Fire Safety Risk Analysis of a Health Care Facility

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Abstract: A methodology for deriving individual risk to people in a health care facility due to fire, is presented. The risk is expressed by the First Order Second Moment reliability index β. The evacuation time for the patients is compared to the time to untenable conditions arise. Subjecting variables to uncertainty results in a reliability index value for the escape time margin. The influence on reliability index of various number of staff is examined. The scenarios are presented with the event tree methodology.

Keywords: Risk analysis, FOSM method, fire, evacuation, health care facility, reliability index.

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Summary

The first objective with this report is to study the safety to humans in a hospital ward on the condition that a fire in a patient room has started. At the fire outbreak, the patients should be evacuated with assistance of the staff. The report is limited to only describe the conditions in one ward where a fire has started, and does not take neighbouring wards into account. The safety is expressed in terms of the reliability index β and its corresponding probability of failure. This measure shows the probability that the evacuation time will exceed the available time, i.e. the time to untenable conditions occur. This means that at least one person will be unable to arrive in safety before these conditions arise. The reliability index β is a measure of the individual risk to persons on the health care ward. The importance of the variables in the analysis is also investigated.

The risk method used is a so called first order second moment method (FOSM) which calculates the reliability index β on a limit state function. This function describes the evacuation time margin by comparing the available time and the needed evacuation time. By subjecting some variables to uncertainty the reliability inherent in the limit state function can be determined. The method has been extensively used in for example structural safety analysis and is well known also in other engineering fields.

The risk calculation is based on an event tree approach with the following branch points: initiating fire, time of the day, flaming fire, fire suppressed by staff, sprinkler failure, detector failure, door to patient room left open, patient asleep and different need of help in evacuating. Each final scenario (path through the event tree) is analysed by the FOSM method resulting in a reliability index β for each end-point. These measures show how the safety varies for the scenarios depending on the circumstances for the specific cases. The reliability index is decreasing as the number of staff is decreased or the preparation time for the patients is increased. The b-values are calculated and presented on the condition that the event has taken place. This means that each scenario is calculated individually and the only uncertainties involved are those in the limit state function. The branch probabilities in the event tree are not part of the limit state function and therefore not included in the reliability index. This results in the fact that the reliability of installed systems or actions taken by staff to extinguish a fire are excluded from this value of reliability or safety. The installations do, however, affect the reliability index as they may decrease some of the variables in the limit state function. A detection system provides a quicker detection time than if no automatic system was installed. The procedure to also incorporate those probabilities into an integrated reliability of a building, will be further investigated in a following report and applied to hotel safety.

The disadvantage with the suggested method is that it is rather time consuming as a number of scenarios have to be calculated. First the fire consequences for each scenario have to be derived and response equations derived to represent the computer output. In the next step, using the results from the fire consequence calculation, reliability calculations have to be performed, for each scenario. As the background data used for the calculations are more or less chosen by

judgement the results derived sofar are also subjected to uncertainty due to this fact. More relevant data covering fire and people behaviour is needed in order to get more realistic results.

The time to untenable conditions on the ward is determined by using the computer program CFAST and fitting a response equation to the computer output. The detection time is determined by using the program Detact-t2 to create a response equation to represent the computer output. The energy release rate from the fire is assumed to follow an at^2 expression, where a is the fire growth factor. The mean value of the fire growth factor has been chosen to result in a fully developed fire within a couple of minutes. The calculations are performed on a standardised health care ward and different data on patient categories have been used. Only the conditions in the ward on fire has been considered and the effect of smoke spread to other wards have been neglected. The calculations reveal that a sprinkler system will have no effect on the safety of the patients on the ward on fire. The sprinkler activation times are longer than the time to untenable conditions. However, the safety on other wards will probably be improved by having sprinklers installed as the sprinkler will limit the fire from spreading to other wards.

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1 Introduction

1.1 Purpose of the study

The main purpose of the study is to define a method that can be used to determine the safety level in a hospital ward for various conditions. The method takes the uncertainty in the variables describing the situation into account. Event tree analysis is used to illustrate the scenarios, see figure 3, 4 and appendix A. Each path through the event tree ends in a final scenario. The safety level is determined by the ability to safely evacuate the ward if a fire occurs.

The objective during a fire is to evacuate all the patients before untenable conditions arise. But, there are factors controlling the safety level which cannot be specified in advance as they are unknown and subjected to uncertainty. ”What fire characteristics can be assumed?”, ”What is the response time for the staff?” and ”How can the patients be moved if they have to be evacuated?”. These questions do not have single answers, but they can be treated as uncertainty variables. Having variables subjected to uncertainty, some situations may occur that are unwanted and a measure of risk has been introduced which has to be treated by engineering methods. One example of unwanted event is that the ward cannot be evacuated before untenable conditions occur because the fire hazard develops too fast or the response time for the staff is too long. One of the objectives with the design process of hospital wards is to avoid that this happens. Still, hospitals are sometimes subjected to fires and have to be evacuated, which means that the unwanted event can happen. The design process, therefore, has the purpose to find the most cost-effective method of obtaining an acceptable level of risk. The question to be asked is, what is acceptable level of safety? Comparison of the safety level in existing buildings can provide the answer.

The method presented in this report can be used to quantify the probability of unsuccessful evacuation and provides a measure of safety that can be used to compare different design solutions. The designer can choose between alternatives that result in the same safety level, but which can be associated with, for example different costs. The results can therefore be seen as indications for the designer in his or her optimisation procedure in the design process. It should, however, be clearly stated that the parameters used in this report are based on a limited amount of information. The actual safety level can therefore deviate from what is assumed in the calculations in the report.

