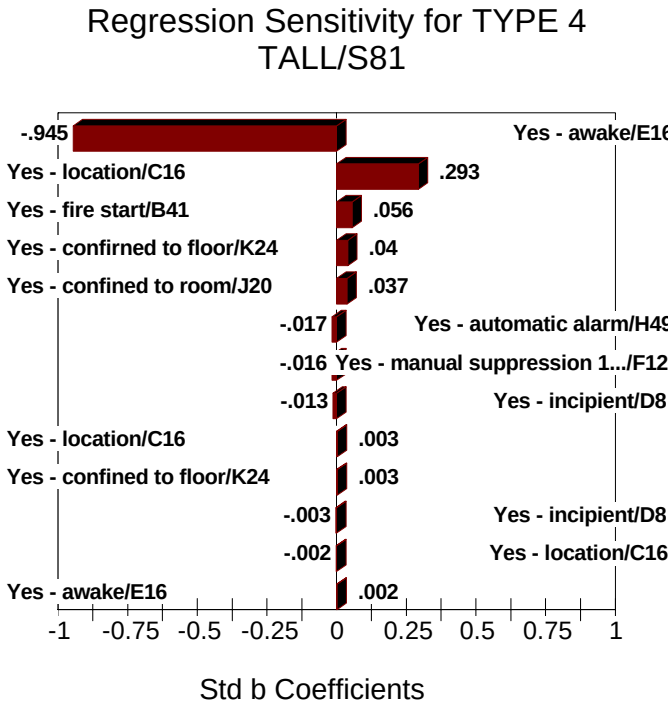

Figure 15: Sensitivity of the TALL in the case study (Type 4)

The results require discussion. Note the positive effect of the fire location being confined to the room and floor. The positive sensitivity implies that increased confinement increases TALL. This is

explained, but not necessarily satisfactorily, by the fact that the event trees in diverting to the escalation model are lowering the risk by having disproportionate probability / consequence relationship. Whilst this is not particularly valid, the sensitivity is low enough for it to be ignored, any errors are 'lost in the noise'. It is also, that this is partially corrected in the sensitivity of the Type 4e where the fire is confined to the room.

Another curiosity of Figure 15 is that there are repeat entries for the same input, such as location. This is because the sensitivity analysis is considering the contribution of individual ELL_i, calculations. Hence the multiple entries. As the case of fire confinement above, the repeated entries beyond the first are insignificant and so can be ignored.

It is also notable, that the variables used within the outcome scenarios do not feature greatly in the sensitivity analysis. Table 13 demonstrates that except for the SCEN 13 and SCEN 16, the $P(G<0)_i$ is 'hit or miss', that is either close to zero or close to unity. This is expected given that many of the predetermining events such as 'occupant awake' or 'automatic alarm' lead to great differences in $P(G<0)$.

4.5 Model calibration

The model will be calibrated by adjusting the fire incidence data. This statistic is discussed in detail in CHAPTER 2: 'Probabilities', specifically section 2.1 'Fire incidence'. The fire incidence data is reduced by half a magnitude of order (ie divided by a factor of five). This takes it to 0.034 per annum per 100 beds and brings it in line with USA and Swedish data (0.038 and 0.050 respectively). Qualitatively, this can be justified by assuming that a large number of motels and hotels included in the EIS sample (NZFS 2002) with > 20 beds will not necessarily require a Type 4 alarm because they will be made up of several low rise detached units, and are therefore outside of the sample set of interest.

A second area of calibration was considered. The model is clearly conservative in that it doesn't incorporate a time dimension to barrier failure. Such a sub-model is incorporated in the CESARE-Risk fire growth and smoke spread model (Beck and Zhao (1999)). However, given that the model is not sensitive to the outcome scenario inputs (see above) this was disregarded as likely to produce an insignificant effect.

4.6 Post-calibration results

SCEN	Type 4		Type 4e		Type 7		Type 7e	
	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%	P(SCEN)	P(G<0) x10^{-2} ie%
04	2.8 x 10^{-3}	1.2	2.8 x 10^{-3}	1.2	3.6 x 10^{-5}	1.2	3.6 x 10^{-5}	1.2
05	1.2 x 10^{-4}	1.5	1.2 x 10^{-4}	1.5	1.6 x 10^{-6}	1.5	1.6 x 10^{-6}	1.5
06	2.8 x 10^{-4}	0.2	2.8 x 10^{-4}	0.2	3.6 x 10^{-6}	0.2	3.6 x 10^{-6}	0.2
09	7.8 x 10^{-4}	100	--	--	1.0 x 10^{-5}	100	--	--
10	3.3 x 10^{-5}	3.0	--	--	4.3 x 10^{-7}	3.0	--	--
11	7.7 x 10^{-5}	0.3	--	--	9.9 x 10^{-7}	0.3	--	--
12	--	--	7.8 x 10^{-4}	100	--	--	1.0 x 10^{-5}	100
13	--	--	3.3 x 10^{-5}	33	--	--	4.3 x 10^{-7}	33
14	--	--	7.7 x 10^{-5}	3	--	--	9.9 x 10^{-7}	3
15	8.6 x 10^{-5}	100	8.6 x 10^{-5}	100	1.1 x 10^{-6}	100	1.1 x 10^{-6}	100
16	3.7 x 10^{-6}	48	3.7 x 10^{-6}	48	4.8 x 10^{-8}	48	4.8 x 10^{-8}	48
17	8.5 x 10^{-6}	5	8.5 x 10^{-6}	5	1.1 x 10^{-7}	5	1.1 x 10^{-7}	5

Table 15: Probability data, post-calibration

TYPE	ELL	TALL
TYPE 4	4.7×10^{-4}	9.8×10^{-6}
TYPE 4e	5.6×10^{-4}	1.2×10^{-5}
TYPE 7	6.1×10^{-6}	1.3×10^{-7}
TYPE 7e	7.3×10^{-6}	1.5×10^{-7}

Table 16: Risk profiles, post-calibration

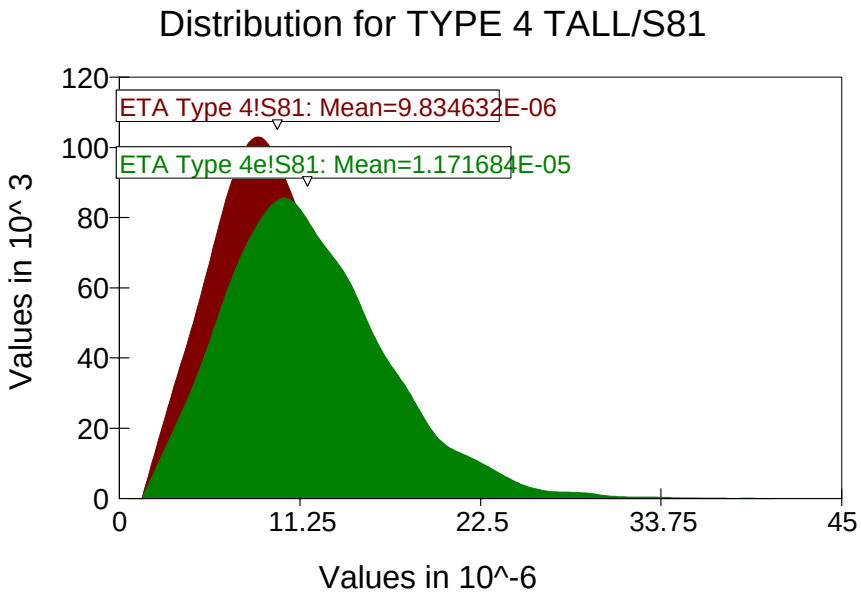

Figure 16: Case study probability density functions of TALL, comparing Types 4 and 4e

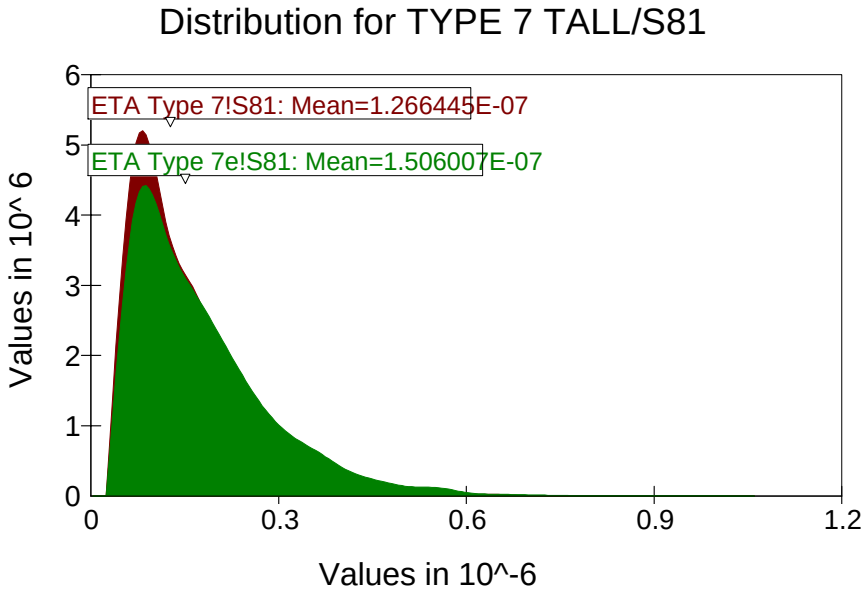

Figure 17: Case study probability density functions of TALL, comparing Types 7 and 7e

CHAPTER 5: Risk assessment

5.1 Risk evaluation & risk assessment

In a conventional risk management process, risk evaluation is concerned about deciding whether a risk is tolerable or not. More formally it is defined as the process to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria. Refer also to Figure 1. Risk assessment is the overall process of risk analysis and risk evaluation

This research does not formally evaluate the risks. It is a risk analysis project rather than a risk assessment. Risk evaluation is in the domain of the policy maker and that is not an objective of this research. A risk evaluation process might look at the increased individual risk of the type five alarm by comparing the TALL results of Table 16 and compare these to tolerable criteria. Detailed information on tolerable criteria in fire risk can be found in Wolski et al (2000).

