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USING THE QUANTITATIVE RISK-BASED APPROACH FOR FIRE SAFETY IN PRACTICE

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QUANTITATIVE RISK-BASED APPROACH FOR FIRE SAFETY

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INTRODUCTION RISK-BASED APPROACH FOR FIRE SAFETY

INTRODUCTION RISK-BASED APPROACH
EFFECTIVENESS OF SMOKE ALARMS IN HOMES

44 fatalities per year of residential fires in the Netherlands

Predictions based on a risk-based approach

- Comparison presence of smoke detectors
  - Current situation with 50% working smoke detectors — 44 fatalities per year
  - Assuming 80% working smoke detectors — 36 fatalities per year
  - Assuming 100% working smoke detectors — 31 fatalities per year

Basis of proposal Dutch Minister:

Smoke detectors in homes will be mandatory for both new and existing homes

INTRODUCTION RISK-BASED APPROACH

REASONS TO DEVELOP A RISK-BASED APPROACH

- Major incidents initiated need for upgrade of regulatory system for fire safety
- All major stakeholders involved noted that existing regulations are limited
  - Mainly prescriptive
  - Based on qualitative risk assumptions
  - Cost might be higher than needed
- Fire safety engineers
  - Are used how to prescriptive rules given by fire code
  - Know how solutions perform in relation to each other in terms of qualitative risks
  - Have difficulty determining how a given solution performs regarding a quantitative risk criterion

A risk-based approach provides safe fire safety solutions for affordable costs

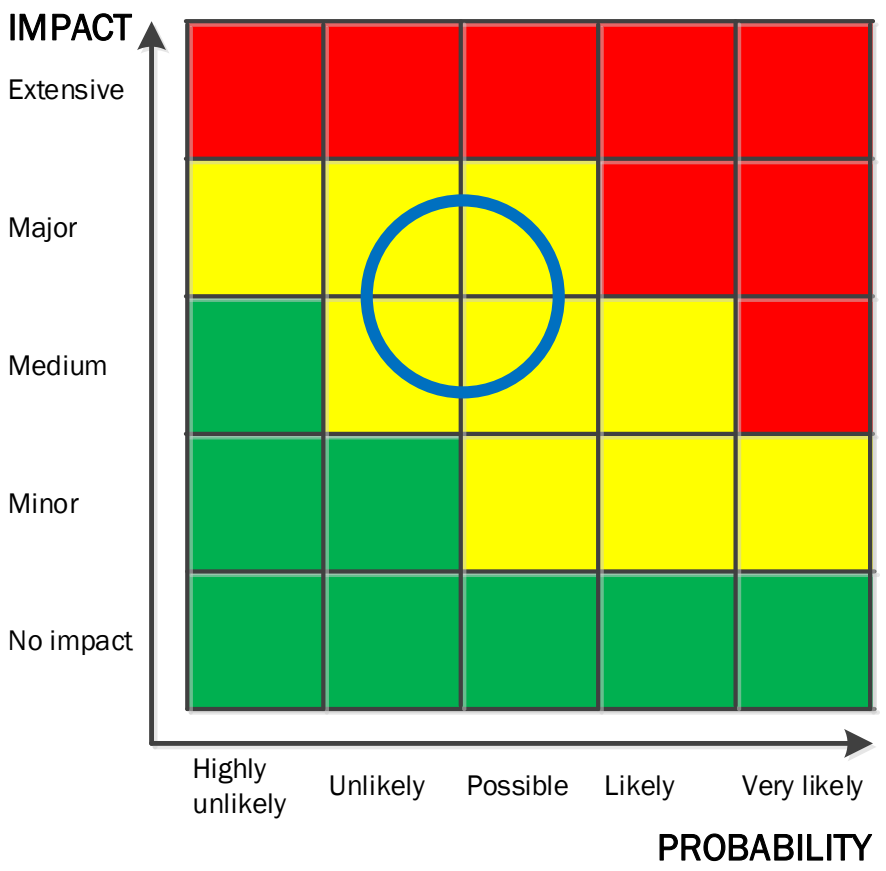
INTRODUCTION RISK-BASED APPROACH

FIRE SAFETY GOALS

- Life safety of attendees
- Life safety of fire fighters
- Property loss
- Business continuity
- Environmental impact
- Reputation

INTRODUCTION RISK-BASED APPROACH
METHODOLOGIES

- Risk is defined as “probability” times “consequences”
  - Human life risk: number of injuries or fatalities per year
  - Financial risk: cost per year
- Risk matrix
- Available approaches: qualitative and quantitative PRA
- Process industry
  - Want to avoid high impact and looking after alternatives
  - Quantitative approach can be used in various cases
- Buildings
  - Have to deal with minimized probabilities and significant impact
  - Quantitative approach is preferred
  - Framework needed to link approach with fire safety code



FRAMEWORK FOR LIFE SAFETY

BASED ON PROBABILISTIC RISK ANALYSES

FRAMEWORK FOR LIFE SAFETY
IMPLEMENTING PROBABILISTIC RISK ANALYSES

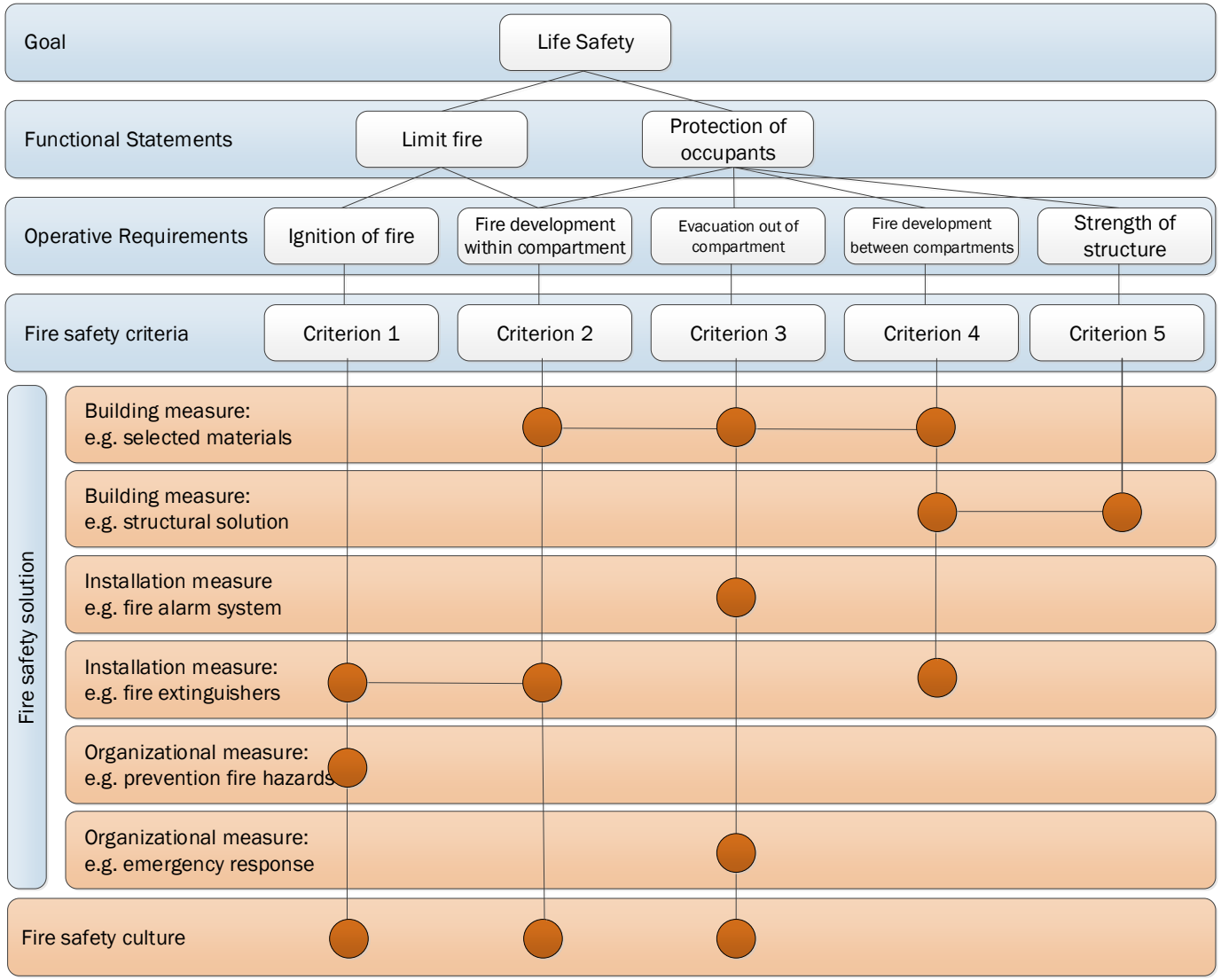
- Guidance on use PRA on fire engineering
  - BS 7975 Fire Safety – PD 7974-7 Probabilistic fire risk assessment (2019)
  - SFPE engineering Guide – Risk Guidance (new edition to be published in 2021)
  - INSTA 951 Fire Safety Engineering – Probabilistic Methods for Verifying Fire Safety Design in Buildings (2019)
- Insight into
  - Probabilistic methods – rather generic
  - Data – limited data available

