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Project I

"Deterministic analysis of a fire in Stenungsbaden Yacht Club"

Tsukuba, Japan

1998

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Abstract

In this report a fire in Stenungsbaden Yacht Club is evaluated. The analysis is based the QRA (Quantitative Risk Analysis) - method. (English)

Keywords:

Deterministic risk analysis, Estimated loss

Summary

In the report "Fire risk evaluation, Stenungsbaden Yacht Club" ref./1/, a number of fire safety actions are recommended to improve the fire safety in the building. In this report the effect from three of the larger suggested safety actions ("Installation of spoken evacuation message", "Education and training and installation of fire extinguishers" and "Installation of sprinkler system") are evaluated in result of estimated loss and number of casualties. The fire scenario used in this report is "Brand i Skepparkrogen", see ref./1/. The event tree method is used to calculate the risks from the different recommended alternatives in ref./1/. After the evaluation, a cost-effectiveness analysis is made for the results.

The result from the cost-effectiveness analysis is that the combination of all the suggested investments (i.e. "a combination of sprinkler, spoken evacuation system and education, training and fire extinguishers") will give the lowest risk in casualties and estimated cost, see table below. The cost of the investment will be the highest, but this is the one to be recommended. A discussion should be made with representatives from Stenungsbaden Yacht Club, when there might be two more investment ("Combination of sprinkler and spoken evacuation message" and "Combination of sprinkler and education, training and fire extinguishers") that could be acceptable and recommended.

	Risk, in casualties	Estimated loss (sek)	Investment cost (sek)	Total savings (sek)
The situation today, when no actions has been taken to increase the fire safety	547	4 768 000	0	0
Combination of sprinkler and spoken evacuation message	4	371 000	881 500	3 515 500
Combination of sprinkler and education, training and fire extinguishers	11	266 000	879 500	3 622 500
Combination sprinkler, spoken evacuation system and education, training and fire extinguishers	1	266 000	1 079 500	3 422 500

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The following report is made in the education. The objective has been training in solving problems and methodology. The quality of the conclusions and the result has not been controlled in a way it has to be done for quality control. The report should therefor be used with great cautions. The one who uses the result in any situation is responsible for that himself.

Introduction

This report is made as a part of the course Risk management II at the Fire Protection Engineering Program, Department of Fire Safety Engineering, Institute of Technology, Lund University.

The main objective of the report has been to analyze a fire scenario with the Quantitative Risk Assessment (QRA) methodology. The fire scenario is taken from the report “Stenungsbaden Yacht Club” ref./1/, which the result from the course Fire technical risk assessment. The report includes a cost-effectiveness analysis of the fire safety recommendations, and a comparison between the risks in the building today and after the fire safety recommendations has been made. Finally, the report includes a foundation for decision making, were the cost of a consultant, the cost of the fire safety recommendations, optimal investment etc. is discussed.

Limitations

When this deterministic analysis is made some limitations has been done:

- Using a simple mathematical model approximates the evacuation time
- Many values of costs and probabilities are rough estimates, because no data are available
- The smaller actions proposed in ref./1/, for an example installation of evacuation signs, is not taken into account when the main purpose of these recommendations is to fulfill the requirements in BBR 94. The result of these actions will of course also increase the safety level at Stenungsbaden Yacht Club but, as mentioned before, this is not taken into account in this report.

1. Fire scenario

The fire scenario is a fire in “Skepparkrogen” at “Stenungsbaden Yacht Club”, for a description and further details see Hedskog et. al. “Fire risk evaluation, Stenungsbaden Yacht Club” ref./1/.

2. The risk of a fire today

The consequence of a fire at “Stenungsbaden Yacht Club” will be expressed as expected number of casualties, i.e. number of persons that is exposed for critical conditions, and estimated cost. The risk will therefor have the unit number of casualties or Swedish krona (sek).

2.1. Number of casualties

When the consequence is expressed as expected number of casualties, it is evaluated from simulations in the computer program CFAST, compared with a simple evacuation model. This model is evaluated from the scenario “Nattklubb, Bohussalar stangda” which is simulated in the computer program Simulex. The model is based on the assumption that, as soon as the evacuation has started, the number of people that escapes the building is linear to the time.