In the design process, the designer also perhaps want to know how sensitive a variable is to changes. Is the safety very much relying on one specific variable, or not? The answer to this can be addressed by making a sensitivity study of the relevant uncertainty variables. Such studies were made for some of the scenarios.

The safety level in this report is defined by the reliability index β. Different conditions on the ward, for example various conditions of the patients, active systems and number of staff, will result in a different safety level and a different reliability index β. A higher value of β indicates a higher safety level. The reliability index β is linked to the probability of failure for the design equation. The method to calculate the reliability index β is further described in section 5.

The reliability index for the scenarios are calculated on the condition that the fire event has occurred. The only uncertainty variables are those indicated by the basic variables in the design equation, the limit state function. No branch probabilities from the event tree alternatives have been considered. This results for example in, if the fire alarm fails, this does not affect the safety measure. A detection system will, however, affect the reliability index β as the detection time is decreased compared to manual detection. Different system reliability or maintenance procedures will, though, have no effect on the resulting reliability index. Each scenario has been treated separately. An integrated reliability index will be presented in a following publication and the method will then be applied to a hotel.

The reliability index in this report is calculated for two locations on the ward, the patient room and the corridor.

1.2 Health care facility back-ground

The ward which is studied can be seen as an ordinary hospital ward in a larger hospital. It is supposed to be occupied with patients residing for a longer or shorter time and where staff are present for taking care of the patients. It is assumed that other wards are present both on the same level and on other levels compared to the studied ward. The reason for this assumption is to have a possibility of staff assisting in the evacuation, coming from other wards. This is the normal procedure in hospitals in Sweden.

The patients in a ward are usually highly dependent on the responses and actions taken by the staff. The two major contributors to the patient safety are the number of staff and the conditions of the patients. The more staff present, the faster an evacuation can take place. If the present fire alarm system, in one way or another is out of order, the fire is more easily detected if more staff are present. At daytime, the number of staff is usually much higher than during the night. To increase the probability of having a successful evacuation during the night, staff from other wards in the health care facility can come and assist in the evacuation. The number of staff has been a variable in deriving the safety level.

The condition of the patients also affects the safety level on the ward. Patients with a high level of help needed for movement, will increase the evacuation time resulting in a lower safety level. This can be circumvented by increasing the number of staff. Also the time necessary for preparing a patient prior to movement can vary. Different patient conditions have been studied. It is assumed that there is a correlation between the movement capability and the preparation time needed. A high walking speed is correlated to a low preparation time needed and vice versa.

To make the calculations less extensive some simplifications have been introduced. The major of those is the standardised layout of the ward. No uncertainty has been incorporated in setting the dimensions of the ward and the rooms within the ward. The dimensions are, however, chosen to comply with the minimum recommendations in the former Swedish building code, NR (1989). The dimensions are 35 x 15 m^2 and the ward contains 14 rooms, each 6 x 5 m^2, on two sides of a 35 x 3 m^2 corridor, see figure 5. As the dimensions of the ward are fixed, the total number of patients on the ward is also fixed to 30 patients. The number in a specific room, i.e. the room containing the fire, are however subjected to uncertainty. The number of patients in the fire room are varying between 1 and 6 patients.

Both these two variables, the total number of patients and the number of patients in the fire room are chosen to represent the reality as accurately as possible.

In the calculations, the fire is always supposed to start in a patient room. The fire source can be a waste paper basket or the patients bed. The reason for the fire can be arson or ignition by accident for example by a candle. The actual object first ignited is for this work not important more than to serve as a base for estimating the energy release rate of the fire.

The fire can of course start on other places on the ward. The risk to the patients are, however, believed to be highest if the fire starts in the patient room. Other possible locations for the fire are the staff room, the TV-room or a storage room on the ward. The conditions in the corridor, due to a fire in for example the TV-room, will be similar to the consequences from the fire located in the patient room. The risk for the patients staying in their rooms will be less with this scenario. For the calculated risk in the corridor, the exact location of the fire room is of less importance. The fire in a patient room is a conservative choice.

2 Knowledge uncertainty and variability (stochastic uncertainty)

One can distinguish between two types of uncertainties: knowledge uncertainty (fundamental, epistemic) due to lack of fundamental knowledge and variability (aleatory uncertainty, stochastic uncertainty, randomness) in a population, IAEA (1989). The former can be reduced by additional fundamental information; the latter can be reduced in principle by exhaustive study. The two types of uncertainties, however, can be measured by the same method (probability). When dealing with a single element in the population, both types of uncertainty become the same (lack of knowledge) and the risk is characterised by one probability (e.g., of failure) that represents both types of uncertainty for decision-making purposes. Knowledge uncertainty reflects a lack of knowledge that is described by a probability distribution. Variability represents heterogeneity across some dimension (population, time, space, etc.) that is represented by a frequency distribution. Conceptually, these are very different. Instead of saying that variability and knowledge uncertainty are both described by probability distributions, one should say that they are different but can both be described by probability distributions in many situations.

Variability cannot be reduced, but it can be stratified into more nearly homogeneous sub-populations. These can be used to characterise especially sensitive sub-populations.

Knowledge uncertainty represents random error, systematic error, irreducible uncertainty, or lack of an empirical basis for making an estimate. It can be addressed, but not necessarily reduced, by better measurements (consider the effect of systematic error on tails of distributions - the systematic error may be revealed by better experimental designs, which could have the effect of increasing uncertainty).