FRAMEWORK FOR LIFE SAFETY
GENERAL RISK CRITERION

- Hazards for people within a building
  - High temperature, radiation and toxic gases
  - Collapse of a structure
- These have a negative effect on the body of a person (injuries or death)
- Risk measure
  - Mostly based on number of deaths
  - Also number of injuries might be considered
- Various matching criteria might be used, slight preference for
  - IR – Individual risk for a person on an annual basis
  - GR – Group risk for a group on an annual basis
- Average number of death per year in buildings in the Netherlands (2001 – 2013) is 53 persons
  - Might be used as an option for a target (17 million inhabitants): IR = $3 \cdot 10^{-6}$

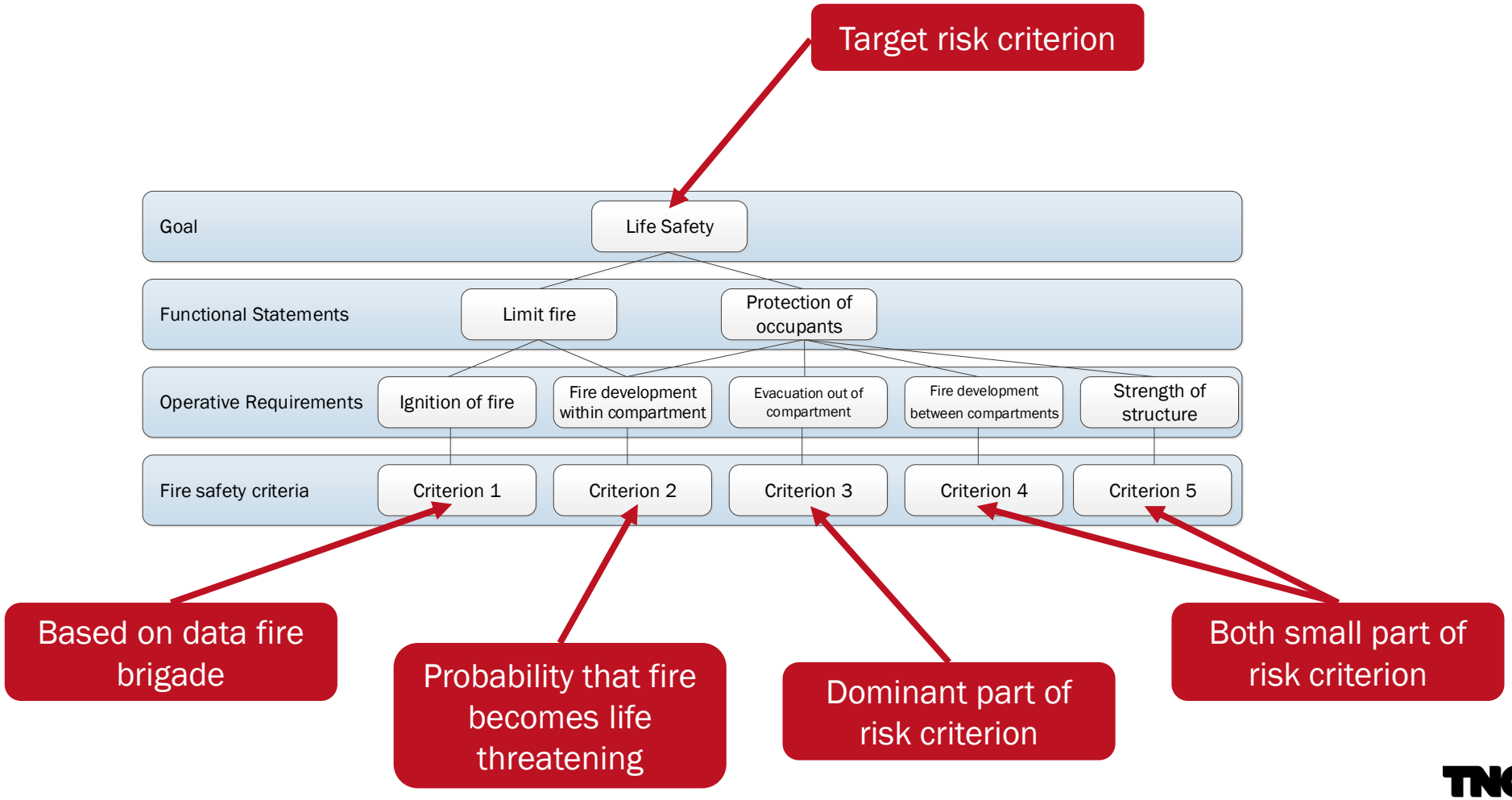
FRAMEWORK FOR LIFE SAFETY

PERFORM-BASED REGULAIONS



FRAMEWORK FOR LIFE SAFETY

BALANCED SUB-CRITERIA FOR OPERATIONAL REQUIREMENTS



EVACUATION OUT OF COMPARTMENT

ASET-RSET ANALYSES GROUP HOME FOR DISABLED PEOPLE

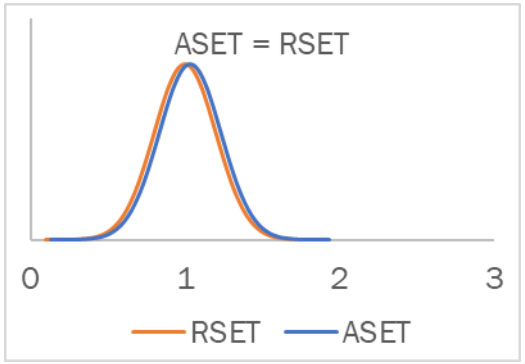
GROUP HOME FOR DISABLED PEOPLE
CURRENT ASET-RSET ANALYSES

- Based on ‘worst-case’ scenarios
  - ASET calculated with zone- of CFD-model
  - RSET based on simulation tools or evacuation exercises
- Safety factor has to be assumed
- No common practice, only generic guidance
  - Which fire scenario has to be considered?
  - How to determine time needed for evacuation?
  - Is chosen value safety factor safe enough? Or too conservative giving additional costs?

GROUP HOME FOR DISABLED PEOPLE
STOCHASTIC NATURE OF ASET AND RSET

- Probability that ASET – RSET < 0, assuming normal distributions & $V_{RSET} = 0.2$
  - Safety factor is 1.0