2.1.1 Evacuation model

From the fire scenario in “Skepparkrogen” at Stenungsbaden Yacht Club, the number of people in the compartment is 800 and the time for evacuation is 180 seconds. If we assume that one meter door opening allow one person per second to escape, the available width of door openings (W_D) are:

$W_D = 800/180 = 4.44$ m

The available width of door openings (W_D) also equals the number of people that escapes every second, the inclination of the line in the diagram below. If the available width of door openings is made lager, the width is added to the W_D-value.

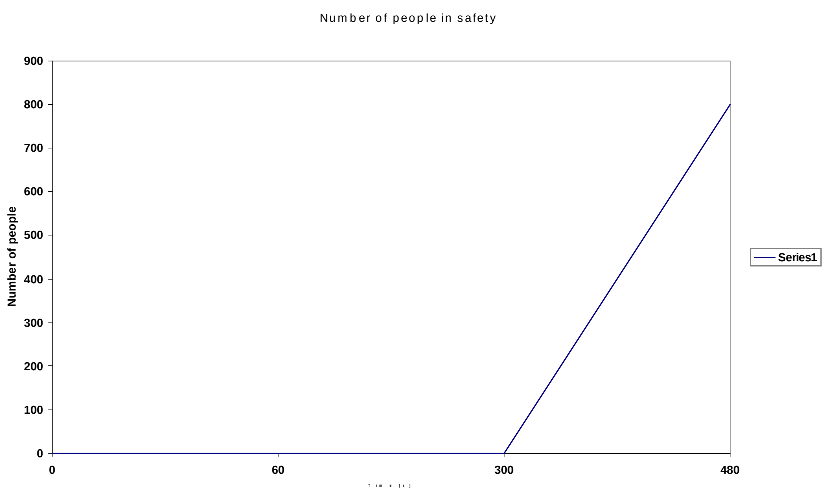

Figure 1. Number of people in safety vs. time, scenario "Nattklubb, Bohussalar stangda".

In the fire scenario "Skepparkrogen", which is described more detailed in ref./1/, the time from that the fire starts to detection is 60 seconds and the time it takes to react and decide to evacuate is 240 seconds. From the simulations made in CFAST, the time to critical conditions is determined to 360 seconds. Therefor the time to evacuate is only 60 seconds. The response from the recommended actions will be discussed below.

2.1.2 Event-tree for the situation today

The possible outcomes from the fire scenario "Skepparkrogen" will be presented in an event-tree below.