Variability and knowledge uncertainty have also been referred to as, respectively Type A uncertainty associated with "stochastic variability with respect to the reference unit of the assessment question" and Type B uncertainty "due to lack of knowledge about items that are in variant with respect to the reference unit in the assessment question". Examples of parameters that are coupled to the two types of uncertainty are given below

- Variability, Type A; wind direction, temperature, fire growth rate over a class of buildings, response times for occupants

- Knowledge uncertainty, Type B; model uncertainty, plume flow coefficient, acceptable heat dose on persons, reliability of a sprinkler system.

One should mention that several variables could be affected by both kinds of uncertainty. That could be taken into consideration in performing the calculations. In Magnusson et al. (1995) this distinction is made for the calculations of evacuation reliability from an assembly room.

3 The choice of parameters

As some variables, the basic variables, are subjected to uncertainty, one way to describe the variable is to use its probability density function or frequency distribution. The basic variables are those that are used in the limit state function, for example detection time, reaction time by staff and fire growth rate of the fire. The distribution shows the values that the variable can be assigned and how often the values are to be expected. The actual value of a basic variable is chosen by random from the distribution and the basic variable is therefore a random variable. The distributions are defined by the parameters mean and standard deviation. These are the two parameters that have to be chosen for the risk calculations.

The actual parameters describing the distributions for the basic variables are chosen according to

- experimental data and statistics
- judgement made by experts

For most of the variables, little systematic information is available that can provide guidance on how to choose parameters for the distributions. Experiments can lead to the choice of some parameters but the basis for choosing a specific value as the mean or standard deviation has not been systematically put together. The overall experimental database is very large but not easily accessible. There is no easy way to obtain the parameters from the experimental database. It is therefore necessary to estimate the parameters mostly by judgement and choose distribution types on basis of what has the highest degree of belief, Haimes et al. (1994). This estimation procedure for the parameters, the use of expert opinion, are quite common in other engineering fields, such as in the chemical process industry, when experimental data are lacking, CPQRA (1989). For most types of input data, such as fire growth rate, there exists a more or less extensive data base, which provides a credible (minimum values to maximum values) for the specific parameter. A rectangular distribution can be used to describe the variable distribution, as a first step. Knowing the outer limits of the variable the mean and standard deviation can easily be calculated. For other cases, the available data might be large enough to provide the most frequent value as well. A triangular distribution is the next approximation of the real distribution.

Actually, it does not matter so much if not the exact distribution type is used for each variable. The resulting distribution is not very sensitive to the choice according to the central limit theorem. The most important information is concerning the parameter values, mean and standard deviation. The parameters are to a high degree chosen as a combination of experimental data, statistics and expert judgement. Collecting and systematically organising the relevant data must be a task given high priority in future work.

The most frequent distribution type used in this report, is the normal distribution. It has been used for variables like time for reaction of staff and movement time of patients. It is believed to represent the variables in a proper way. A log-normal distribution is chosen for the fire growth rate as it provides no negative values and is believed to represent the variable in the best possible way. The parameters for the fire growth rate distribution are chosen according to findings from experiments and post fire investigations in health care facilities. The mean value of the fire growth rate is chosen to represent a likely level of the parameter. The standard deviation is chosen by judgement to be in the same order of magnitude. Only a few post fire investigations have been studied and the base for these choices are limited. The other distribution parameters are more or less chosen according to judgement. The choices have been discussed among other experts and people with knowledge of health care facilities.

4 Definition of risk

Before introducing different risk methods it is necessary to define what is meant by risk. The risk associated with fire in a building takes into account the likelihood of fires and their potential consequences, e.g. the potential number of deaths. Hence it is possible to define risk as a function of hazard, probability and consequences:

Risk = f (hazard, probability, consequence)

When calculating the risk associated with a particular hazard it is more common to write:

Risk = S (probability • consequence), for all consequences.

The risk can be expressed in monetary unit/year if a fire loss consequence in average is X units and the probability of a fire is Y % per year or in number of deaths per year in a building. But risk is not always simply the multiplication of two quantities, i.e. a numerical value. There is a distinction between the calculated risk and the perceived risk. The latter is important when it comes to answering the question about what is the acceptable risk. An important aspect is the degree of voluntariness with which the decision is taken and the risk is endured. The person who is making a decision weighs the risk against the advantages of the activity. The person might do the activity voluntarily and is therefore likely to accept a little higher risk for example when climbing mountains. The focus for this report will, however, be on risk as a quantitative measure. Also here, a distinction in risk can be made, by dividing the risk in the categories individual risk and risk to the society. Other methods are available for measuring risk, for example average individual risk and fatal accident rate (FAR), CPQRA (1989), Covello et al. (1993).

The structured method used in performing a risk analysis is usually called probabilistic risk assessment or probabilistic risk analysis, both abbreviated PRA. In some publications risk analysis is a part of the risk assessment. The latter is sometimes also including the risk management aspect, Kolluru et al. (1996). This report is purely devoted to risk analysis which is defined as ”The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies” ,CPQRA (1989).

4.1 Individual risk

The individual risk is defined as the probability that a person will be affected by the unwanted consequence. If a person is located in the hazardous position the risk will affect him or her. The risk is calculated for each location, which in this case is two, the patient room and the corridor. The risk is independent of the number of persons affected by the consequences. The individual risk is the result from the calculations presented in this report. The risk is expressed as both the reliability index β and the probability that the unwanted event will occur. The evacuation conditions can change depending on the circumstances, for example if doors are open or if a detection system is failing.