    RSET = ASET : $P_f = 0.5$

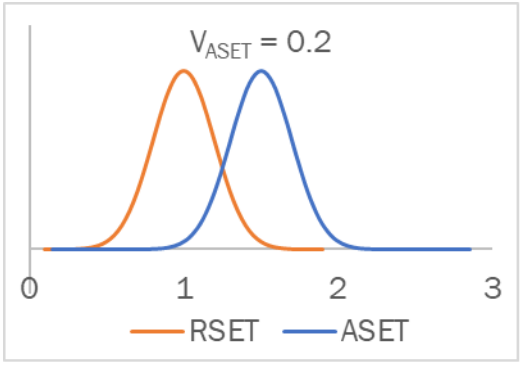


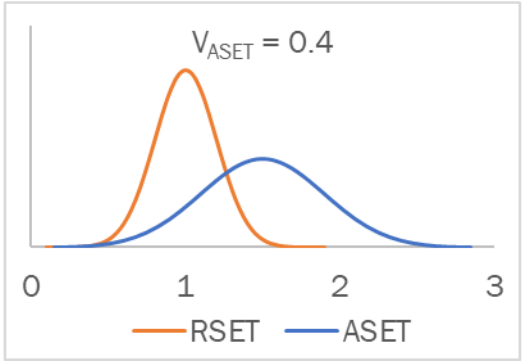
  - Safety factor is 1.5

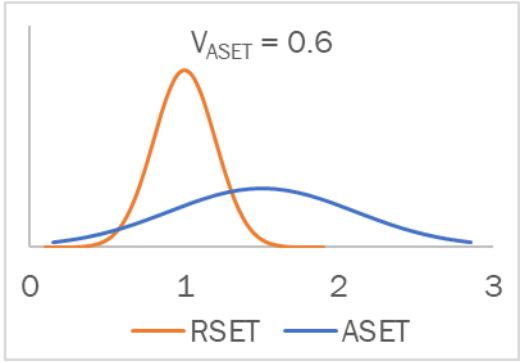
    $V_{ASET} = 0.2$: $P_f = 0.08$

    $V_{ASET} = 0.4$: $P_f = 0.24$

    $V_{ASET} = 0.6$: $P_f = 0.32$







Value safety factor strongly depends on scenarios and criterion for RSET, expressed in value of V

GROUP HOME FOR DISABLED PEOPLE
ASET-RSET ANALYSES BASED ON PROBABILISTICS

- Individual risk measure

$$F(A) \cdot P_c \cdot P_f \leq f_{IR} \cdot IR$$

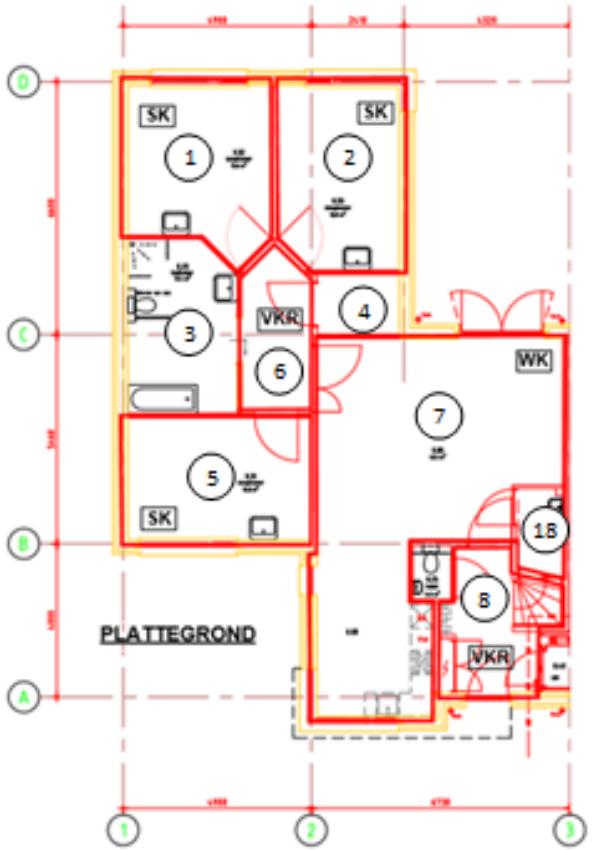
  - F(A) is frequency that a fire occurs, depending on floor area A (assumed to be $F(A) = K \cdot A$, with $K = 10^{-5}$ per $m^2 \cdot$ year)
  - P_c is probability that fire becomes life threatening (assumed to be $P_c = 0.04$)
  - P_f is probability that a person is not capable to evacuate safely in time; based on ASET-RSET
  - f_{IR} is fraction of risk measure operational requirement “evacuation out of compartment”, a value of $f_{IR} = 0.8$ is assumed
  - IR is target of $12 \cdot 10^{-6}$ per year (probability fatalities in health care approximately 3 to 4 times higher than in average)

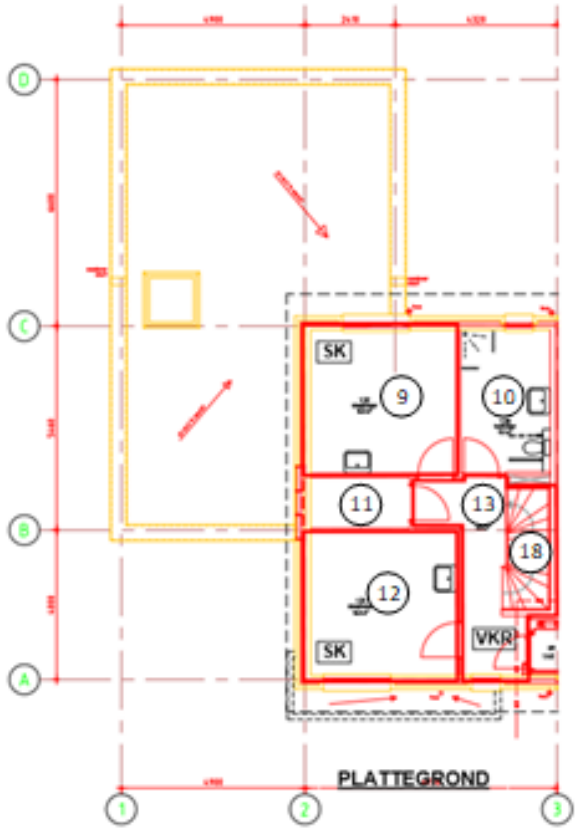
- Event tree (analyzed with use of Monto Carlo simulations)
  - To evaluate ASET-RSET for number of scenarios
  - For all relevant scenarios

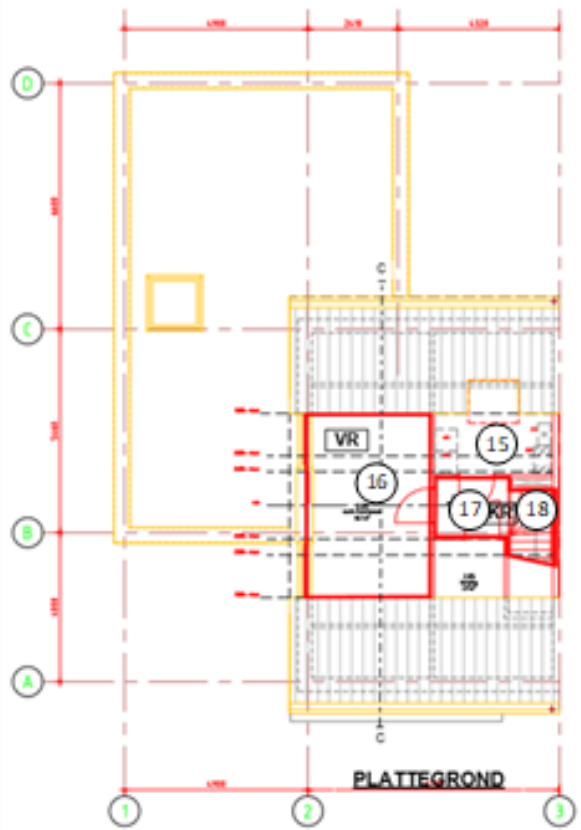
GROUP HOME FOR DISABLED PEOPLE
DESCRIPTION OF GROUP HOME

- Group home for 6 clients (disabled people)
  - Own sleeping room
  - Common living room and kitchen
- Need assistance from personnel
  - Present during daytime (7h – 22h)
  - Need to come during night (22h – 7h)