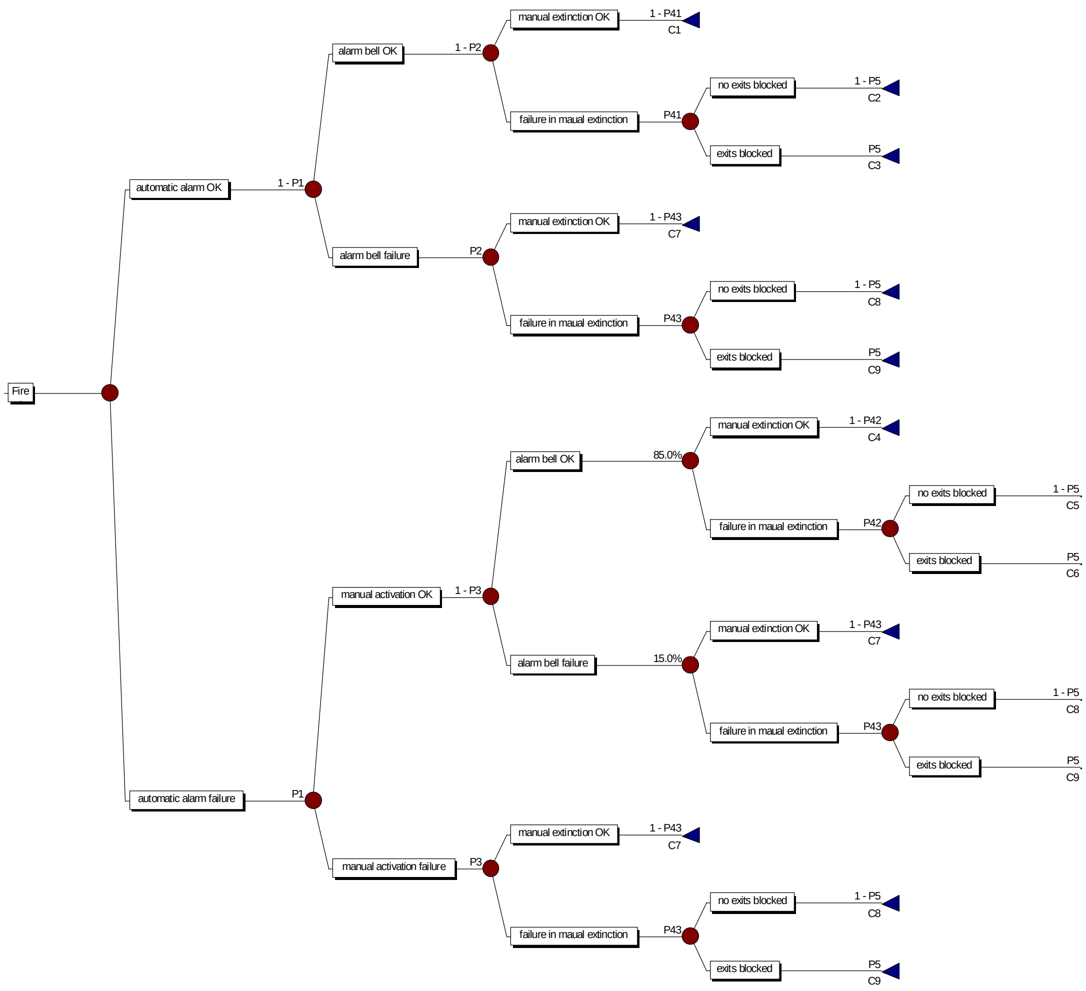

Figure 2. Event-tree

In this event-tree there are many assumptions and approximations for an example some of the probabilities and the number of branches (alarm bell etc. is not taken into account). The used probabilities in figure 2 are presented in table 1 below. Below the table there is also a short discussion about the estimated probabilities.

	Probability of failure	Reference
Heat detection system	0.10 (P_1)	/4/
Alarm bell	0.15 (P_2)	/4/
Manual activation of alarm	0.50 (P_3)	Estimate
Manual extinction	0.90 (P_{41}); 0.95 (P_{42}); 1.00 (P_{43})	Estimate
Exits	1.00 (P_5)	/1/

Table 1. Probabilities used in Figure 2

With the evacuation model, described above, the consequences can be determined. At the time when critical conditions occur, you can see how many people who have been able to get out from the building. This figure minus the total number of people gives the consequence. For the branches where neithe neither the automatic alarm nor the alarm bell are working, 20 seconds are added to the time before the evacuation starts. This because of the delay, of the alarm caused by the manual activation that has to be done. Cause. Another 60 seconds are added to the time before the evacuaton starts for the branches where manual activation does not work or the manual activation do work but there is an alarm bell failure. The figures are based on judgement from the authors.

According to this delay in time for some branches, the probability for a successful "Manual extinction" decreases. This is the reason why the "Manual extinction", in table 1, has three different values (0.90, 0.95, 1.00), depending on this delay in time. For the branch where neither the alarm nor the manual activation does work, the probability of failure for manual extinction is set to be 1.00, which is a conservative assumption. The report described in ref./1/ is based on a visit at Stenungsbaden Yacht Club. At this visit one of the emergency doors were locked (!) and one was blocked. This is the reason why the probabilities of failure for "Exits" are set to 1.00.

For the branches where manual extinguish of the fire has succeeded the consequence is set to zero, because critical conditions will never occur. The consequences C_1 - C_9 for each branch in the event-tree are presented in table 2 below.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
0	416	534	0	544	624	0	800	800

Table 2. Consequences 1-9 from the event-tree

The expected value of the risk is then calculated as:

$\text{Risk} = P_{T1} \times C_1 + \ldots + P_{T9} \times C_9$

$\text{Risk} = 546.85 \approx 547$ casualties.

2.2 Estimated loss today

The estimated loss for the situation today can be calculated from the described event-tree in figure 2. But the consequence is different, expressed as the cost of the damage that the fire causes.

To evaluate the estimated loss, it is divided into three parts:

- Direct cost due to fire, such as damage to interior and smoke damage

- Cost of water damage
- Cost of the interruption in the activity.

To further approximate, the costs of each branch in the event tree is set to a cost A or B, where cost A and B are described as:

A - succeeded manual extinction, only a small damages to the interior within the fire compartment.

Direct cost due to fire:	50 000 sek (interior costs).
Cost of water damage:	0 sek.
Cost of interruption in activity:	2 weeks of interruption in this part which gives a cost of 10 000 sek.