5.2 Individual versus societal risk

This research measures fire risk as fatalities per annum per person. It deals with individual risk, ie the risk to a specific building occupant.

Another risk measure, that was not used in this research, is societal risk, ie multiple fatality fires. Society is less tolerant of one fire killing 10 people in a year than ten fires killing one.

The event trees can be used to calculate societal risk by summing the probabilities of the multiple fatality fires and reporting probabilities of ELL for N (or more) deaths. Unfortunately, because the methodology doesn't incorporate a fire separation failure sub-model, overly conservative results are obtained for societal risk. As discussed in section 4.3 'Model calibration', individual risk is not sensitive to the lack of such a sub-model, but societal risk is. This is an expected result, since multiple fire fatalities are clearly a function of fire barrier reliability. Future research may incorporate a sub-model for fire barrier failure.

For more information on societal risk, refer to Frantzich (1997), Keey (2000) and Vrijling et al (1995).

CHAPTER 6: Conclusions

The June 2001 revision of the New Zealand Building Code 'Approved Document C/AS1' for fire safety (BIA 2001) introduced a new type of fire safety precaution (FSP). Termed a Type 5 alarm, this is applicable within accommodation and multi-unit residential buildings. Essentially, the Type 5 alarm allows localised warning and non-brigade connected alarms in guest suites. This is a departure from previous practice and increases the fire risk to occupants. The benefits are the reduction in unnecessary Fire Service call-out and the reduction in unnecessary total building evacuation. Qualitative arguments supported the new Type 5 alarm. This research develops the following quantitative methodology to measure the increased risk.

The analysis is based on four event trees generic to a guest suite fire in an accommodation building, ie the event trees can be applied to most accommodation buildings with a Type 5 alarm. These are paired as; the Type 4 and 4e, and the Type 7 and 7e systems. Non-safe outcomes on each event tree are characterised by generic models comprising of limit state equations of escape time margin. The event trees and limit state equations are populated with probability distributions. The former gained from NZ fire incident statistics and the latter based on Swedish research. A case study is then developed to provide a magnitude for the consequences.

The analysis is run in a two-step process using Monte Carlo simulation for each event tree. The first step determines the probability distribution of escape time margin for each potentially life threatening scenario. The second step incorporates this new distribution and calculates probability distributions for expected loss of life for each scenario and sums these and divides by the population for a theoretical annual loss of life, which is the measure of risk.

The measure of risk for the complimentary event trees are compared to quantify the increase in life safety. Because the fire origin is assumed in a guest room, which is the point of differentiation of the Type 5, the risk measures are not complete for the whole building but only the subset that will affect a Type 5. For this reason the risk measures should be compared relative to each other. Absolute comparisons should allow for and incorporate the proportion of fire deaths in accommodation buildings that have origins other than in the guest rooms. Table 17 summarises the increase in life safety for the representative case study.

ALARM TYPE	TALL	Increase
TYPE 4	9.8×10^{-6}	
TYPE 4e	1.2×10^{-5}	2.2×10^{-6}
TYPE 7	1.3×10^{-7}	
TYPE 7e	1.5×10^{-7}	2.0×10^{-8}

Table 17: Impact of the Type 5 alarm (case study)

It can be seen from Table 17 that the risk increases by about 20%. This research does not comment on the magnitude of the increased risk, as risk evaluation is the domain of the policy maker. However, this research does conclude, that given the ability to measure the risk, decisions such as the introduction of the Type 5 alarm which lower safety, should be supported by a formal and quantitative risk analysis.

This research also concludes, that even allowing for sprinkler failure, the risk to life in sprinkler-protected buildings is typically two magnitudes of order better than in non-sprinklered. Therefore, future research using multiple case studies, may give consideration to the cost-benefit of fire safety systems incorporating fire sprinklers without the necessity of smoke alarm systems in corridors, assuming that alarms are required in guest rooms to detect smouldering fires.

Future research may also incorporate a sub-model for fire barrier failure as a function of time, to allow for meaningful societal risk calculations.

Notation

α	Fire growth rate (kW.m^{-2})
μ	Mean (units vary)
σ	Standard deviation (units vary)
Δt_d	Type 5 Alarm delay time (s)
ASET	Available safe egress time (s)
G	Escape time margin (s)
q	Geometry dependent constant (--)
r	Geometry dependent constant (--)
RSET	Required safe egress time (s)
S	Time to untenable conditions, calculated (s)
t_d	Detection time, calculated or random variables (s)
t_{d_1}	Time to automatic smoke detection (s)
t_{d_2}	Time to manual detection if awake and intimate with fire (s)
t_{d_3}	Time to manual detection otherwise (s)
t_{d_4}	Time to automatic thermal (inc. sprinkler) detection (s)
t_e	Occupant movement time, random variable (s)
t_i	Investigation time (from Frantzich) or delayed alarm if Type 5, random variable (s)
t_r	Occupant response time, random variable (s)
t_{r_1}	Response time for occupants awake and intimate with the fire (s)
t_{r_2}	Response time otherwise (s)
U_s	Model uncertainty factor, random variable (--)

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Appendix A

Event trees (post-calibration)

TYPE 4

Fire Start	Location sleeping area?	Fire growth incipient only?	Occupant awake?	Manual suppression?	Automatic suppression ?	Automatic alarm?	Alarm direct to all occupants?	Fire confined to room of origin?	Fire confined to floor of origin?	Outcome scenario	P(SCEN)	MODELLING OF OUTCOME SCENARIOS	mean G (s)	P(G<0)	N	ELL
START		Yes - incipient 2% RiskNormal(0.02, 0.005)								1	9.52E-05	$SAFE$				
				Yes - manual suppression 1 12.5% RiskUniform(0.125, 0.072)						2	4.60E-04	$SAFE$				
	Yes - location 14% RiskNormal(0.14, 0.015)		Yes - awake 79% RiskNormal(0.79, 0.08)		Yes - automatic suppression 0% RiskNormal(0.99,0.01)					3	0.00E+00	$SAFE$				
				No 87.5%				Yes - confined to room 88% RiskNormal(0.876,0.044)		4	2.82E-03	$G=S_r \cdot U_S-\left(t_{d_2}+t_{r_1}+t_e\right)$	44	1.2%	1	3.38E-05
		No 98%			No 100%				Yes - confirned to f 30% RiskNormal(0.303,0.015)	5	1.21E-04	$G=S_c \cdot U_S-\left(t_{d_2}+t_{r_2}+t_e\right)$	179	1.5%	12	2.19E-05
								No 12%	No 70%	6	2.79E-04	$G = esc._mdl$		0.2%	30	1.26E-05
				Yes - manual suppression 2 0% Binary						7	0.00E+00	$SAFE$				
					Yes 0%					8	0.00E+00	$SAFE$				
	Yes - fire start 3.40E-02 RiskNormal(0.034, 0.0068)		No 21%					Yes 88%		9	7.76E-04	$G=S_r \cdot U_S-\left(t_{d_1}+t_{r_2}+t_e\right)$	-113	100%	1	7.76E-04
							Yes - alarm direct to occupants 100% Binary		Yes 30%	10	3.34E-05	$G=S_c \cdot U_S-\left(t_{d_1}+t_{r_2}+t_e\right)$	127	3%	12	1.20E-05
								No 12%	No 70%	11	7.67E-05	$G = esc._mdl$		0.3%	30	6.90E-06
				No 100%	No 100%	Yes - automatic alarm 90% RiskNormal(0.90, 0.02)		Yes 88%		12	0.00E+00	$G = 0$				
							No 0%		Yes 30%	13	0.00E+00	$G = 0$				
								No 12%	No 70%	14	0.00E+00	$G = 0$				
						No 10%		Yes 88%		15	8.62E-05	$G=S_r \cdot U_S-\left(t_{d_3}+t_{r_1}+t_e\right)$	-151	100%	1	8.62E-05
									Yes 30%	16	3.71E-06	$G=S_c \cdot U_S-\left(t_{d_3}+t_{r_2}+t_e\right)$	-16	48%	12	2.14E-05
								No 12%	No 70%	17	8.52E-06	$G = esc._mdl$		5%	30	1.23E-05
	No 86%									18	2.92E-02	$SAFE$				