GROUP HOME FOR DISABLED PEOPLE
FLOOR PLANS

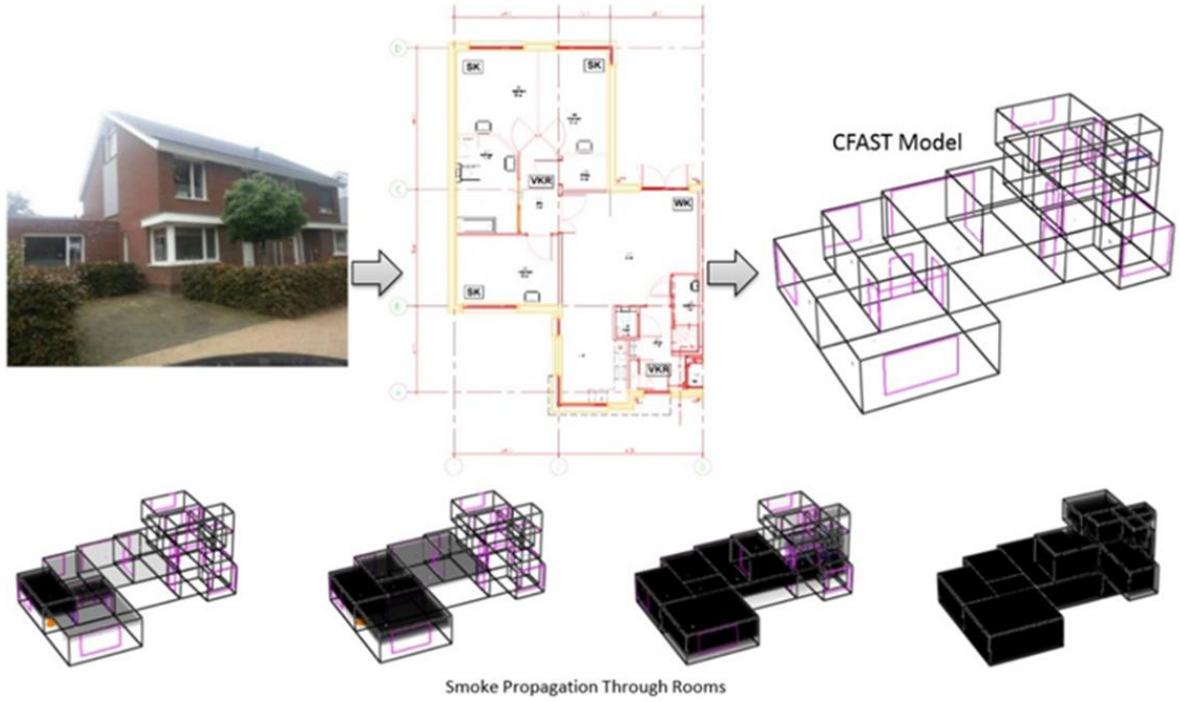






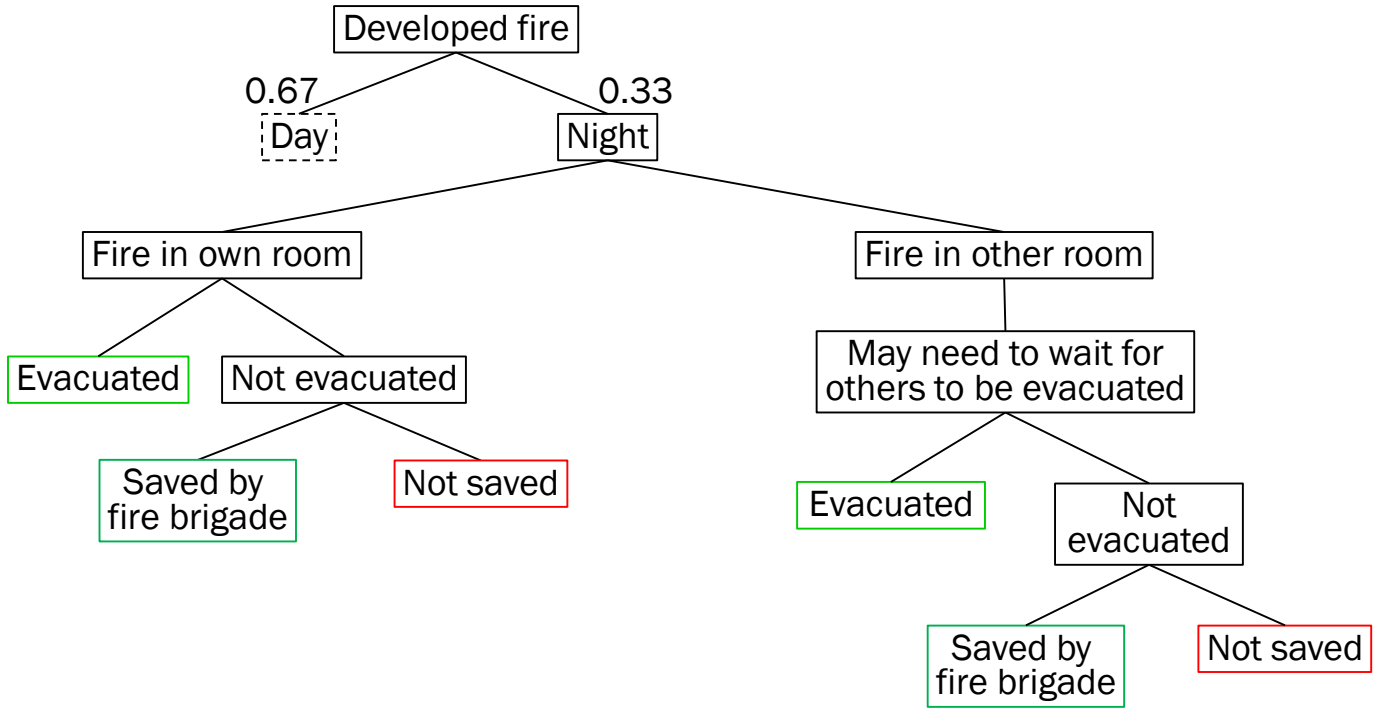
GROUP HOME FOR DISABLED PEOPLE
SCENARIOS ASET AND RSET

- ASET based on large number of CFAST calculations
  - Medium and large fire
  - Doors open or closed
  - Windows open or closed
  - Windows break due to fire
  - Door fail due to fire after 15 minutes
- RSET based on evacuation times
  - Action time day and night (30 s versus 9 minutes)
  - Time needed per client day and night (20 s versus 40 s)
  - Number of staff (1 and 6 considered)



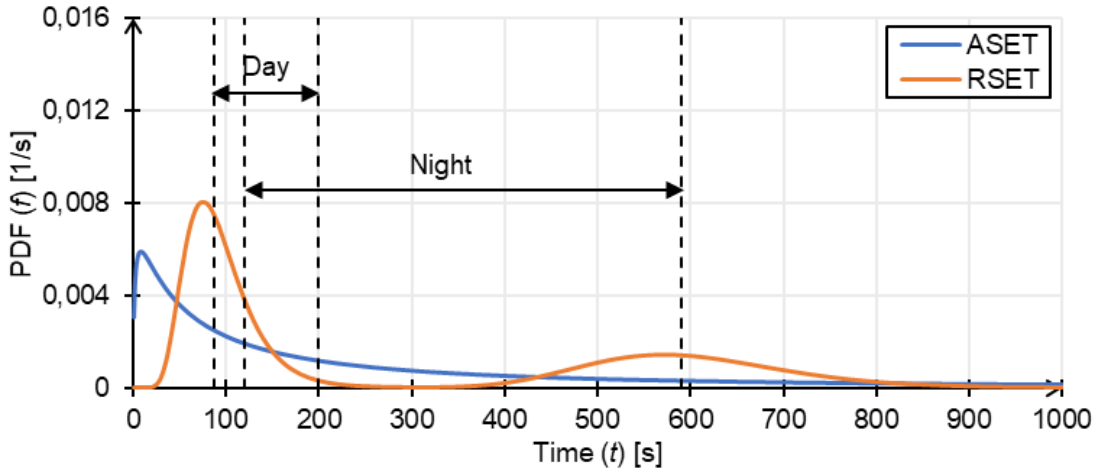
GROUP HOME FOR DISABLED PEOPLE

EVENT TREE FOR THE NIGHT

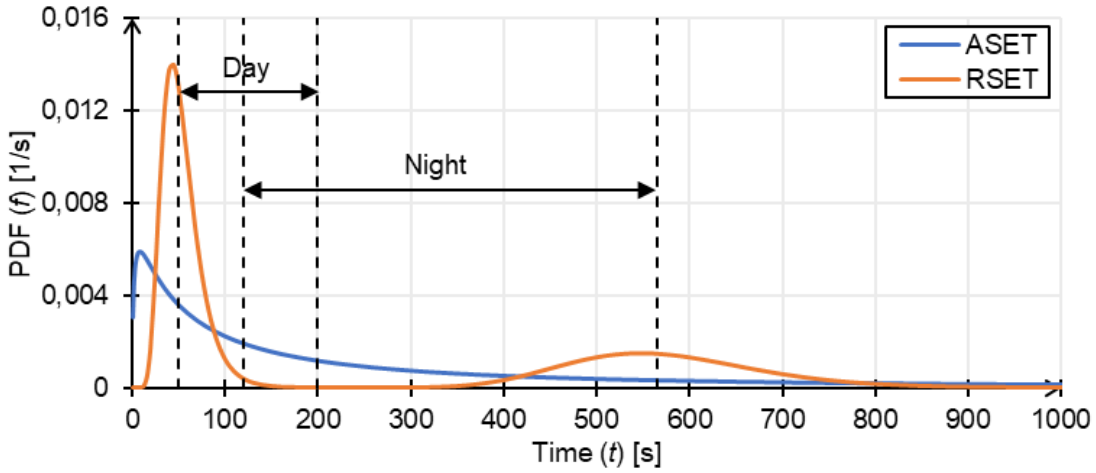


GROUP HOME FOR DISABLED PEOPLE
RESULTS PROBABILISTIC ANALYSIS

- Distribution functions ASET and RSET for sequential evacuation (1 staff member)