Total cost for cost A = 60 000 sek.

B - failure in manual extinction, the fire can continue to grow until the fire brigade arrives, the fire is limited to the fire compartment.

Direct cost due to fire:	5 000 000 sek (interior costs).
Cost of water damage:	50 000 sek.
Cost of interruption in activity:	6 months of interruption in this part, which gives a cost of 120 000 sek.

Total cost for cost B = 5 170 000 sek.

Each branch will now get a consequence, A or B, depending on if the fire is extinguished manually or by the fire brigade. This is shown in table below.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A	B	B	A	B	B	A	B	B

Table 3. The consequences 1-9 in the event-tree.

The expected value of the risk is then calculated (in the same way as before) as:

Risk = $P_{T1} \times C_1 + \ldots + P_{T9} \times C_9$

Estimated loss = 4 768 226 ≈ 4 768 000 sek.

3. Suggested safety actions

The conclusions from ref./1/ is that today, actions has to be taken to increase the fire safety in the building. The suggested actions to be taken are fully presented in ref./1/. In the chosen scenario, “Skepparkrogen”, there are four suggested actions to be taken, which is analyzed further:

1. Installation of sprinkler
2. Installation of a spoken evacuation message
3. Installation of fire extinguisher in all bars

4. Education and training of the personnel.

Suggestions 3 and 4 will further be treated as one action.

The above mentioned actions can be combined into seven different investment alternatives. The result of the different alternatives is presented in chapters 3.1 to 3.8.

3.1 Installation of a spoken evacuation message

When a spoken evacuation message is installed the probabilities will be the same as in table 1. This investment is assumed to just decrease the time for reaction and decision, with two minutes. This gives the time for reaction and decision to two minutes, which is also recommended in ref./5/. This decrease in time before the evacuation starts will only change the consequences in casualties and not the estimated loss. There might also be a decrease in the estimated loss, due to the decrease in time for reaction and decision, but this has not been taken into account. The consequences are calculated from the evacuation model. The consequences are shown in table 4.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
0	0	0	0	0	89.6	0	156	356

Table 4. The consequences, in casualties, after a spoken evacuation message have been installed.

The risk is calculated (similar to the earlier case) to 72.1 ≈ 73 casualties.

The cost of the investment will be approximately 200 000 sek.

The total savings are defined in this report as: "the Estimated loss today" minus "the Estimated loss after the installation" minus "the cost of the installation". Note that costs like consultant costs etc. is not taken into account in the total savings. The total savings can therefor only be used to rank the different alternatives.

For this case the total savings are: – 200 000 sek (4 768 000 – 4 768 000 – 200 000).

3.2 Education and training of the personnel and installation of fire extinguishers

If fire extinguishers are installed in all bars and the personnel is trained to use them and also get education in fire safety, both probabilities and consequences in casualties (not the cost due to fire) will be changed. The probability of failure for manual activation of the alarm and manual extinction is decreased when the personnel is trained and has higher odds to do a successful intervention. There is also a decrease in the probability that the exits are blocked. The education and training will make the personnel more alert and they will therefor react faster. This result in a shorter time before the evacuation starts, approximately 30 seconds. There will also be a decrease in the probabilities of failure for "Manual extinction" and "Exits", compared with the situation today. The new probabilities and consequences are shown in table 5 and 6 below.

	Probability of failure	Reference
Heat detection system	0,10 (P_1)	/4/
Alarm bell	0,15 (P_2)	/4/
Manual activation of alarm	0,20 (P_3)	Estimate
Manual extinction	0,50 (P_{41}); 0,55 (P_{42}); 0,60 (P_{43})	Estimate
Exits	0,50 (P_5)	Estimate

Table 5. Probabilities after the personnel has been trained and educated and fire extinguishers have been installed in all bars.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
0	220.4	400.4	0	349.2	489.2	0	735.6	755.6

Table 6. The consequences, in casualties, after the personnel has been trained and educated and fire extinguishers has been installed in all bars.

The risk in casualties is calculated (similar to the earlier case) to 209.12 ≈ 210 casualties.

There is no change in consequence expressed as cost due to fire, compared to the previous case. However, the probabilities has been changed and therefor also the estimated loss. The estimated loss is calculated to 2 717 711 ≈ 2 718 000 sek.