Note all distributions truncated at 0 and 1.00

SUM = 3.40E-02

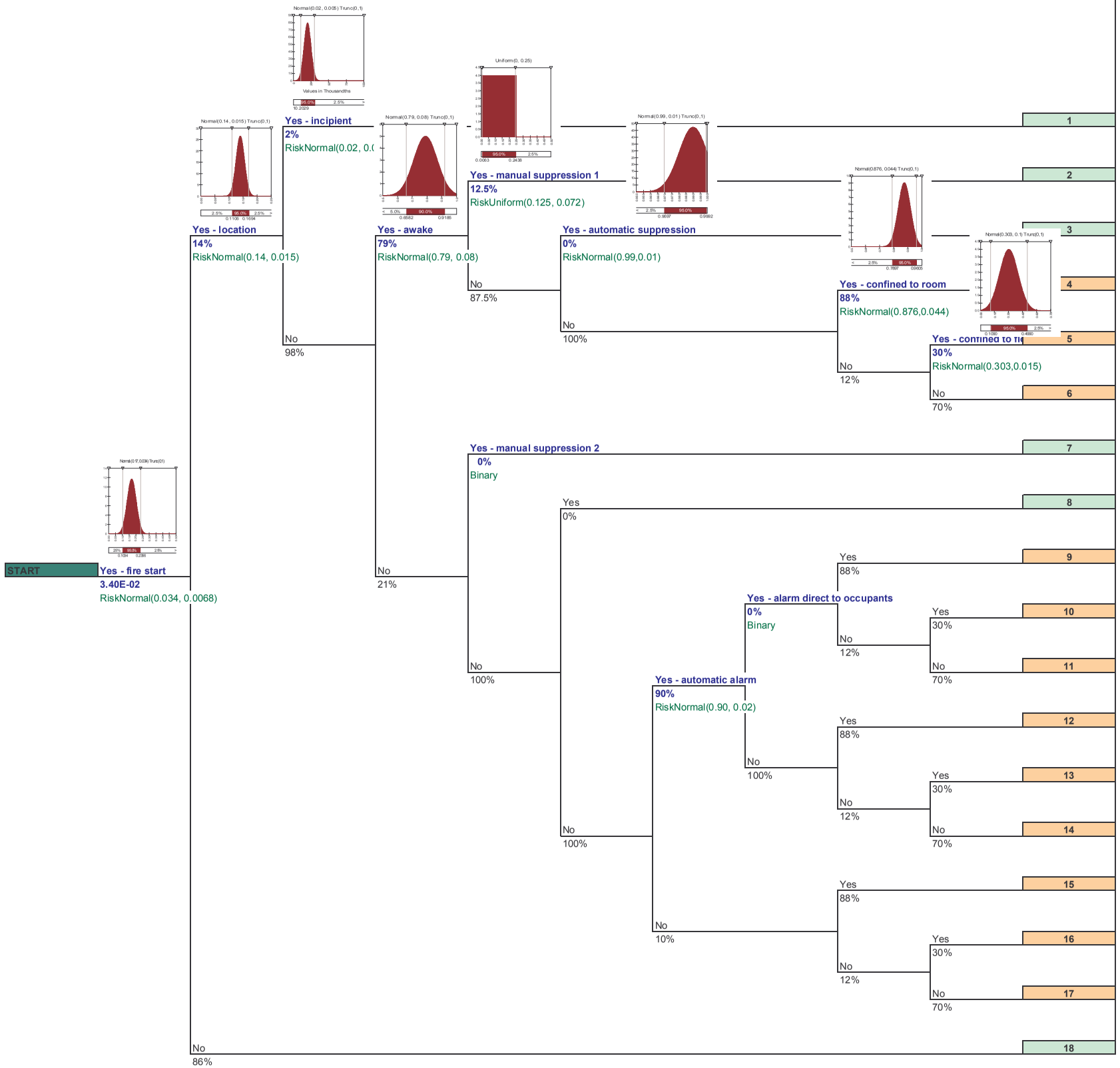
CheckSUM = 1.00

ELL = 4.72E-04

TALL = 9.83E-06

Connell Mott MacDonald
...building the future

TYPE 4e



	P(SCEN)	MODELLING OF OUTCOME SCENARIOS	mean G (s)	P(G<0)	N	ELL
1	9.52E-05	$SAFE$				
2	4.60E-04	$SAFE$				
3	0.00E+00	$SAFE$				
4	2.82E-03	$G = S_r \cdot U_S - \left(t_{d_2} + t_{f_1} + t_e\right)$	44	1%	1	3.38E-05
5	1.21E-04	$G = S_c \cdot U_S - \left(t_{d_2} + t_{r_2} + t_e\right)$	179	2%	12	2.19E-05
6	2.79E-04	$G = esc._mdl$		0.2%	30	1.26E-05
7	0.00E+00	$SAFE$				
8	0.00E+00	$SAFE$				
9	0.00E+00	$G = 0$				
10	0.00E+00	$G = 0$				
11	0.00E+00	$G = 0$				
12	7.76E-04	$G = S_r \cdot U_S - \left(t_{d_1} + t_{r_2} + t_e\right)$	-113	100%	1	7.76E-04
13	3.34E-05	$G = S_c \cdot U_S - \left(t_{d_1} + t_f + t_{r_2} + t_e\right)$	8	33%	12	1.32E-04
14	7.67E-05	$G = esc._mdl$		3%	30	7.59E-05
15	8.62E-05	$G = S_r \cdot U_S - \left(t_{d_3} + t_{f_1} + t_e\right)$	-151	100%	1	8.62E-05
16	3.71E-06	$G = S_c \cdot U_S - \left(t_{d_3} + t_{r_2} + t_e\right)$	-16	48%	12	2.14E-05
17	8.52E-06	$G = esc._mdl$		5%	30	1.23E-05
18	2.92E-02	$SAFE$				

Note all distributions truncated at 0 and 1.00

SUM = 3.40E-02

CheckSUM = 1.00

ELL = 5.62E-04

TALL = 1.17E-05

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TYPE 7

Fire Start	Location sleeping area?	Fire growth incipient only?	Occupant awake?	Manual suppression?	Automatic suppression ?	Automatic alarm?	Alarm direct to all occupants?	Fire confined to room of origin?	Fire confined to floor of origin?	Outcome scenario	P(SCEN)	MODELLING OF OUTCOME SCENARIOS	mean G (s)	P(G<0)	N	ELL
START		Yes - incipient 2% RiskNormal(0.02, 0.005)								1	9.52E-05	$SAFE$				
				Yes - manual suppression 1 12.5% RiskUniform(0.125, 0.072)						2	4.60E-04	$SAFE$				
	Yes - location 14% RiskNormal(0.14, 0.015)		Yes - awake 79% RiskNormal(0.79, 0.08)		Yes - automatic suppression 99% RiskNormal(0.99,0.01)					3	3.18E-03	$SAFE$				
				No 87.5%				Yes - confined to room 88% RiskNormal(0.876,0.044)		4	3.63E-05	$G = S_r \cdot U_S - \left(t_{d_2} + t_{r_1} + t_e\right)$	44	1%	1	4.35E-07
		No 98%			No 1%				Yes - confined to ro 30% RiskNormal(0.303,0.015)	5	1.56E-06	$G = S_c \cdot U_S - \left(t_{d_2} + t_{r_2} + t_e\right)$	179	2%	12	2.81E-07
								No 12%	No 70%	6	3.59E-06	$G = esc._mdl$		0%	30	1.61E-07
				Yes - manual suppression 2 0% Binary						7	0.00E+00	$SAFE$				
					Yes 99%					8	9.71E-04	$SAFE$				
Yes - fire start 3.40E-02 RiskNormal(0.034, 0.0068)			No 21%					Yes 88%		9	9.98E-06	$G = S_r \cdot U_S - \left(t_{d_1} + t_{r_2} + t_e\right)$	-113	100%	1	9.98E-06
							Yes - alarm direct to occupants 100% Binary		Yes 30%	10	4.30E-07	$G = S_c \cdot U_S - \left(t_{d_1} + t_{r_2} + t_e\right)$	127	3%	12	1.55E-07
				No 100%				No 12%	No 70%	11	9.87E-07	$G = esc._mdl$		0.3%	30	8.88E-08
						Yes - automatic alarm 90% RiskNormal(0.90, 0.02)		Yes 88%		12	0.00E+00	$G = 0$				
							No 0%		Yes 30%	13	0.00E+00	$G = 0$				
					No 1%			No 12%	No 70%	14	0.00E+00	$G = 0$				
								Yes 88%		15	1.11E-06	$G = S_r \cdot U_S - \left(t_{d_3} + t_{r_1} + t_e\right)$	-151	100%	1	1.11E-06
						No 10%			Yes 30%	16	4.77E-08	$G = S_c \cdot U_S - \left(t_{d_3} + t_{r_2} + t_e\right)$	-16	48%	12	2.75E-07
								No 12%	No 70%	17	1.10E-07	$G = esc._mdl$		5%	30	1.58E-07
	No 86%									18	2.92E-02	$SAFE$				