- Distribution functions ASET and RSET for parallel evacuation (6 staff members)



GROUP HOME FOR DISABLED PEOPLE
RESULTS SAFETY FACTOR

- Calculation of safety factor based on target $f_{IR} \cdot IR = 0.8 \cdot 12 \cdot 10^{-6} = 10 \cdot 10^{-6}$
  - Variation in ASET large
  - RSET divided in day and night

	Daytime	Night	
	Living room	Rooms level 1	Rooms levels 2/3
Sequential	2.3	0.20	0.51
Parallel	4.0	0.21	0.53

Conclusion: Not possible to derive fixed values for safety factor in this example; focuses on IR

GROUP HOME FOR DISABLED PEOPLE
IR COMPARISON OF ALTERNATIVES

- Comparison with home sprinkler

	Sequential evacuation	Parallel evacuation
No active extinguisher	$29 \cdot 10^{-6}$	$19 \cdot 10^{-6}$
Home sprinkler	$21 \cdot 10^{-6}$	$13 \cdot 10^{-6}$

- Target $10 \cdot 10^{-6}$ still not reached
- Remarks
  - Water mist system will be more effective
  - Only evacuation is considered; consider also event survive in case of smoke conditions

EVACUATION OUT OF COMPARTMENT

EXAMPLE SMOKE ALARMS

SMOKE ALARMS
REDUCTION OF FATALITIES

- Research question of the Dutch Standardisation Committee Fire Alarm Systems

  What is positive effects of applying smoke alarms with a 520 Hz tune compared with the usual 3100 Hz tune?

- Result

  Reduction of number of fatalities

SMOKE ALARMS
FINDINGS IN LITERATURE

- Bruck, D. & Thomas, I. (2008a), Towards a Better Smoke Alarm Signal – an Evidence Based Approach, pp. 403-414, Fire Safety Science – Proceedings of the Ninth International Symposium

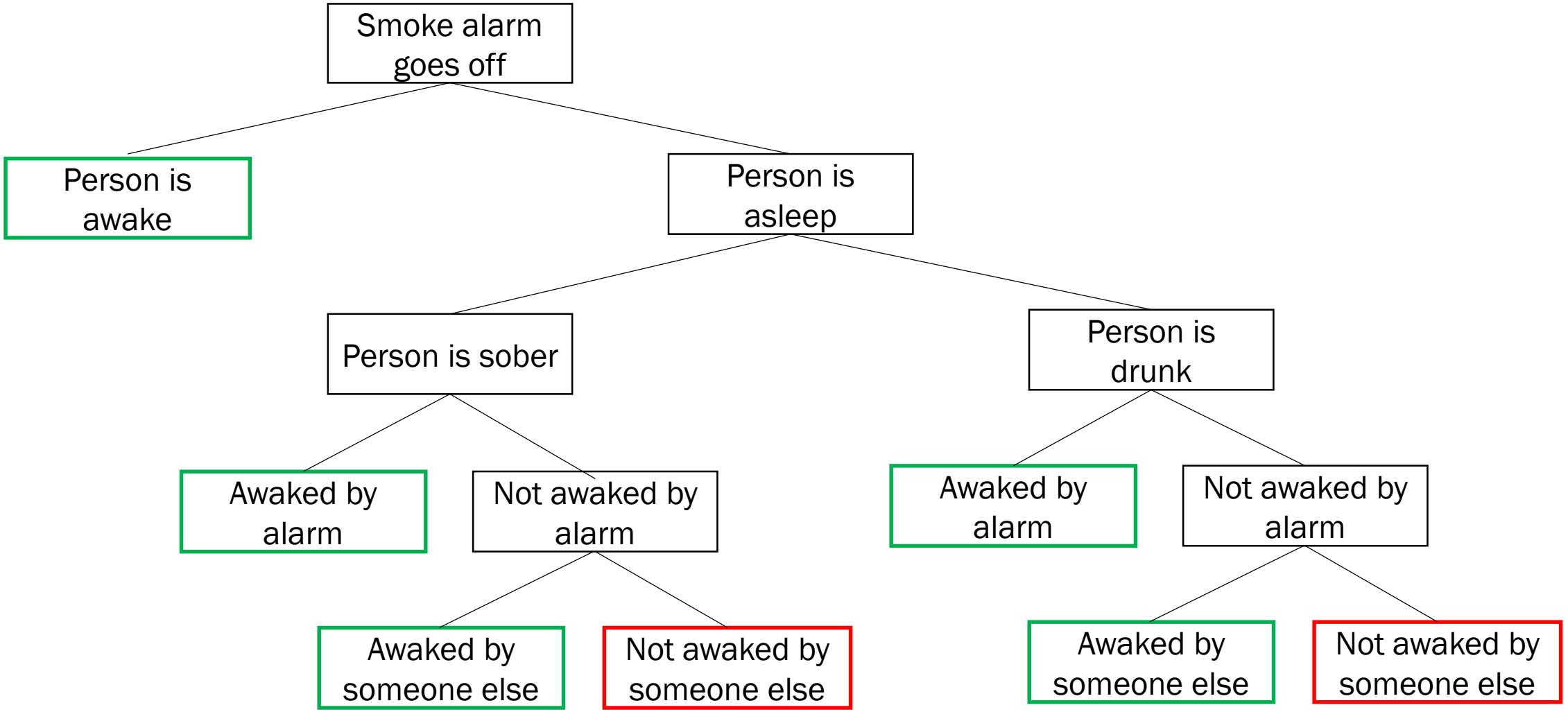
Participants	Alarm volume dB(A)	Precentage slept through	
		Current alarm	520 Hz square wave alarm
Children aged 6-10 yrs	89	43%	3.5%
Deep sleeping young adults	75	43%	7%
0.05 BAC young adults	75	38.5%	0%
Sober young adults	75	21%	0%
Older adults aged > 65 yrs	75	18%	4.5%
Hard of hearing adults	75	56%	8%

SMOKE ALARMS
GOAL TO DETERMINE EFFECT ON FATALITIES

- These percentage only explain the effectiveness of the alarming effect
- Also other parameters will affect fatalities
  - Other options to be alarmed (e.g. by partner)
  - Development and severity of the fire
  - Ability to escape: reaction time and travel speed
  - Action by fire brigade
- Studied cases
  - Probability that person will not be alarmed
  - Probability that a person is not able to escape out of home
  - Number of fatalities per year