The cost of this investment is approximately:

Education and training of personnel: 150 000 sek (30 people a' 5 000 sek)
Fire extinguishers: 48 000 sek (8 pieces)

Total cost: 198 000 sek.

The training and education has to be done annually. It is also important that temporary personnel get the education and training. This can be done by one of the ordinary personnel to keep the costs down.

The total savings are: 1 852 000 sek (4 768 000 – 2 718 000 – 198 000).

3.3 Combination of spoken evacuation message, training, education and installation of fire extinguishers

In this case the probabilities will be as for the case when only training, education and installation of fire extinguishers has been done. The consequence in casualties will be as in table 7 below, calculated from the evacuation model with all the time changes from the earlier chapters. The consequence in cost due to fire is as in table 6.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
0	0	0	0	0	0	0	0	222.8

Table 7. The consequences, in casualties, when a combination of spoken evacuation message, training, education and installation of fire extinguishers is done.

The risk in casualties is calculated (similar to the earlier case) to 11.16 ≈ 12 casualties.

There is no change in consequence expressed as cost due to fire or probabilities, compared to the previous case in 3.2. The estimated loss is therefor 2 718 000 sek.

The cost of this investment is approximately 398 000 sek.

The total savings for the investment are: 1 652 000 sek (4 768 000 – 2 718 000 – 398 000).

3.4 Installation of sprinkler

If there is an installation of an automatic sprinkler the event-tree, figure 3, will be slightly different to the one in figure 2. The only difference is that the installation of sprinkler is now taken into account.