4.2 Societal risk

The societal risk considers the risk of multiple fatality fires. In this case, not only the probability of the unwanted event is considered but also the number of persons subjected to the hazard. Simplified, it can be said that the societal risk is the individual risk for a specific location, multiplied with the number of persons on that location. This is repeated for every location. The results are sorted by increasing consequence. The risk is often described by the exceedance curve of the probability of the event and the consequences of that event in terms of number of deaths. This curve is known as the frequency-number-curve or FN-curve, see figure 1. This means that the risk is not constant in terms of number of deaths and the probability of those deaths. The society is less willing to accept a large number of deaths happening at the same time compared to the same number of deaths happening in a number of accidents. This risk measure is usually derived by using a numerical Monte Carlo sampling procedure.

For the scenarios in this report, the risk to the society can be calculated. This risk is, however, an approximation of the real societal risk, but on the conservative side. The reason for this is that the number of persons subjected to the hazard is not constant. Persons are evacuated out from the hazardous area. This means that the number of persons used to derive the societal risk is less than the originating number for the location. The risk calculation method used cannot be used to predict the exact number of persons not able to be evacuated, therefore the approximation. The risk to the society is further elaborated in section 5.3 when introducing the event tree method.

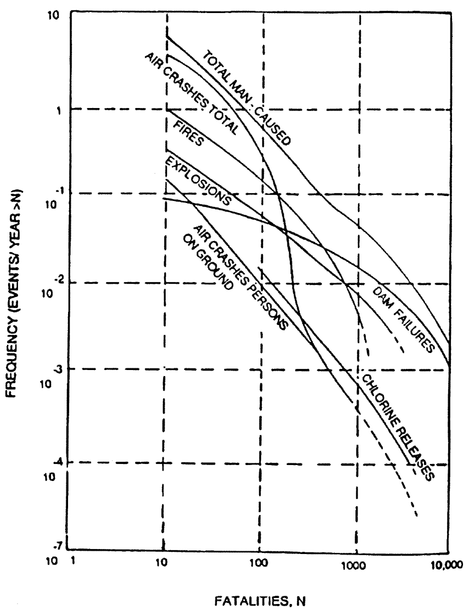

Figure 1. Example of F-N-curves for some risks, CPQRA (1989)

5 Risk method

5.1 Limit state function

The life safety is expressed by using the reliability index β. This measure represents a value of safety which is comparative between different solutions. Methods of deriving β are in detail described in Ang and Tang (1984) and Thoft-Christensen and Baker (1982), and only a brief description is given here.

Safety is described by the margin of evacuation time. When a fire occurs there is a certain time available before the room is untenable for humans. By comparing the time available to the time needed, the margin is calculated as

$$G = t_a - t_e \qquad (1)$$

G = evacuation margin
t_a = available time
t_e = evacuation time

This equation is referred to as the limit state function. In the safe state the margin is positive. In the present case the available time is determined by the interaction of the fire and of the building. Energy release rate of the fire and opened or closed doors are factors affecting the available time. The evacuation time is the sum of detection time, behaviour and response time and movement time.

The times t_a and t_e, are composed of basic variables that can be constants or subjected to uncertainty, random variables. These random variable distributions are described with an expected value and a deviation from the expected value, i.e. mean and standard deviation. Using random variables in the limit state function, results in a corresponding distribution of the margin.

The available time is expressed as

$$t_a = S \bullet U_s \qquad (2)$$

and the evacuation time as

$$t_e = D + R + E \text{ (or } E_{corr}) \qquad (3)$$

resulting in the limit state function

$$G = S \bullet U_s - D - R - E \text{ (or } E_{corr}) \qquad (4)$$

S time to untenable conditions (calculated)
U_s model uncertainty factor for CFAST (random variable)

D	detection time (calculated or random variable)
R	reaction and response of the staff (random variable)
E	movement time for patient room (calculated)
E_{corr}	movement time for corridor (calculated).

The calculated variables are functions of other random variables such as the fire growth rate, α, and preparation time of patients by the staff prior to movement, t_{Care}. Table 1 shows all the random variables and constants used in the calculations.

Table 1. Random variables (RV) and constants (CV) for the calculations.

5.2 Calculation method

The random variables in the limit state equation can be transformed into the standardised space, where a standardised variable is expressed as

$$X' = (X - \mu_X)/\sigma_X \quad (5)$$

and X indicates the random variable. The limit state function is the same in both the real space and in the standardised space. The minimum distance from the origin in the standardised space to the limit state function is equal to the reliability index β, figure 2, according to Hasofer and Lind (1974) which has been shown to be the most suitable measure. Other reliability indices such as the one presented by Cornell (1969) shows some inconsequent behaviour depending on how the limit state equation is formulated, Thoft-Christensen and Baker (1982), and is therefore not used here.

The origin, in the standardised space, is placed in the point of the mean value of the margin, G, expressed in the original space. This is a result from standardising the variables. The point on the limit state function which has the shortest distance to the origin in the standardised system is called the most probable failure point. This is the point on the limit state function, resulting in the highest probability of failure of the system described by this function. The value of the probability of failure can be approximated by the following relation

$$p_f \cong 1 - \Phi(\beta) \quad (6)$$

The symbol Φ indicates the standardised normal distribution function. If the limit state function is linear and the basic variables are normally distributed there is an equality in the expression. Other transformation functions, than the normal, can be used to achieve an approximation of the probability of failure. However, if the basic variables or functions of these, are summarised, the sum can be approximated to a normal distribution according to the central limit theorem.

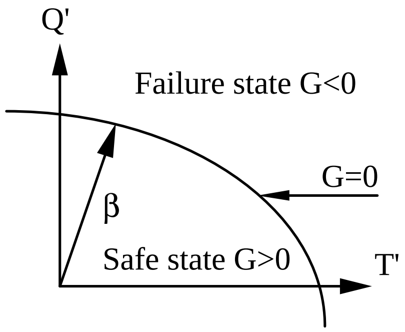

Figure 2. Reliability index β in a two dimensional standardised space with the basic variables Q and T. G=0 indicates the limit state function =0.