Note all distributions truncated at 0 and 1.00

SUM = 3.40E-02

CheckSUM = 1.00

ELL = 6.07E-06

TALL = 1.26E-07

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TYPE 7e

Fire Start	Location sleeping area?	Fire growth incipient only?	Occupant awake?	Manual suppression?	Automatic suppression ?	Automatic alarm?	Alarm direct to all occupants?	Fire confined to room of origin?	Fire confined to floor of origin?	Outcome scenario	PROBABILITY	MODELLING OF OUTCOME SCENARIOS	mean G (s)	P(G<0)	N	ELL
START		Yes - incipient 2% RiskNormal(0.02, 0.005)								1	9.52E-05	$SAFE$				
				Yes - manual suppression 1 12.5% RiskUniform(0.125, 0.072)						2	4.60E-04	$SAFE$				
	Yes - location 14% RiskNormal(0.14, 0.015)		Yes - awake 79% RiskNormal(0.79, 0.08)		Yes - automatic suppression 99% RiskNormal(0.99,0.01)					3	3.18E-03	$SAFE$				
				No 87.5%				Yes - confined to room 88% RiskNormal(0.876,0.044)		4	3.63E-05	$G=S_r \cdot U_S-\left(t_{d_2}+t_{r_1}+t_e\right)$	44	1%	1	4.35E-07
		No 98%			No 1%				Yes - confined to fl 30% RiskNormal(0.303,0.015)	5	1.56E-06	$G=S_c \cdot U_S-\left(t_{d_2}+t_{r_2}+t_e\right)$	179	2%	12	2.81E-07
								No 12%	No 70%	6	3.59E-06	$G = esc._mdl$		0%	30	1.61E-07
				Yes - manual suppression 2 0% Binary						7	0.00E+00	$SAFE$				
					Yes 99%					8	9.71E-04	$SAFE$				
Yes - fire start 3.40E-02 RiskNormal(0.034, 0.0068)			No 21%					Yes 88%		9	0.00E+00	$G = 0$				
							Yes - alarm direct to occupants 0% Binary		Yes 30%	10	0.00E+00	$G = 0$				
				No 100%				No 12%	No 70%	11	0.00E+00	$G = 0$				
						Yes - automatic alarm 90% RiskNormal(0.90, 0.02)		Yes 88%		12	9.98E-06	$G=S_r \cdot U_S-\left(t_{d_1}+t_{r_2}+t_e\right)$	-113	100%	1	9.98E-06
							No 100%	No 12%	Yes 30%	13	4.30E-07	$G=S_c \cdot U_S-\left(t_{d_1}+t_i+t_{r_2}+t_e\right)$	8	33%	12	1.70E-06
					No 1%				No 70%	14	9.87E-07	$G = esc._mdl$		3%	30	9.77E-07
								Yes 88%		15	1.11E-06	$G=S_r \cdot U_S-\left(t_{d_3}+t_{r_1}+t_e\right)$	-151	100%	1	1.11E-06
						No 10%		No 12%	Yes 30%	16	4.77E-08	$G=S_c \cdot U_S-\left(t_{d_3}+t_{r_2}+t_e\right)$	-16	48%	12	2.75E-07
									No 70%	17	1.10E-07	$G = esc._mdl$		5%	30	1.58E-07
	No 86%									18	2.92E-02	$SAFE$				

Note all distributions truncated at 0 and 1.00

SUM =	3.40E-02	ELL =	7.24E-06
CheckSUM =	1.00	TALL =	1.51E-07

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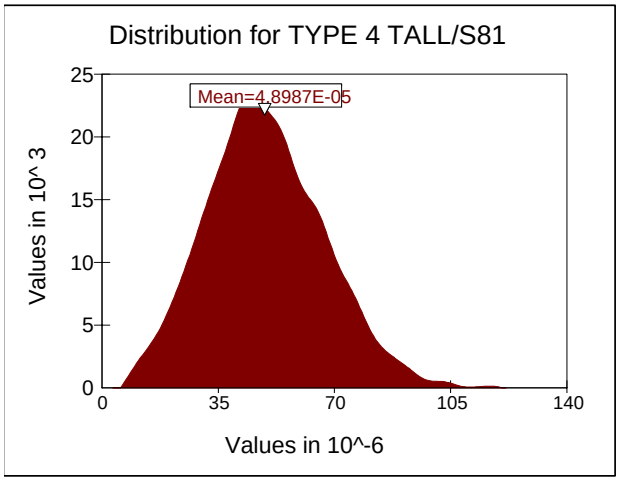
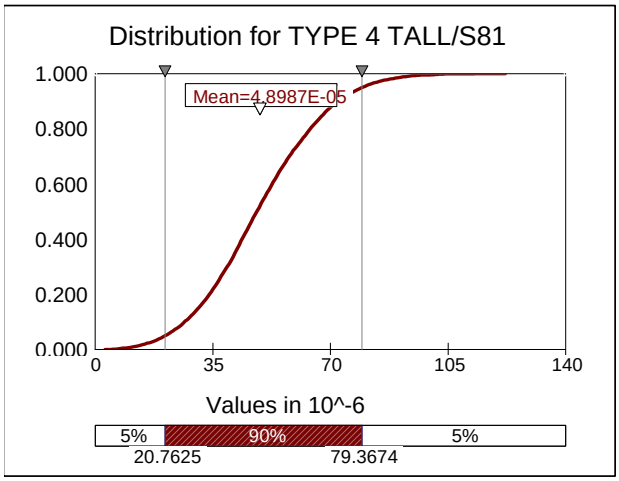
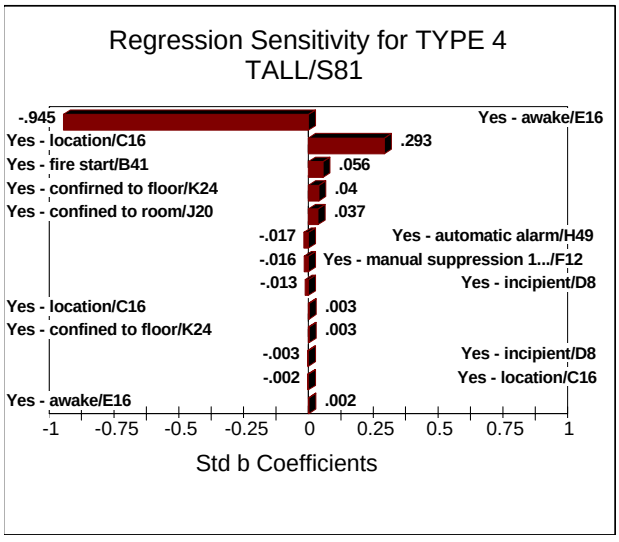
Appendix B

Results, pre-calibration

Simulation Results for TYPE 4 TALL / S81





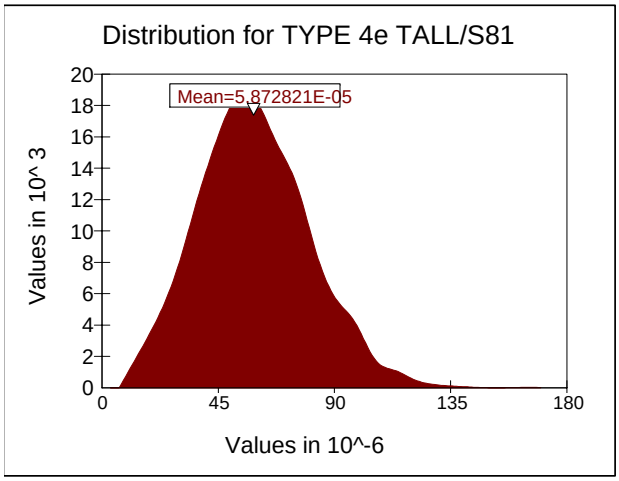


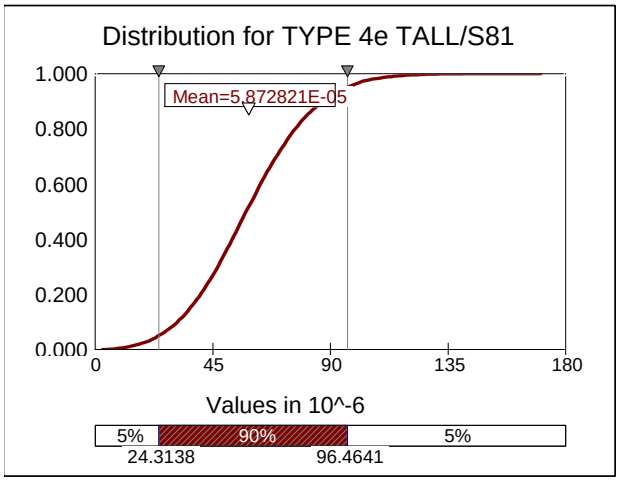
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	41
Number of Outputs	20
Sampling Type	Latin Hypercube
Simulation Start Time	4/02/03 09:13
Simulation Stop Time	4/02/03 09:15
Simulation Duration	00:01:58
Random Seed	1243287559