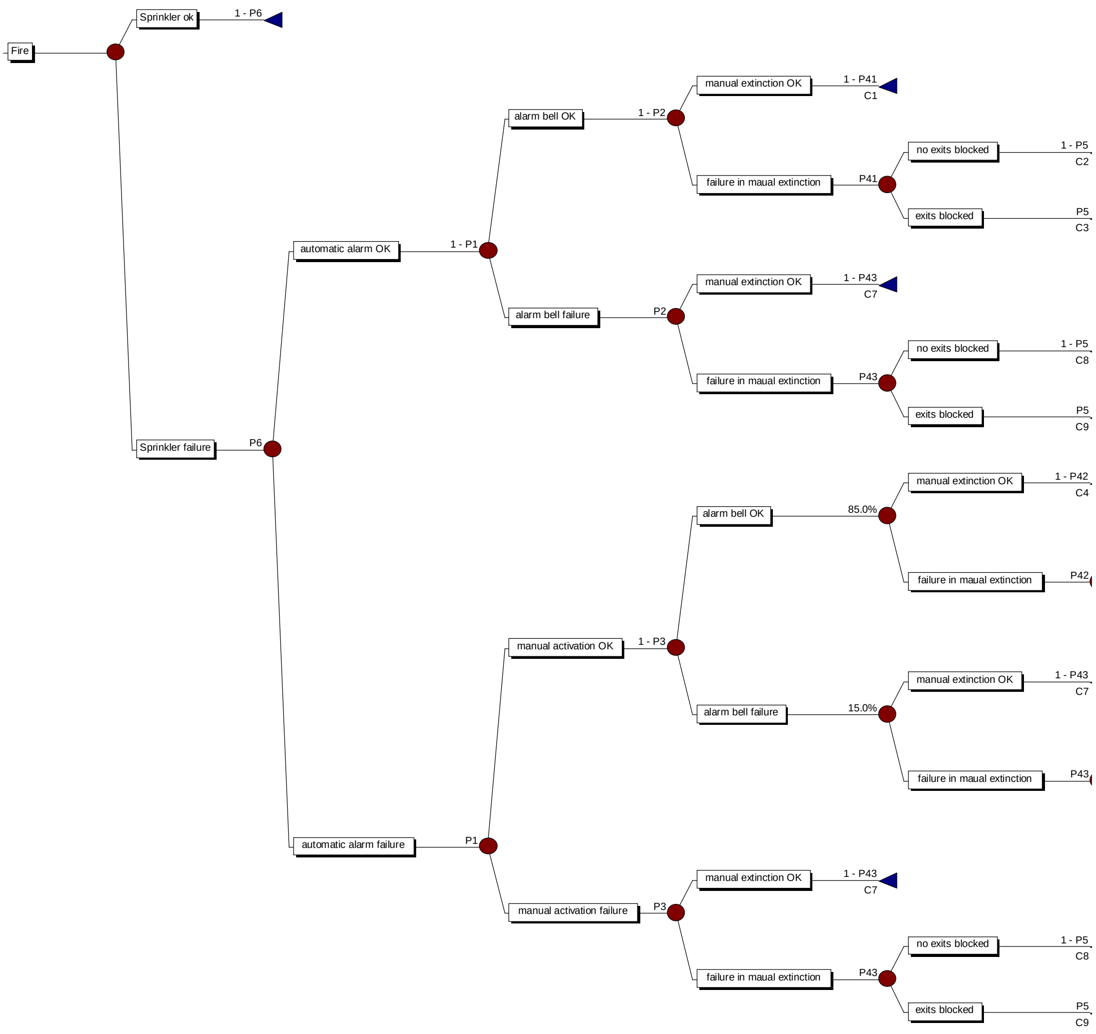

Figure 3. Event-tree when sprinkler is installed.

The probabilities used in this case are the same as if no actions are taken, except from that the probability for sprinkler function is added. The probability of failure of the automatic sprinkler system is set to 0.05 ref./2/.

In all the cases discussed above only two costs, A and B, has been taken into account. However, when a sprinkler system is installed another cost, C, is added. This cost arises when the sprinkler is working and is approximated as:

Direct cost due to fire:	50 000 sek (interior costs).
Cost of water damage:	50 000 sek.
Cost of interruption in activity:	2 months of interruption in this part, which gives a cost of 40 000 sek.

Total cost for cost C = 140 000 sek.

The consequences, in casualties and cost due to fire, will be almost the same as for the case when no fire safety actions are taken. The only difference is that now one consequence, C_{10}, is added for the extra branch in event-tree 3, se table 8 and 9.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_8	C_{10}
0	416	534	0	544	624	0	800	800	0

Table 8. The consequences, in casualties, after sprinkler are installed.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_8	C_{10}
A	B	B	A	B	B	A	B	B	C

Table 9. The consequences, in cost due to fire, after sprinkler are installed.

The risk in casualties is calculated (similar to the earlier case) to 27.30 ≈ 28 casualties

The estimated loss is calculated to 371 411 ≈ 371 000 sek

The cost of this investment is, according to ref./3/, approximately:

Sprinkler: 30 000 sek (70 sek/m^2)
Pump (electric): 100 000 sek
Water tank (steel): 540 000 sek.
Connection fee: 11 500 sek

Total cost: 681 500 sek.

The total savings for the investment are: 3 715 500 sek (4 768 000 – 371 000 – 681 500).

3.5 Installation of sprinkler combined with a spoken evacuation message

For this alternative the probabilities will be the same as when only the sprinkler is installed. The consequences, both in casualties and in cost due to fire, will be as for the case when only the spoken message is installed (chapter 3.1), except for the extra consequence due to the sprinkler. This extra consequence will be 0, when expressed in casualties, and cost C, when expressed in cost due to fire.

The risk in casualties is then calculated to 3.36 ≈ 4 casualties

The estimated loss is then calculated to 371 411 ≈ 371 000 sek

The cost of this investment is approximately 881 500 sek.

The total savings for the investment are: 3 515 500 sek (4 768 000 – 371 000 – 881 500).

3.6 Installation of sprinkler combined with training, education and installation of fire extinguishers

In this case the probabilities and consequences, both in casualties and in cost due to fire, will be the same as when only the training and education of personnel and installation of fire extinguisher have been done chapter 3.2. The only difference is that the probabilities and consequences that follow with the sprinkler installation are added.

The risk in casualties is then calculated to 10.59 ≈ 11 casualties

The estimated loss is then calculated to 265 783 ≈ 266 000 sek

The cost of this investment is approximately 879 500 sek.

The total savings for the investment are: 3 622 500 sek (4 768 000 – 266 000 – 879 500).

3.7 Installation of sprinkler combined with training, education, and installation of fire extinguishers and installation of a spoken evacuation message

When all the actions, recommended in ref./1/, are taken the probabilities and consequences will be as when both a spoken evacuation message and training, education and installation of fire extinguishers has been done. The only difference is that the probabilities and consequences that follow with the sprinkler installation are added.

The risk in casualties is then calculated to 0.59 ≈ 1 casualties

The estimated loss is then calculated to 265 783 ≈ 266 000 sek

The cost of this investment is approximately 1 079 500 sek.

The total savings for the investment are: 3 422 500 sek (4 768 000 – 266 000 – 1 079 500).