SMOKE ALARMS

PROBABILITY THAT PERSON WILL NOT BE ALARMED

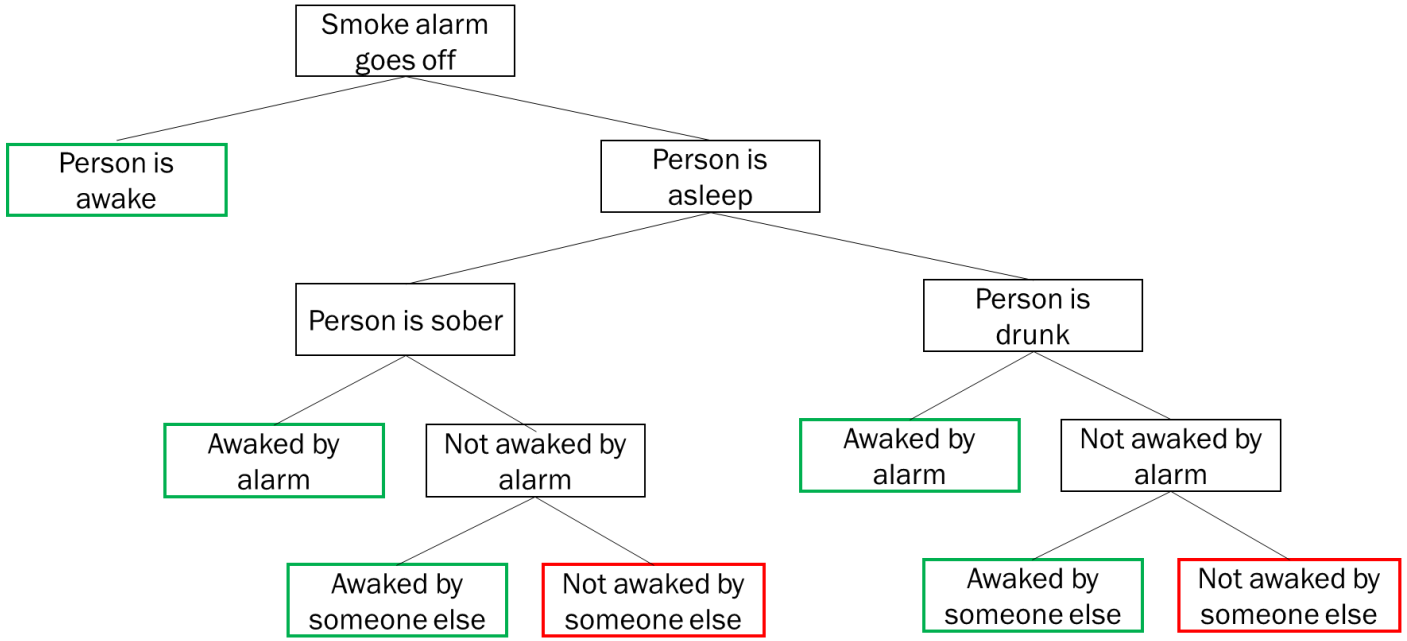


SMOKE ALARMS
PROBABILITY OF EVENTS

Event	< 16 years	16-65 years	> 65 years
Awake	0.58	0.67	0.71
Sober	1.00	0.99	0.99
Alarmed 3100 Hz, sober	0.50	0.80	0.70
Alarmed 3100 Hz, drunk	-	0.60	0.50
Alarmed 520 Hz, sober	0.95	1.00	0.95
Alarmed 520 Hz, drunk	-	1.00	0.95
Alarmed by someone else	0.90	0.50	0.30

SMOKE ALARMS

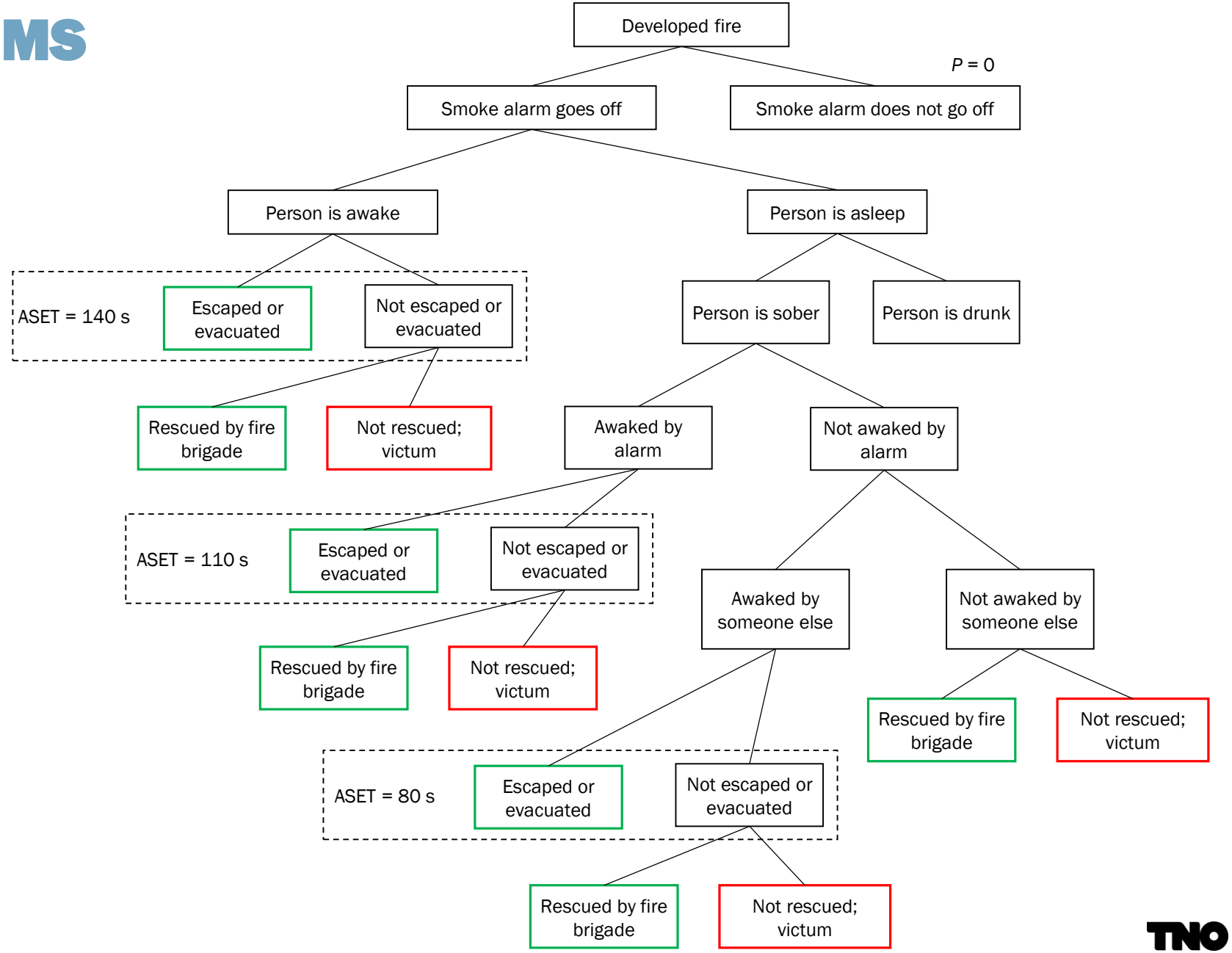
PROBABILITY THAT PERSON WILL NOT BE ALARMED



	< 16 years	16-65 years	> 65 years
Alarm 3100 Hz	2.1%	3.3%	6.1%
Alarm 510 Hz	0.2%	0.0%	1.0%