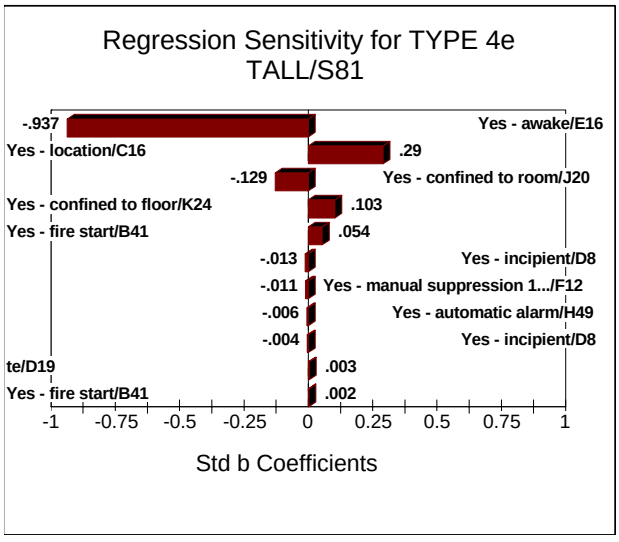
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	2.95E-06	5%	2.08E-05
Maximum	1.22E-04	10%	2.65E-05
Mean	4.90E-05	15%	3.06E-05
Std Dev	1.77E-05	20%	3.40E-05
Variance	3.13466E-10	25%	3.67E-05
Skewness	0.242986004	30%	3.93E-05
Kurtosis	2.936347143	35%	4.16E-05
Median	4.80E-05	40%	4.36E-05
Mode	4.82E-05	45%	4.59E-05
Left X	2.08E-05	50%	4.80E-05
Left P	5%	55%	5.03E-05
Right X	7.94E-05	60%	5.27E-05
Right P	95%	65%	5.50E-05
Diff X	5.86E-05	70%	5.77E-05
Diff P	90%	75%	6.08E-05
#Errors	0	80%	6.39E-05
Filter Min		85%	6.77E-05
Filter Max		90%	7.24E-05
#Filtered	0	95%	7.94E-05

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - awake / $E	-0.945	-0.947
#2	Yes - location / $	0.292	0.285
#3	Yes - fire start /	0.056	0.052
#4	Yes - confirned	0.040	0.039
#5	Yes - confined t	0.037	0.028
#6	Yes - incipient /	-0.013	-0.018
#7	Yes - confined t	0.003	-0.014
#8	Yes - location / $	-0.002	0.019
#9	alpha / D4	0.000	0.012
#10	Us / D7	0.000	-0.013
#11	td3 / D12	0.000	-0.012
#12	Yes - awake / $E	0.000	0.014
#13	Yes - automatic	0.000	0.011
#14	Yes - automatic	0.000	0.015
#15	Yes - location / $	0.000	0.015
#16	Yes - confined t	0.000	-0.011

Simulation Results for TYPE 4e TALL / S81





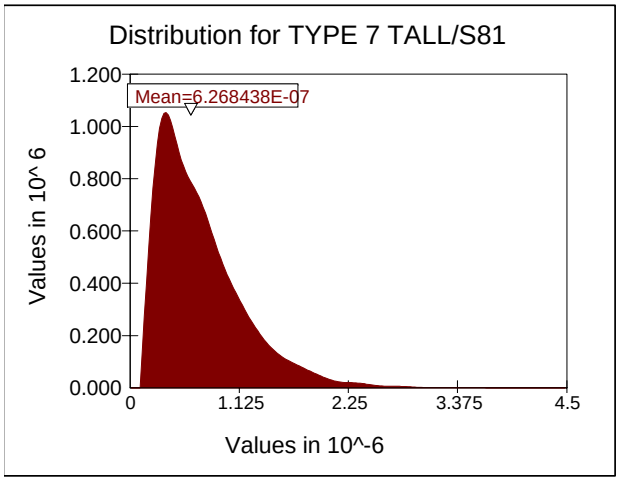


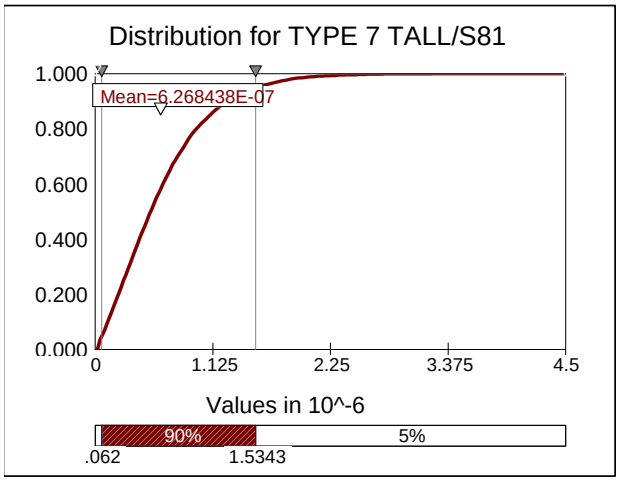
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	41
Number of Outputs	20
Sampling Type	Latin Hypercube
Simulation Start Time	4/02/03 09:13
Simulation Stop Time	4/02/03 09:15
Simulation Duration	00:01:58
Random Seed	1243287559

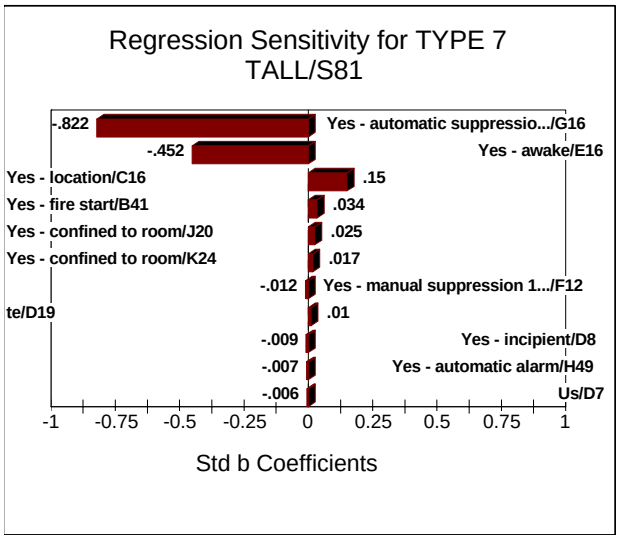
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	2.84E-06	5%	2.43E-05
Maximum	1.70E-04	10%	3.14E-05
Mean	5.87E-05	15%	3.62E-05
Std Dev	2.17E-05	20%	4.03E-05
Variance	4.71292E-10	25%	4.37E-05
Skewness	0.28645083	30%	4.68E-05
Kurtosis	3.107372412	35%	4.96E-05
Median	5.77E-05	40%	5.25E-05
Mode	4.81E-05	45%	5.51E-05
Left X	2.43E-05	50%	5.77E-05
Left P	5%	55%	6.07E-05
Right X	9.65E-05	60%	6.32E-05
Right P	95%	65%	6.60E-05
Diff X	7.22E-05	70%	6.93E-05
Diff P	90%	75%	7.28E-05
#Errors	0	80%	7.66E-05
Filter Min		85%	8.11E-05
Filter Max		90%	8.71E-05
#Filtered	0	95%	9.65E-05

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - awake / $t	-0.937	-0.933
#2	Yes - location / $	0.290	0.261
#3	Yes - confined t	-0.129	-0.129
#4	Yes - confined t	0.103	0.101
#5	Yes - fire start /	0.054	0.041
#6	Yes - incipient /	-0.013	-0.019
#7	Yes - manual su	-0.011	-0.024
#8	Yes - automatic	-0.006	-0.015
#9	Us / D7	0.000	0.019
#10	tr1 / D16	0.000	-0.017
#11	tr2 / D17	0.000	0.015
#12	Yes - awake / $t	0.000	0.014
#13	Yes - automatic	0.000	-0.018
#14	Yes - confined t	0.000	-0.015
#15	Yes - automatic	0.000	-0.016
#16	Yes - awake / $t	0.000	-0.013