4. Summary of results

The comparison between different alternatives will be done according to risk expressed in number of casualties and cost due to fire. The risk, expressed as number of casualties, will be shown in Frequency – Number (FN) curves below. The cost-effectiveness analysis, shown in table, will include the estimated loss and investment cost. There will also be a short discussion about recommended investments.

4.1 Frequency – Number curves

To make it easier to compare the risk, in casualties, this is shown in the F-N curves below, figure 4 and 5. The explanations to the denominations in figures below are:

- "Today" equals the situation today
- "Case 1" equals Installation of a spoken evacuation message
- "Case 2" equals Education and training of the personnel and installation of fire extinguishers
- "Case 3" equals a combination of "Case 1" and "Case 2"
- "Case 4" equals installation of sprinkler
- "Case 5" equals a combination of "Case 4" and "Case 1"
- "Case 6" equals a combination of "Case 4" and "Case 2"
- "Case 7" equals a combination of "Case 4" and "Case 3".

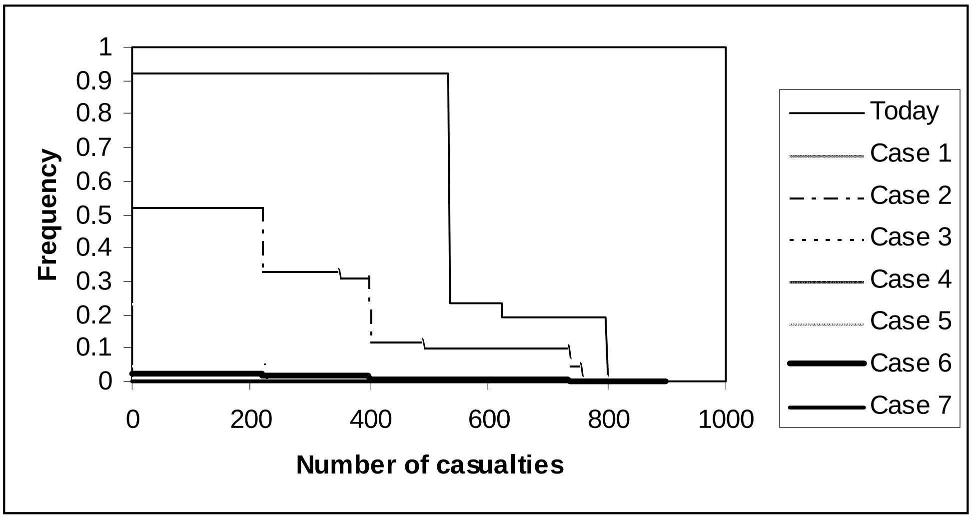

Figure 4. The consequences of all the alternatives, presented as an F-N curve.

In figure 4 it is difficult to make out some of the cases due to the scale on the y-axis, therefor the cases are also presented in figure 5. Note the change in scale on the y-axis.

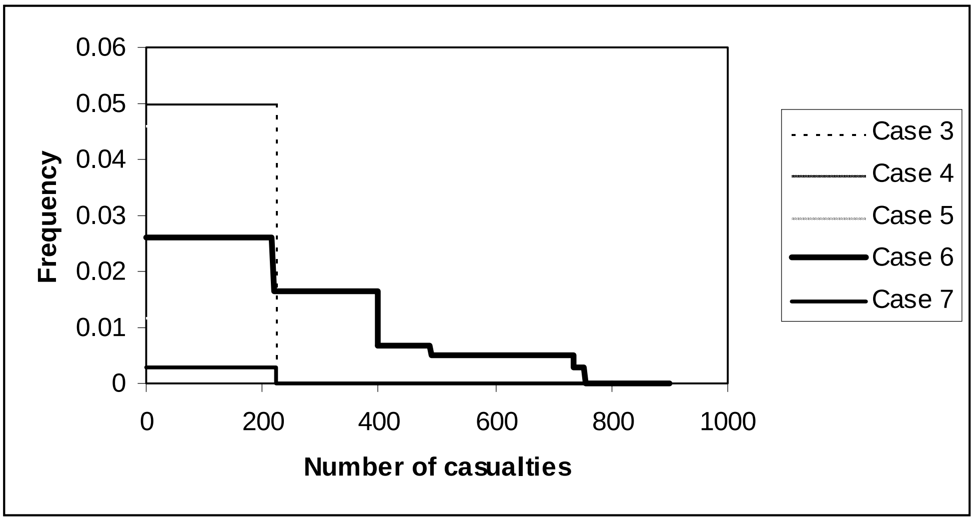

Figure 5. The consequences of the alternatives, presented as an F-N curve. Note the change in scale on the x-axis compared to figure 4.