SMOKE ALARMS

PROBABILITY THAT A PERSON IS NOT ABLE TO ESCAPE



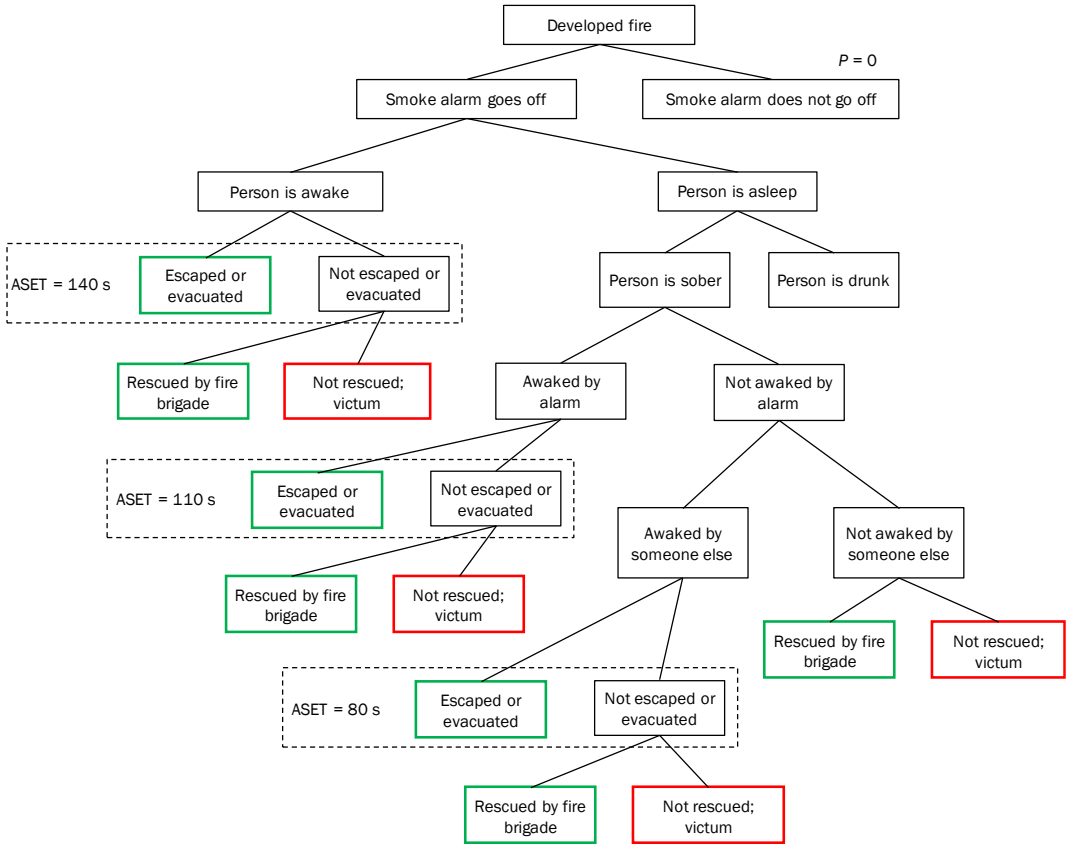
SMOKE ALARMS
PROBABILITY EVENTS P(ASET-RSET) > 0

- ASET and RSET (based on previous research TNO)
  - Normal distributions
  - Mean values are given
  - Coefficient of variation V = 0.2

Event	ASET	< 16 years RSET = 90 s	16-65 years RSET = 60 s	> 65 years RSET = 120 s
Escaped or evacuated	140 s	0.93	1.00	0.71
	110 s	0.76	0.98	0.38
	90 s	0.34	0.84	0.08
Rescued by fire brigade	Not relevant	0.50	0.50	0.30

SMOKE ALARMS

PROBABILITY THAT A PERSON IS NOT ABLE TO ESCAPE



Alarm	< 16 years	16-65 years	> 65 years
None	0.165	0.097	0.246
3100 Hz sound	0.118	0.024	0.210
520 Hz sound	0.075	0.005	0.197

SMOKE ALARMS
NUMBER OF FATALITIES PER YEAR

- Average probability of having a fire in a home $6{\cdot}10^{-4}$ per year
- 0.04 fraction of those fire will develop in life threatening circumstances

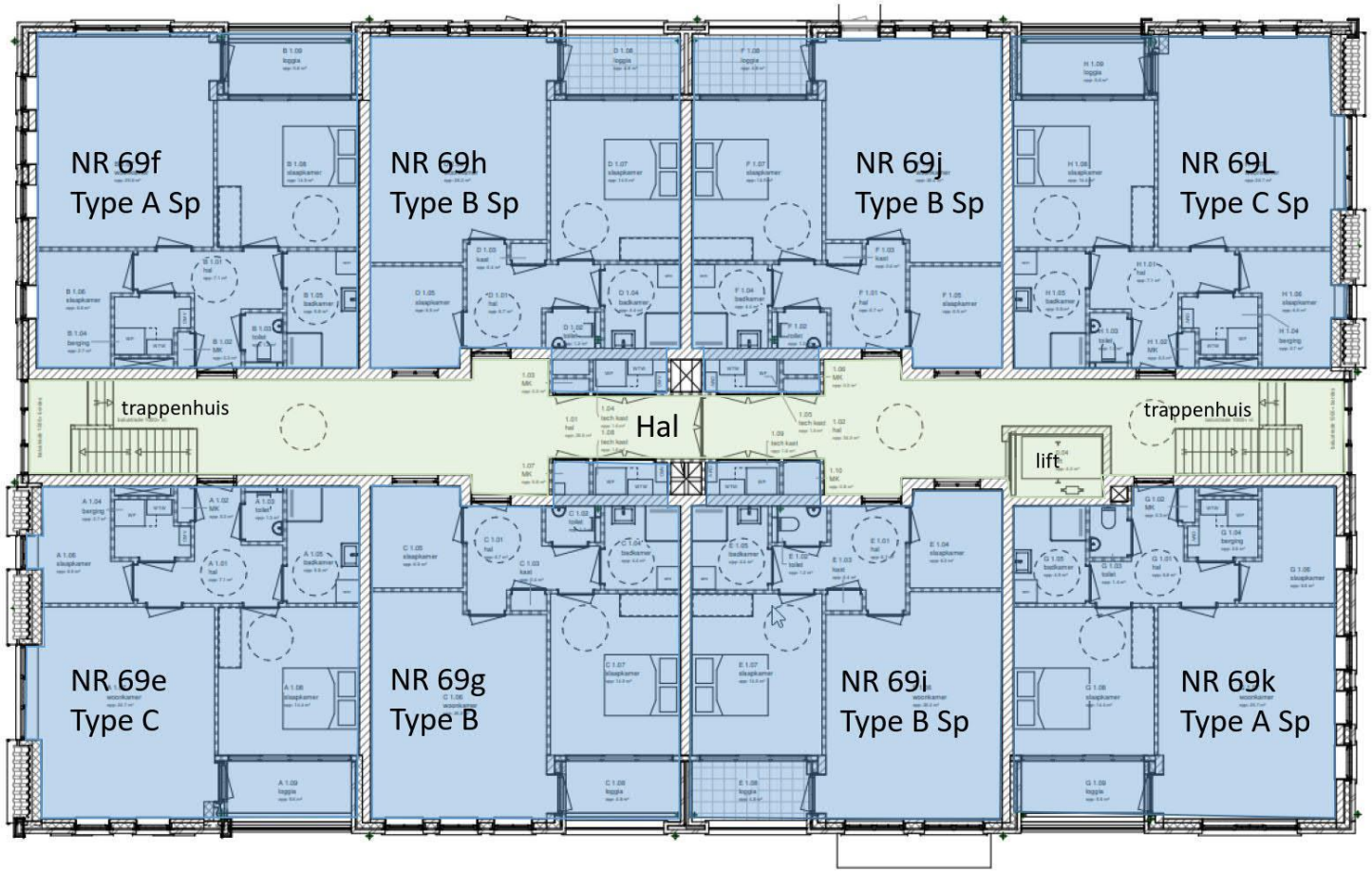
Alarm	< 16 years 2.8 million	16-65 years 11 million	> 65 years 3.3 million	Total 17.1 million
None	11	26	20	56
50% 3100 Hz sound	10	16	18	44
100% 3100 Hz sound	8	6	17	31
100% 520 Hz sound	5	1	16	22