The procedure of finding the β-value is to minimise the distance between the limit state function and the origin in the standardised system. Several such methods are available and described in for example Ang and Tang (1984) and Thoft-Christensen and Baker (1982). This analytical derivation is based on approximations of the limit state function in a first or second order Taylor expansion. These methods are referred to first order or second order reliability methods, FORM or SORM. They can also be referred to as FOSM, first order second moment method or SOSM. It is then implied that the method uses the two first moments of the random variable distributions, mean and standard deviation.

In this work, the reliability calculations have been executed using a computer program, STRUREL (1995). This program calculates both the first and second order reliability index. It is also possible to take the distributions of the variables into consideration and not just the two first moments. A more accurate prediction of β is therefore achieved.

It is not evident that the reliability index β is the most appropriate for describing the risk to humans in a fire situation. As a matter of fact there are methods which are more detailed in addressing the risk to humans in fire, CPQRA (1989). The most obvious disadvantage with the β-method is that it only takes the lack of escape time for the last person reaching the safe area into consideration when trying to describe the probability of failure of the evacuation system. The probability is only addressing the fact that persons are unable to evacuate safely, i.e. the time margin is less than zero. No information is available of the probability that exactly one or two or more are unable to escape. The problem is that the acceptance from the society of having one person unable to escape in 10 fires is higher than having 10 persons being unable to escape from one fire. The consequences is the same for the both cases but the willingness of the society to accept them are not the same.

Still the method is used because it delivers information that is useful and not accessible in other ways such as the design values needed to obtain a specific safety level. Methods providing the information of differentiated human risk dependant on the number of persons unable to escape, PRA-analysis, should be used for deriving F-N-curves, see section 4.2. Comparison of the two methods, b-method and PRA might be used to derive parameters that could be used for design purposes.

As mentioned above the β-method provides the most probable failure point. As this is the desired design-point that should be used in designing an evacuation system, it is required that the β-method is used for this purpose, even with its disadvantages. The future design-point can be calculated using an optimisation procedure for a class of scenarios for a specific building type, Frantzich et al. (1996). The design values will then be valid for a class of buildings and not just one specific. This method can be used to derive a simple design method for the specific class.

It should also be noted that there are variables in the calculations that are not subjected to uncertainty i.e. deterministic or constant values. Some of those are in fact subjected to uncertainty which has been neglected in the risk calculations. The number of random variables have been limited due to the following reasons.

- Not all variables subjected to uncertainty will affect the final result to a degree that is detectable. The uncertainty in the resulting safety measure is mostly determined by those variables, in the limit state function, having the the highest level of uncertainty. By adding a new variable, subjected to uncertainty, to the existing ones will always increase the total uncertainty. Every new uncertainty variable adds to the total uncertainty. Even for the simple example

  $$Z = X - Y$$

  the variance of Z = Var(X) + Var(Y), if Z, X and Y are random variables. But variables known with higher degree of precision will not substantially affect the overall uncertainty as their variances are low. The standard deviation, used to measure the uncertainty, is the square root of the variance. Finding important variables can be done by screening methods, IAEA (1989).

- In this case the most significant uncertainty variables have been chosen by judgement. Examples of unimportant variables are size of leakage openings between the patient room and the corridor, location of patients in the patient room and different patient movement methods. Some of these variables are implicitly considered in the overall uncertainty of the used random variables.

- As the dimensions of the ward are treated as constants, the influence of these are not possible to reveal. The dimensions of the ward are otherwise variables which can have a significant influence on the result. The dimensions are, however, chosen to represent an average ward.

- Response equations, see section 7.5, which are used to replace time consuming computer calculations, must be derived using sets of all possible variable combinations. If the number of variables are large the work load to produce such a response equation would be very high. Furthermore, the ability to accurately predict the computer output will be considerably lower as the number of variables in the response equation increases. The reason for this is that it is difficult to find a response equation which can predict all the computer results without too much deviation. The equation is usually obtained by fitting the computer output to an equation by the method of least squares. A low number of variables are therefore desired, to be able to get a good prediction from the response equation.

5.3 Event tree description

The evacuation safety can be described by using a structured event tree that graphically shows the different scenarios. The event tree is organising the events that can occur, for example detection system failing and door to the patient room being open. All these events are associated with a certain probability. By combining these probabilities, the total probability of the scenario can be calculated. That probability is normally calculated by multiplying the branch probabilities leading to the scenario. These probabilities associated to the final scenarios can be used to derive the risk to the society as described in section 4.2. Some values of the necessary branch probabilities are presented in this report for completeness.

As the purpose with the report is to derive the reliability for each scenario on the condition that the scenario has occurred, this information will not be used apart from, in an example, illustrating the calculation procedure for total risk. The risk to the society will be further analysed in a following report.

By combining the scenario probability to the consequences for the scenario, repeated for every scenario, a picture of the overall safety can be visualised by using the F-N-curve technique. The scenarios can also be compared to each other knowing of the occurrence rates for the design alternatives. A decision maker can perhaps choose an alternative with lower b-value on the condition that the likelihood of that scenario is low. The opposite strategy can of course be chosen, i.e. a high b-value scenario with a high occurrence rate. The way to choose the most optimum alternative is, however, outside the scope of this report.