Simulation Results for TYPE 7 TALL / S81





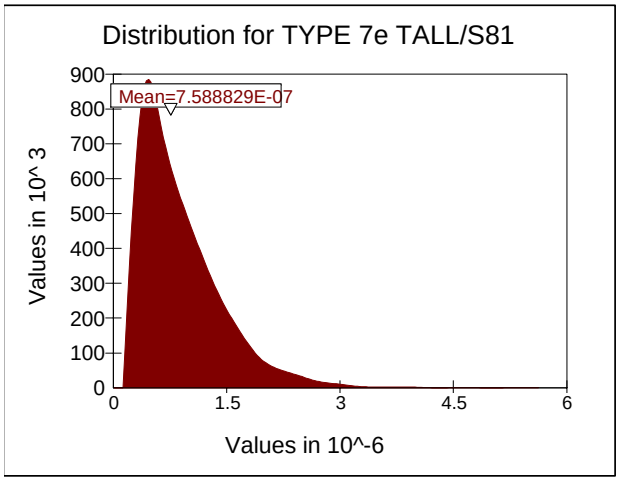


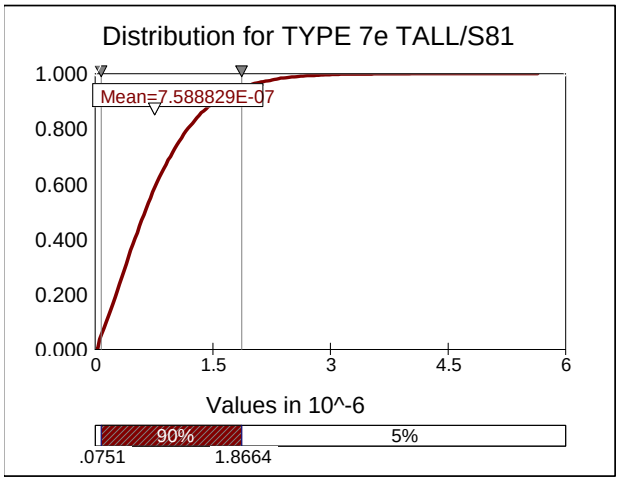
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	41
Number of Outputs	20
Sampling Type	Latin Hypercube
Simulation Start Time	4/02/03 09:13
Simulation Stop Time	4/02/03 09:15
Simulation Duration	00:01:58
Random Seed	1243287559

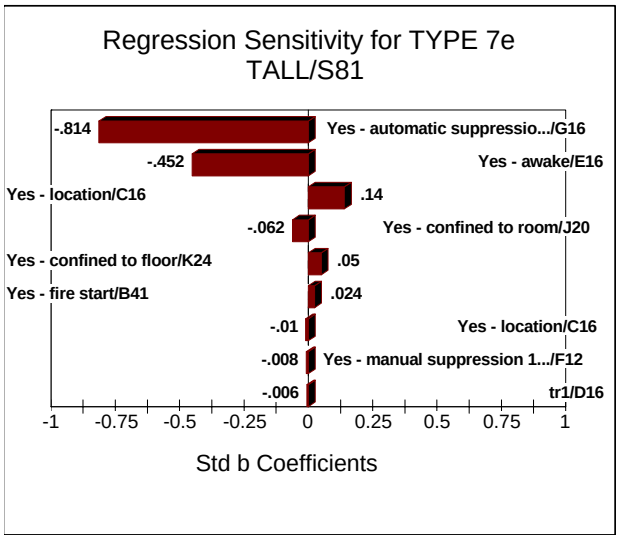
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	4.56E-11	5%	6.20E-08
Maximum	4.49E-06	10%	1.20E-07
Mean	6.27E-07	15%	1.69E-07
Std Dev	4.71E-07	20%	2.21E-07
Variance	2.21782E-13	25%	2.70E-07
Skewness	1.281312287	30%	3.22E-07
Kurtosis	5.444135287	35%	3.69E-07
Median	5.28E-07	40%	4.22E-07
Mode	9.10E-07	45%	4.75E-07
Left X	6.20E-08	50%	5.28E-07
Left P	5%	55%	5.87E-07
Right X	1.53E-06	60%	6.48E-07
Right P	95%	65%	7.12E-07
Diff X	1.47E-06	70%	7.87E-07
Diff P	90%	75%	8.69E-07
#Errors	0	80%	9.69E-07
Filter Min		85%	1.10E-06
Filter Max		90%	1.26E-06
#Filtered	0	95%	1.53E-06

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - automatic	-0.822	-0.860
#2	Yes - awake / $	-0.452	-0.431
#3	Yes - location / $	0.150	0.124
#4	Yes - confined t	0.025	0.020
#5	Yes - confined t	0.016	0.025
#6	te / D19	0.010	-0.020
#7	td2 / D11	0.000	0.013
#8	tr1 / D16	0.000	-0.014
#9	Yes - confirned	0.000	-0.012
#10	Yes - awake / $	0.000	0.015
#11	Yes - fire start /	0.000	0.011
#12	Yes - automatic	0.000	-0.025
#13	Yes - location / $	0.000	-0.016
#14	Yes - automatic	0.000	-0.012
#15	Yes - confined t	0.000	0.015
#16	Yes - fire start /	0.000	0.014

Simulation Results for TYPE 7e TALL / S81







Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	41
Number of Outputs	20
Sampling Type	Latin Hypercube
Simulation Start Time	4/02/03 09:13
Simulation Stop Time	4/02/03 09:15
Simulation Duration	00:01:58
Random Seed	1243287559

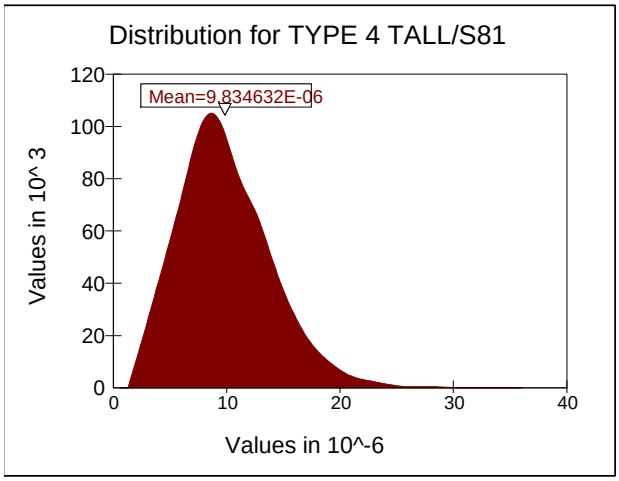
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	8.71E-11	5%	7.51E-08
Maximum	5.64E-06	10%	1.42E-07
Mean	7.59E-07	15%	2.05E-07
Std Dev	5.78E-07	20%	2.67E-07
Variance	3.34291E-13	25%	3.24E-07
Skewness	1.352747996	30%	3.85E-07
Kurtosis	5.985296617	35%	4.39E-07
Median	6.36E-07	40%	5.04E-07
Mode	8.14E-07	45%	5.67E-07
Left X	7.51E-08	50%	6.36E-07
Left P	5%	55%	7.06E-07
Right X	1.87E-06	60%	7.77E-07
Right P	95%	65%	8.65E-07
Diff X	1.79E-06	70%	9.60E-07
Diff P	90%	75%	1.06E-06
#Errors	0	80%	1.18E-06
Filter Min		85%	1.33E-06
Filter Max		90%	1.53E-06
#Filtered	0	95%	1.87E-06

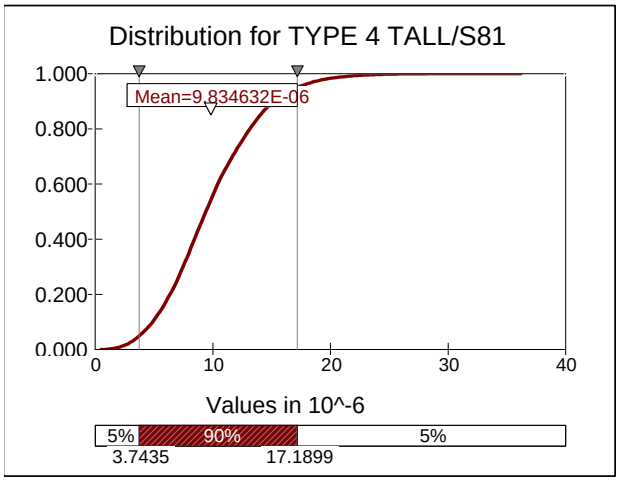
Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - automatic	-0.814	-0.859
#2	Yes - awake / $D	-0.451	-0.434
#3	Yes - location / $	0.140	0.119
#4	Yes - confined t	-0.062	-0.053
#5	Yes - confined t	0.050	0.038
#6	Yes - fire start /	0.024	0.038
#7	Yes - location / $	-0.010	-0.012
#8	Yes - manual su	-0.008	-0.020
#9	alpha / D4	0.000	-0.012
#10	td2 / D11	0.000	-0.013
#11	te / D19	0.000	0.010
#12	Yes - automatic	0.000	-0.013
#13	Yes - confined t	0.000	-0.018
#14	Yes - confined t	0.000	-0.020
#15	Yes - incipient /	0.000	0.011
#16	Yes - automatic	0.000	0.015