4.3 Presentation in table

Another way to present the results of the different alternatives is in a table that presents the risk (both in casualties and estimated loss), investment cost and total savings. This is done in table 10 below.

	Risk, in casualties	Estimated loss (sek)	Investment cost (sek)	Total savings (sek)
The situation today, when no actions has been taken to increase the fire safety	547	4 768 000	0	0
Installation of spoken evacuation message	73	4 768 000	200 000	- 200 000
Education and training and installation of fire extinguishers	210	2 718 000	198 000	1 852 000
Combination of spoken message and education, training and fire extinguishers	12	2 718 000	398 000	1 652 000
Installation of sprinkler system	28	371 000	681 500	3 715 500
Combination of sprinkler and spoken evacuation message	4	371 000	881 500	3 515 500

Combination of sprinkler and education, training and fire extinguishers	11	266 000	879 500	3 622 500
Combination sprinkler, spoken evacuation system and education, training and fire extinguishers	1	266 000	1 079 500	3 422 500

Table 10. *Presentationof the risk (both in casualties and estimated loss), investment cost and total savings of the different investment alternatives.*

4.3 Conclusions

From table 10, presented in the last chapter, it is easy to define the most cost-effectiveness alternatives to increase the safety level at Stenungsbaden Yacht Club. Three of the investments ("Installation of spoken evacuation message", "Education and training and installation of fire extinguishers" and "Installation of sprinkler system") are refused due to too high risk in casualties. The reader should specially note that only installation of a automatic sprinkler system does not solve all your problems. It will give you a low estimated loss but, it is hard (impossible?) to put a value on a human life. Here the risk in casualties is not necessary equal to number of deaths but when the number of exposed people to critical conditions increases, the possibility to have a fire with deaths increases.

If you look at statistics and estimates the probability of fire occurs in a building as Stenungsbaden Yacht Club, there is a rather high probability of fire starts. In ref./4/ the figure is estimated to 1.2 x 10^{-1} $year^{-1}$ (assembly entertainment). The results in table 10 is based on the probability of fire starts is 1, therefor the risks in table 10 should be multiplied with 1.2 x 10^{-1} or approximately divided by a factor 10. Uncertainties in calculations is taken into account by dividing or multiplying the annual risks with approximately a factor 10.

If criteria for what risks the society is willing to accept ref./6/ is taken into account, you find that these risk criteria is much smaller than the risk at Stenungsbaden Yacht Club. The risk criteria in ref./6/ is expressed in deaths, and not in number of exposed persons to critical conditions. But, as mentioned above when the number of exposed people to critical conditions increases, the possibility to have a fire with deaths increases. This means that we can only accept a small number of casualties. If we can accept one casualty per year and also takes the uncertainty factor into account we can accept four of the investments in table 10, where the number of casualties ranges from 1 to about 10.

The combination of all the suggested investments (i.e. "a combination of sprinkler, spoken evacuation system and education, training and fire extinguishers") will give the lowest risk in casualties and estimated cost. The cost of the investment will be the highest, but this is the one to be recommended. A discussion should be made with representatives from Stenungsbaden Yacht Club, when there might be two more investment ("Combination of sprinkler and spoken evacuation message" and "Combination of sprinkler and education, training and fire extinguishers") that could be acceptable and recommended. The investment with a combination of spoken evacuation message and education, training and fire extinguishers gives a lower total saving and highest risk, compared with the recommended investments, and is therefor not recommended.

5. Consultant cost of the investigation

An evaluation of the cost for a consultant to make the investigation (both this report and ref./1/) is shown below:

- Visit at and background reading of the object, 4 h
- Simulations and calculations of the smoke-filling process and evacuation, 30 h
- “Utarbeta” suggestions for actions to be taken, 10 h
- Deterministic analysis of the suggestions, 15 h
- Report writing, 20 h.

This gives a total cost for the consultant as about (79 h x 700 sek/h.) 55 000 sek.

This cost could also be added to the total savings. This has not been done in this report when the comparison between the different investment alternatives is the most important thing.

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