The calculation of risk is performed on the final scenarios indicated in the event tree, each having its specific limit state function, figures 3, 4 and appendix A. Each of the basic scenarios A1 to A4 and A1C and A3C in figure 3 are combined with the patient categories, illustrated in figure 4. For basic scenario A1, this results in the six final scenarios A11 to A17. This is repeated for the other basic scenarios, see appendix A for clarification.

The initial event is a fire that has started in a patient room. The first condition is whether it is daytime or night-time and if there are one or two smoke detectors in a patient room. This gives four branch alternatives, A - D. The next condition is if the fire is a smouldering fire or a flaming fire. The smouldering fire is not further examined as a consequence of the calculation in section 7.3. If the fire continues to grow to a flaming fire, the staff available can perhaps extinguish it or it might self-extinguish. Both these two alternatives are treated as one because they are both ending with the same result. If that event occur, no evacuation will be needed and no further analysis is performed.

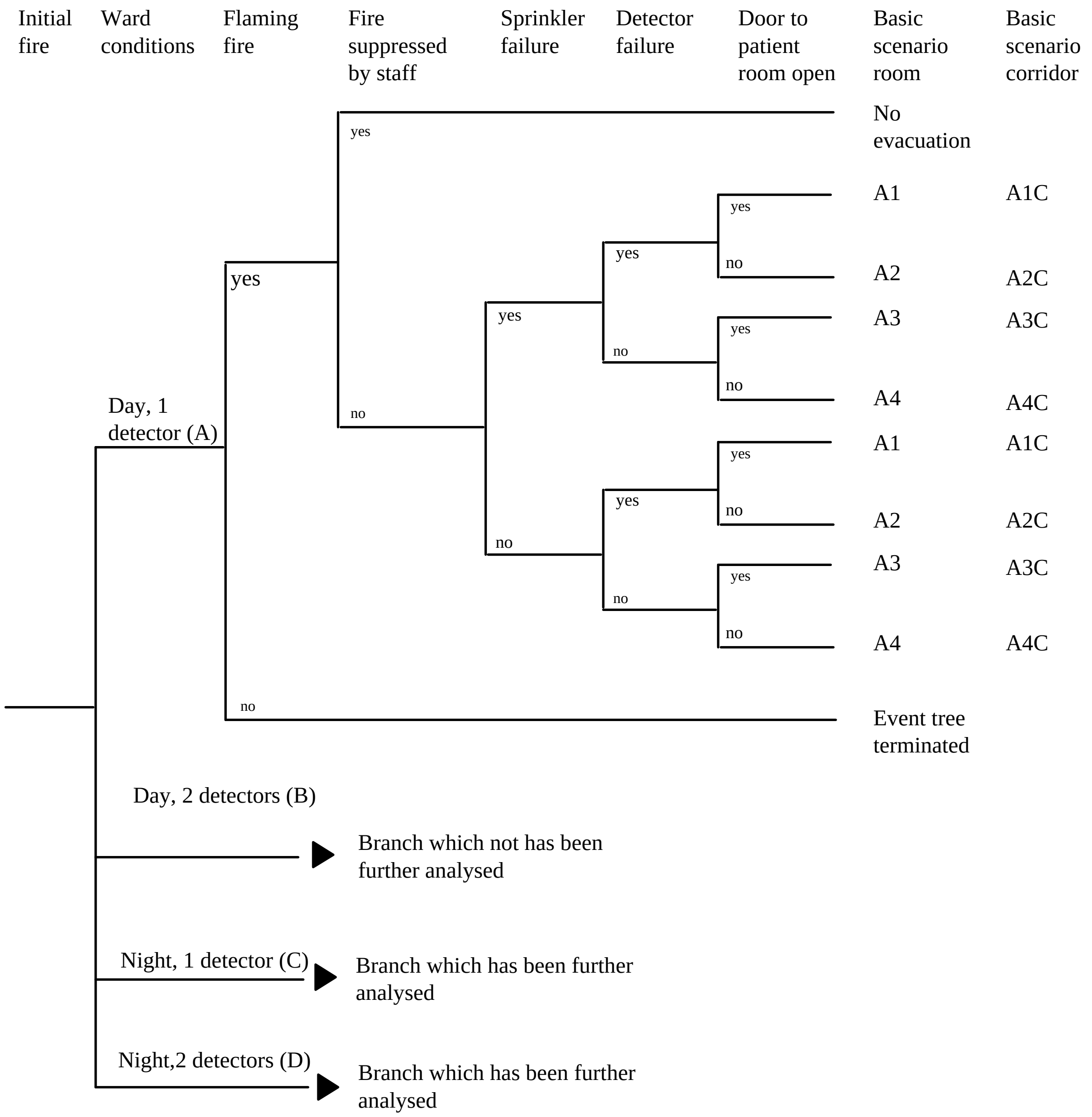

Figure 3. Illustration of the event tree used for the fire safety calculations.

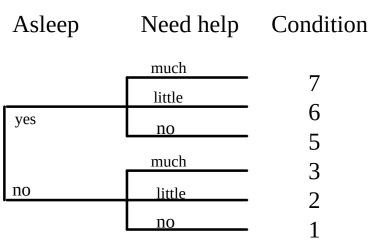

Figure 4. Events to be analysed for each basic scenario.

In appendix A the event tree is, for graphical reasons, divided in two parts at this point. For each of these eight alternatives separate event trees are created. Only paths I, V and VII are, however, displayed and further analysed.