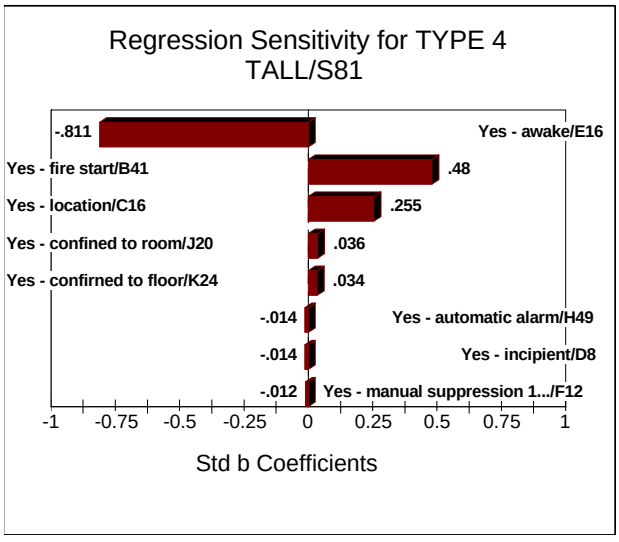
Appendix C

Results, post-calibration

Simulation Results for TYPE 4 TALL / S81





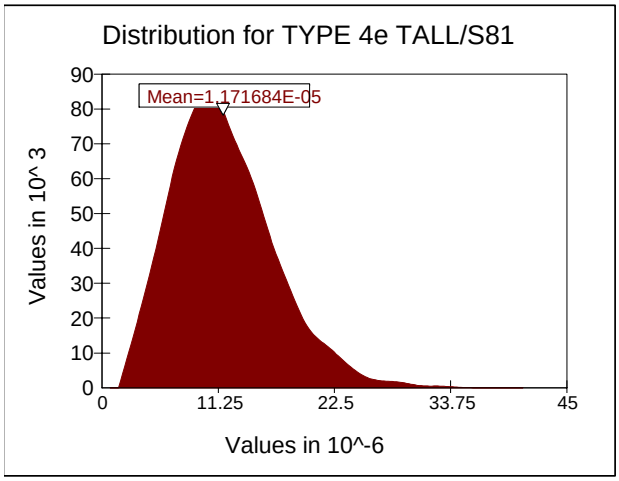


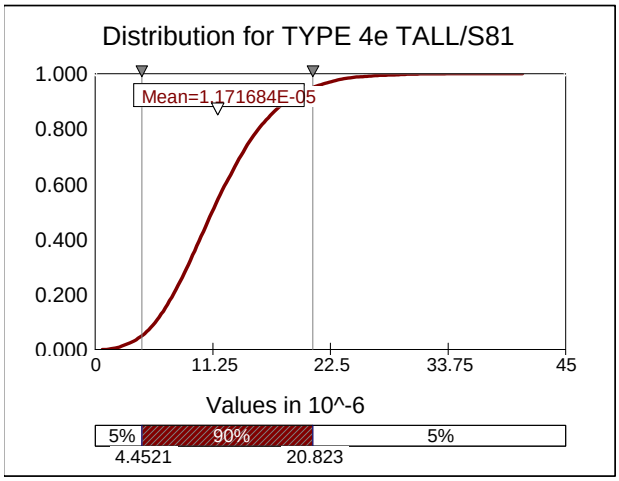
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	38
Number of Outputs	32
Sampling Type	Latin Hypercube
Simulation Start Time	5/02/03 18:36
Simulation Stop Time	5/02/03 18:38
Simulation Duration	00:01:48
Random Seed	2078304831

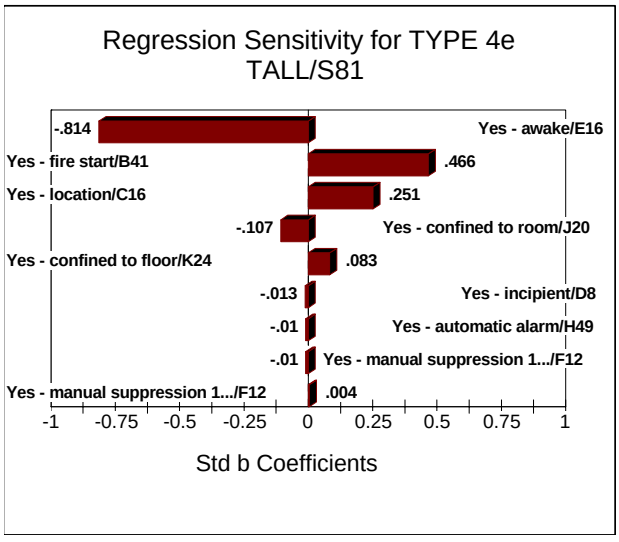
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	4.85E-07	5%	3.74E-06
Maximum	3.62E-05	10%	4.86E-06
Mean	9.83E-06	15%	5.69E-06
Std Dev	4.12E-06	20%	6.35E-06
Variance	1.69563E-11	25%	6.95E-06
Skewness	0.629209875	30%	7.46E-06
Kurtosis	3.706575717	35%	7.96E-06
Median	9.40E-06	40%	8.44E-06
Mode	8.25E-06	45%	8.94E-06
Left X	3.74E-06	50%	9.40E-06
Left P	5%	55%	9.91E-06
Right X	1.72E-05	60%	1.04E-05
Right P	95%	65%	1.10E-05
Diff X	1.34E-05	70%	1.17E-05
Diff P	90%	75%	1.24E-05
#Errors	0	80%	1.31E-05
Filter Min		85%	1.40E-05
Filter Max		90%	1.53E-05
#Filtered	0	95%	1.72E-05

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - awake / $D	-0.811	-0.816
#2	Yes - fire start /	0.480	0.465
#3	Yes - location / $	0.255	0.246
#4	Yes - confined t	0.036	0.020
#5	Yes - confirned	0.035	0.036
#6	Yes - automatic	-0.014	-0.014
#7	Yes - manual su	-0.013	-0.016
#8	alpha / D4	0.000	-0.011
#9	Us / D7	0.000	0.027
#10	tr2 / D17	0.000	-0.013
#11	Yes - incipient /	0.000	-0.012
#12	Yes - location / $	0.000	0.011
#13	Yes - confined t	0.000	0.016
#14	Yes - confined t	0.000	-0.020
#15	Yes - location / $	0.000	-0.019
#16	Yes - confined t	0.000	-0.019

Simulation Results for TYPE 4e TALL / S81





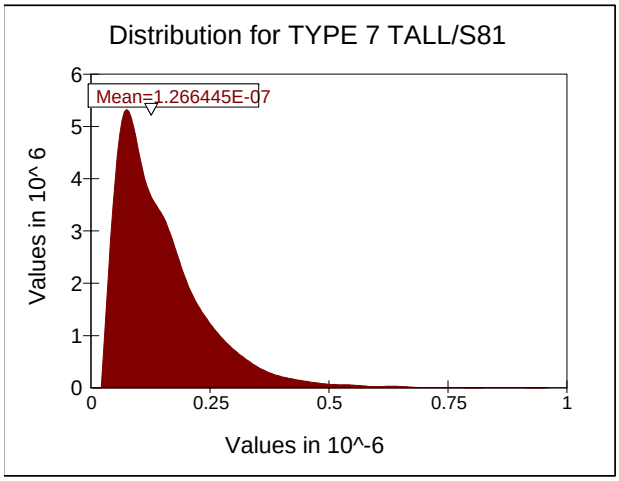


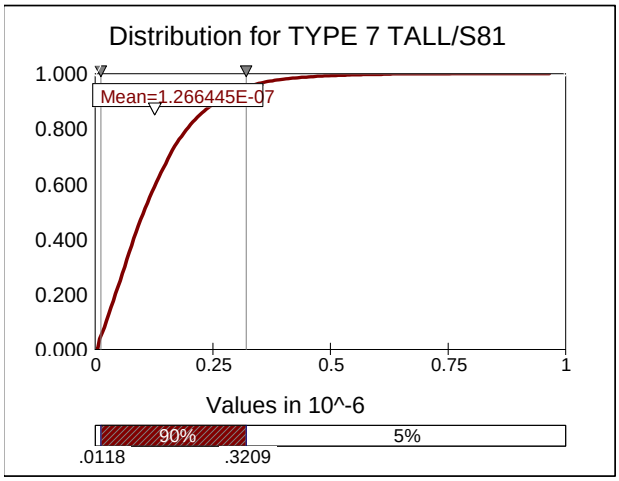
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	38
Number of Outputs	32
Sampling Type	Latin Hypercube
Simulation Start Time	5/02/03 18:36
Simulation Stop Time	5/02/03 18:38
Simulation Duration	00:01:48
Random Seed	2078304831