EVACUATION OUT OF COMPARTMENT

EXAMPLE SENIOR APARTMENT

SENIOR APARTMENT
FLOOR PLAN

Appartement
Algemene ruimte



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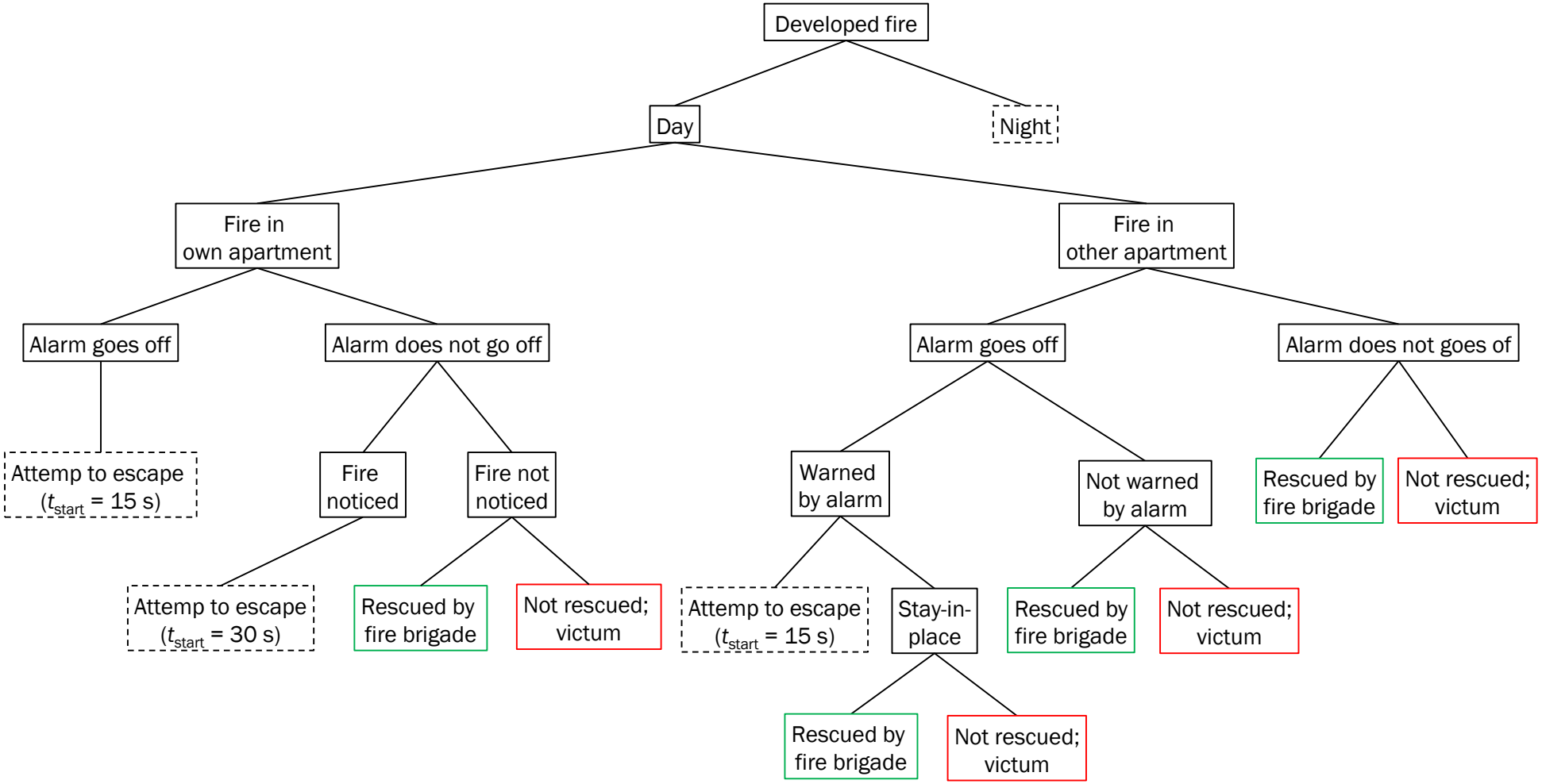
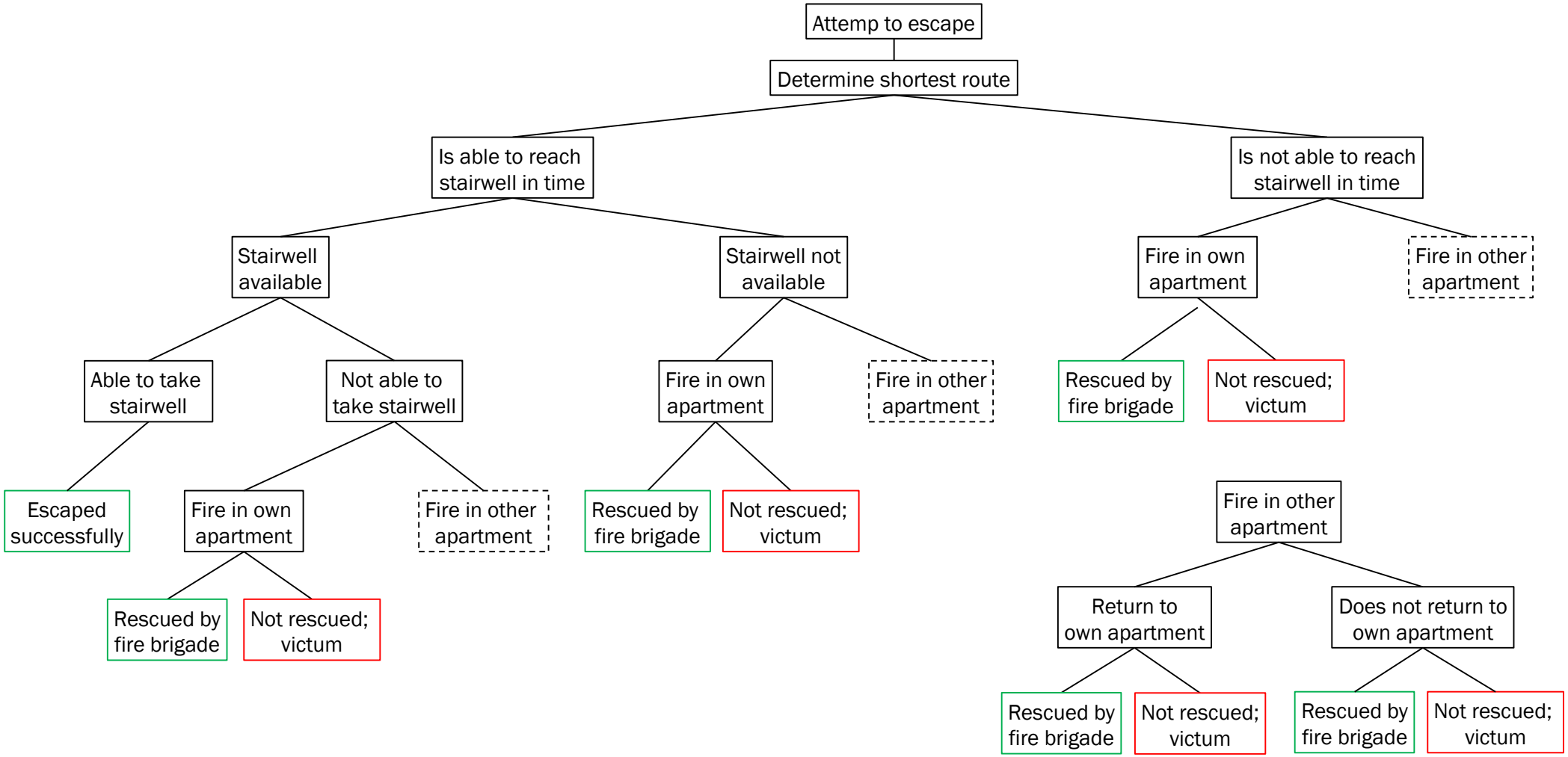
SENIOR APARTMENT
EVENT TREES



SENIOR APARTMENT
EVENT TREES



SENIOR APARTMENT

CALCULATED VALUE OF IR (10^{-6} PER YEAR) VARIOUS MEASURES

Situation	Fire safety measure	Fire in own dwelling	Fire in other dwelling	Total
Existing code	Non self-closing door; E20 smoke resistance; 50% smoke alarm	5.44	0.56	6.00
New code	Self-closing door; S200 smoke resistance; 100% smoke alarm	1.96 (-3.48)	0.04 (-0.52)	2.00 (-4.00)
Existing building stock	100% smoke alarm	3.47 (-1.97)	0.84 (+0.28)	4.41 (-1.59)
	Self-closing door	4.39 (-1.05)	0.22 (-0.34)	4.61 (-1.39)
	Sprinkler 2mm/min	4.15 (-1.29)	0.02 (-0.54)	4.16 (-1.84)
	Stay-in-place principle	5.42 (-0.02)	0.38 (-0.18)	5.80 (-0.20)

Probabilities of events are based on assumptions, data from literature and other TNO research

Individual risk for people >65 years is IR = $6 \cdot 10^{-6}$

QUANTITATIVE RISK-BASED APPROACH FOR FIRE SAFETY

CONCLUSIONS

QUANTITATIVE RISK-BASED APPROACH FOR FIRE SAFETY OF BUILDINGS

- Introduction of a risk-based approach for fire safety of buildings
- Quantified framework for life safety
  - Based on principles of a risk-informed performance-based approach
  - Fire safety criterium has to be quantified and balanced for the relevant operation requirements
- Risk-based ASET-RSET based on individual risk measure and event tree analysis
  - Able to identify advantages of change of requirements in the fire code
  - Able to show effects of various fire safety measures
- Methodology applicable for all fire safety goals

THANK YOU FOR YOUR ATTENTION

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