The following events in the event tree are: sprinkler failure, detector failure, door to patient room being open. This results in six basic scenarios, see figure 3. As the door between the patient room and the corridor for two scenarios is closed, only two corridor cases are relevant. It is assumed that evacuation from the patient room temporarily has ended when the patients have reached the corridor and the patients have then reached a safer location. The b-value for the patient room therefore gives information on the safety of escape from the room to the corridor. The reliability for the patient room is, therefore, not based on the fact that the patients have reached the protected lobby but only the corridor.

The protected lobby outside the ward is considered the safe location for patients escaping the complete ward (corridor). If the sprinkler system works, a new set of basic scenarios are created. This is the same for every one of the alternatives A - D.

For each basic scenario, six different patient categories are applied, according to the small event tree in figure 4. The differences in these six categories are due to differences in the help level a patient needs for preparation and whether the patient is awake or asleep. This results in six final scenarios for each investigated basic scenario. The final scenarios are denoted A11 to A17 if they are originating from the basic scenario A1. For reasons mentioned above, the basic scenarios A2C and A4C are not further investigated. For each final scenario, the reliability index β is calculated for a varying number of staff present.

6 Initial probabilities

6.1 Probability of initiating fire

In defining the risk associated to the patients in a health care facility, it is necessary to know the fire occurrence rate, i.e. the probability that a fire will start. The statistics on this area is rather limited. Usually it is possible to tell the number of fires occurring in a town or country each year. Unfortunately, the information about the number of premises of a certain kind, for example health care facilities, are missing. It is not enough to know the number of fires in a town hospital ward. The total number of wards must also be known to be able to predict the fire frequency. Therefore the information on the probability that a fire will start in a ward or in a hospital is limited. Some information is given in Rutstein (1979) which relates the probability of fires occurring to the floor area, in m^2, of the building. According to this reference the probability of having a fire in a health care facility per year can be calculated as

$$p_{fire} = 0.0007 \cdot A^{0.75} \qquad (7)$$

The probability is derived from reports from fire departments in the UK. The expression gives an average value of the probability and the deviation can be large. As the number of fires in hospitals is few the validity of the expression can be questioned. The figure 0.75 is, according to the author, arbitrarily assumed due to the reason of low incident rate. It is although generally assumed that the probability is increasing with increasing building area but the dependence is not linear and the exponent should be less than one.

Using this expression for the health care ward used in this report the probability of a fire event will be 0.077 fires $\cdot$ year^{-1}. The area used for this calculation is 35 x 15 m^2.

In the Draft British standard on fire safety engineering (1995) the overall probability of a fire event in a hospital is assumed to be 0.3 fires $\cdot$ year^{-1}. This number is of course very much depending on the size of the hospital. The former probability is valid only for a single ward in a hospital and should of course be less than the probability of a fire starting in any place in a hospital.

Some preliminary Swedish data concerning fire occurrence rates are available from different fire departments in the country. The data is collected from the rescue reports following an emergency operation from the fire department. Almost all Swedish health care facilities are equipped with smoke detectors which are connected to the local fire department. This means that if a fire occurs in a health care facility it is very likely that the fire department will be notified of the fire. The fire department rescue reports are therefore a good estimate of the number of actual fires in a health care facility.

The data collected are coming from 3 different fire departments located in different parts of the country. The incidents reported are those where a fire certainly has started, and all the false alarms are omitted. The number of reported fires are compared to the number of hospital wards in the region of the fire departments. The ward has been chosen as the depending parameter because the variation in size among wards is assumed to be low. This is a simplification as there are differences between wards, but the number of fires are small and other depending variables, such as number of fires per m^2, would not necessarily increase the reliability in the prediction of fire frequency.

The fire frequencies for the different communities are presented in table 2. The table also contain other relevant information such as the time period over which the data is collected.

Table 2. Fire incident rates in health care facilities.

Community	No. of fires	No. of wards	Time period, year	Number of fires put out by staff or self extinguished	Evac. needed	Prob. fire start $(\text{year ward})^{-1}$
Solna KS	10	52	2.83	10	0	0.068
Lund	14	90*	2	14	?	0.078
Helsingborg	35	119	7	26**	0	0.038

*Estimated by head of security at hospital. **One fire extinguished by fire department. The rest unknown. KS = Karolinska sjukhuset (Specific hospital)

Based on the above information the fire start likelihood in the ward is chosen to 0.07 fires•year^{-1}. The value is in the same region as the value derived with equation 7 and from two of the town hospitals in table 2. The value for the wards in Helsingborg is half of the others but still in the same order of magnitude.

6.2 Staff actions

If a fire really occurs the next probability to take into consideration is the chance that the staff will put it out. According to the statistics above the staff is normally able to extinguish the fire in an early stage. In those numbers of successful extinguishments, in table 2, the self-extinction of the fire is also included. Therefore the cases when the ward has to be evacuated have the following characteristics; a fire must start and no one in the staff is able to put it out nor does it self-extinguish. This is a very infrequent event and the probability is estimated on the basis of the statistics and discussion with other fire professionals. Training of the staff for this event occurs at least once every two or three year and therefore the likelihood of having the staff to put out the fire is very high. The probability of a successful activity of the staff or the fire will self-extinguish, is chosen to 0.95.

On the basis of the statistics from the fire departments it is assumed that the probability of a fire occurring at night is 0.33 and 0.67 that it occurs during the day.

The condition that will lead to an evacuation, is that a fire is initiated and will continue to grow. This means that a smouldering fire will not lead to evacuation unless it develops to a flaming fire.

In the present report it is assumed that a smouldering fire is harmless, at least in the time scale considered. Calculation of the conditions in a room subjected to a smouldering fire has been done using the input parameters from Quintiere et al. (1982), see also section 7.3.