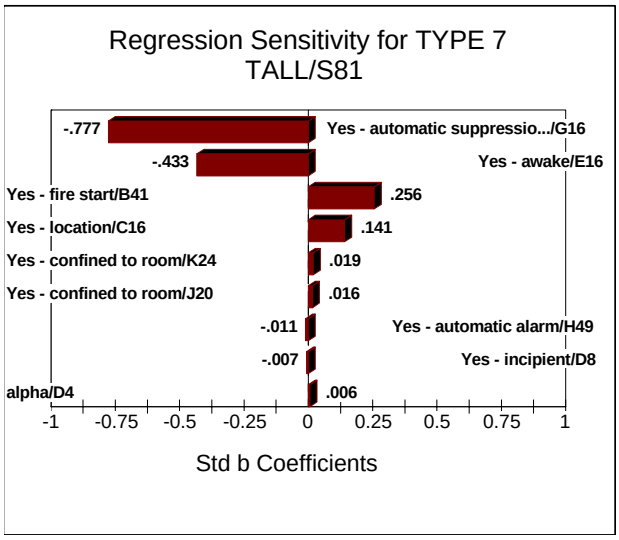
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	6.95E-07	5%	4.45E-06
Maximum	4.09E-05	10%	5.76E-06
Mean	1.17E-05	15%	6.70E-06
Std Dev	5.00E-06	20%	7.47E-06
Variance	2.49516E-11	25%	8.16E-06
Skewness	0.656482892	30%	8.82E-06
Kurtosis	3.709723762	35%	9.44E-06
Median	1.12E-05	40%	1.00E-05
Mode	9.59E-06	45%	1.06E-05
Left X	4.45E-06	50%	1.12E-05
Left P	5%	55%	1.18E-05
Right X	2.08E-05	60%	1.25E-05
Right P	95%	65%	1.32E-05
Diff X	1.64E-05	70%	1.39E-05
Diff P	90%	75%	1.47E-05
#Errors	0	80%	1.56E-05
Filter Min		85%	1.68E-05
Filter Max		90%	1.83E-05
#Filtered	0	95%	2.08E-05

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - awake / $t	-0.814	-0.817
#2	Yes - fire start /	0.466	0.445
#3	Yes - location / $	0.251	0.235
#4	Yes - confined t	-0.107	-0.089
#5	Yes - confined t	0.082	0.063
#6	Yes - incipient /	-0.013	-0.024
#7	Yes - automatic	-0.010	0.014
#8	Yes - manual su	0.004	0.016
#9	Us / D7	0.000	0.014
#10	td3 / D12	0.000	-0.017
#11	Yes - confirned	0.000	0.012
#12	Yes - incipient /	0.000	0.014
#13	Yes - manual su	0.000	0.018
#14	Yes - incipient /	0.000	0.023
#15	Yes - manual su	0.000	0.014
#16	Yes - automatic	0.000	0.013

Simulation Results for TYPE 7 TALL / S81





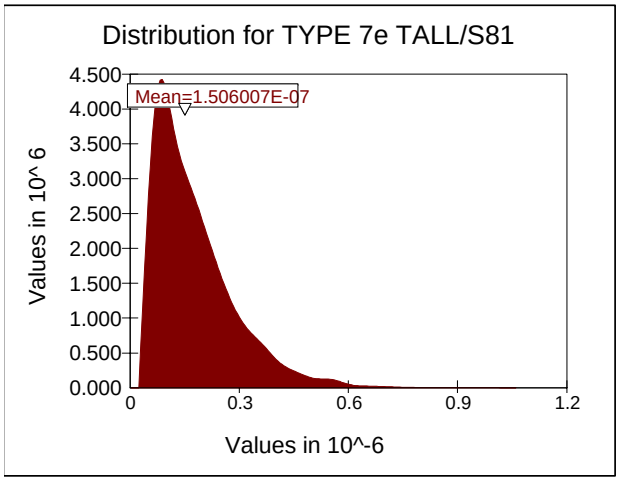


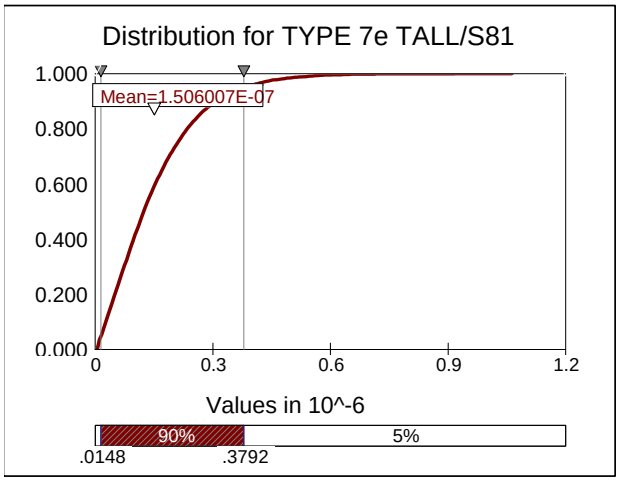
Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	38
Number of Outputs	32
Sampling Type	Latin Hypercube
Simulation Start Time	5/02/03 18:36
Simulation Stop Time	5/02/03 18:38
Simulation Duration	00:01:48
Random Seed	2078304831

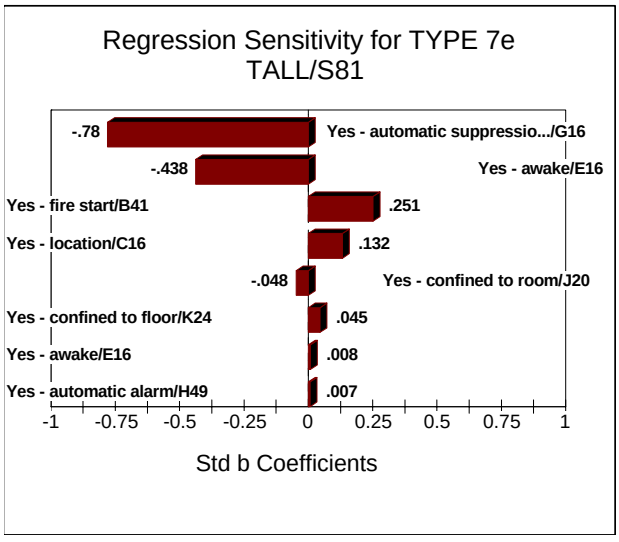
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	2.08E-11	5%	1.18E-08
Maximum	9.65E-07	10%	2.34E-08
Mean	1.27E-07	15%	3.29E-08
Std Dev	1.01E-07	20%	4.30E-08
Variance	1.01614E-14	25%	5.33E-08
Skewness	1.580214865	30%	6.27E-08
Kurtosis	7.137097876	35%	7.17E-08
Median	1.03E-07	40%	8.15E-08
Mode	1.09E-07	45%	9.20E-08
Left X	1.18E-08	50%	1.03E-07
Left P	5%	55%	1.16E-07
Right X	3.21E-07	60%	1.29E-07
Right P	95%	65%	1.43E-07
Diff X	3.09E-07	70%	1.57E-07
Diff P	90%	75%	1.73E-07
#Errors	0	80%	1.95E-07
Filter Min		85%	2.22E-07
Filter Max		90%	2.58E-07
#Filtered	0	95%	3.21E-07

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - automatic	-0.776	-0.834
#2	Yes - awake / $	-0.433	-0.416
#3	Yes - fire start /	0.256	0.217
#4	Yes - location / $	0.141	0.116
#5	Yes - confined t	0.019	0.011
#6	td3 / D12	0.000	-0.015
#7	Yes - incipient /	0.000	0.017
#8	Yes - manual su	0.000	0.015
#9	Yes - location / $	0.000	0.018
#10	Yes - confined t	0.000	0.021
#11	Yes - incipient /	0.000	0.013
#12	Yes - manual su	0.000	0.019
#13	Yes - awake / $	0.000	-0.012
#14	Yes - manual su	0.000	-0.013
#15	Yes - awake / $	0.000	-0.012
#16	Yes - confined t	0.000	-0.011

Simulation Results for TYPE 7e TALL / S81







Summary Information	
Workbook Name	ETA.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	38
Number of Outputs	32
Sampling Type	Latin Hypercube
Simulation Start Time	5/02/03 18:36
Simulation Stop Time	5/02/03 18:38
Simulation Duration	00:01:48
Random Seed	2078304831

Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	1.41E-11	5%	1.48E-08
Maximum	1.06E-06	10%	2.66E-08
Mean	1.51E-07	15%	3.82E-08
Std Dev	1.19E-07	20%	5.00E-08
Variance	1.4067E-14	25%	6.16E-08
Skewness	1.433990115	30%	7.33E-08
Kurtosis	6.213695574	35%	8.53E-08
Median	1.24E-07	40%	9.74E-08
Mode	1.14E-07	45%	1.11E-07
Left X	1.48E-08	50%	1.24E-07
Left P	5%	55%	1.38E-07
Right X	3.79E-07	60%	1.53E-07
Right P	95%	65%	1.70E-07
Diff X	3.64E-07	70%	1.88E-07
Diff P	90%	75%	2.10E-07
#Errors	0	80%	2.34E-07
Filter Min		85%	2.65E-07
Filter Max		90%	3.10E-07
#Filtered	0	95%	3.79E-07

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Yes - automatic	-0.780	-0.825
#2	Yes - awake / $	-0.438	-0.414
#3	Yes - fire start /	0.251	0.234
#4	Yes - location / $	0.132	0.109
#5	Yes - confined t	-0.048	-0.053
#6	Yes - confined t	0.045	0.029
#7	Yes - awake / $	0.008	0.019
#8	td3 / D12	0.000	-0.013
#9	tr1 / D16	0.000	-0.017
#10	Yes - confined t	0.000	0.026
#11	Yes - incipient /	0.000	-0.015
#12	Yes - manual su	0.000	0.012
#13	Yes - location / $	0.000	0.014
#14	Yes - confined t	0.000	-0.012
#15	Yes - awake / $	0.000	-0.020
#16	Yes - automatic	0.000	0.015