7 Fire safety calculation conditions

7.1 Building

The calculations have been performed on a health care ward with fixed dimensions. This is to reduce the number of alternative calculation scenarios. The conditions for choosing the building layout was that it should comply with the minimum recommendations for health care wards set out in the former Swedish building code, NR (1989). These recommendations say that the walking distance to the closest evacuation exit from any point in the ward should not exceed 30 m. The condition for using 30 m is that one of two exits does not permit horizontal evacuation, i.e. it is a stair leading to the street level. If both exits permit horizontal evacuation to another ward in a separate fire compartment, the maximum distance can be 45 m.

In the scenario, the 30 m limit is chosen and it is always assumed that the fire is located in a room close to the stair exit preventing it from being used. Figure 5 shows the assumed ward with 11 patient rooms, a TV room and a staff room. The exit to the right leads to a protected lobby which in the other direction is connected to a second health care ward. All the calculations are performed on fires in the first ward. The patients and the staff are in safety when they have reached the protected lobby.

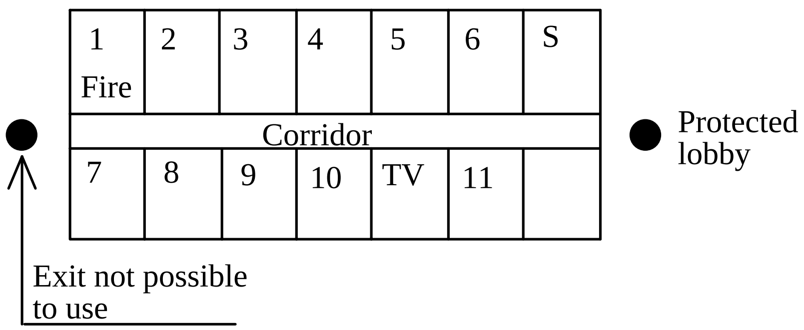

Figure 5. Ward layout. TV is a TV-room and S indicates the staff room.

All rooms in the ward are 5 x 6 x 3.2 m^3 (WxDxH) and the corridor is 35 x 3 x 3 m^3 (LxWxH). All patient rooms are equipped with one window and a door leading to the corridor. The window is 0.9 x 0.9 m^2 and the sill is located 1.2 m above floor level. The window is initially closed in the fire room and breaks when the fire in the room reaches a certain heat exposure level on the window.

Different breaking conditions have been studied and is further discussed in section 7.5.2. It is assumed that there is a leakage to the outside close to the window with the size of 0.02 m width and 0.9 m height. The door between the patient room and the corridor is 1.2 x 2.1 m^2 (WxH). It is open or closed according to the scenario description. Figure 7 and 8 show the two different door conditions used, in the smoke transport calculations, for open and closed door. The figures show the time the doors are used for evacuation. A leakage opening between the patient room and the corridor is provided to consider the not completely closing door and includes a normal ventilation opening between the patient room and the corridor.

The door between the corridor and the protected lobby is, in the smoke transport calculations, kept open 0.3 m during the whole simulation. This will simulate the time averaged opening of the door as it is used for escape. The door is, during evacuation, only fully open when people are using it. Otherwise it is closed, as it is equipped with a closing device. The door has a height of 2.1 m. The patient rooms are not separate fire compartments. It is, however, assumed that no smoke can leak direct from one patient room to another. The walls between the patient rooms and the corridor are, however, smoke separating.

The ceiling and walls are covered with gypsum sheets and the floor is constructed of concrete. These conditions are valid for the whole ward.

7.2 Staff and patients

There are 30 patients on the ward, located in the patient rooms. There can be between one and six patients in a single room. However, in the calculations the number of patients in a room is always six. Other patient/staff ratios can be obtained from the results, as six patients and two staff are equal to three patients and one staff. Depending on the time of the day the patients may be asleep or awake. The physical conditions of the patients may also vary. Three different physical conditions have been used in the calculations grading the patients depending of their need of help. The gradings are

- much help needed
- a little help needed
- no help needed.

The help is needed to make the patient aware of the evacuation and to prepare the patient before movement. In the reliability calculations the conditions of the patients are considered as differences in Care-time. The time period, t_{Care}, is defined as the time spent by the staff in preparing a patient for movement and also the physical movement time. Safe conditions are temporarily reached when the patient is in the corridor. The staff can then start to help the next patient in the room if there are any left. The values for t_{Care} for the six different patient categories are according to table 3.

The values for t_{Care} are chosen rather low. This implies that patients requiring a lot of help in preparing and movement are omitted from the investigation. Wards like an intensive care unit are deliberately excluded as the patients on this type of wards are very difficult to even move from the ward. Other safety measures has to be considered for these wards.

When looking at the evacuation from the corridor the differences in patient conditions also affects the movement capabilities. The movement time in the corridor is determined by t_{PatM}. This variable is defined as the time spent in moving a patient from the door of the patient room to a point of safety outside the ward and the time occupied by the staff to reach the next patient. The time t_{PatM} for patient categories 1 and 5 are more or less assumed to cover only the movement time for the patients as they are moving without any help. Both t_{Care} and t_{PatM} are normally distributed.

Table 3. Duration of t_{Care} and t_{PatM}. Numbers are mean value and standard deviation in seconds.

Condition	1	2	3	5	6	7
Awake/asleep	Awake	Awake	Awake	Asleep	Asleep	Asleep
Need of help	No	A little	Much	No	A little	Much
t_{Care}	5,5	10,5	15,5	10,3	20,5	30,10
t_{PatM}	20,5	30,30	40,40	20,5	40,30	50,30

The number of staff is depending on if it is daytime or night-time. The daytime staff is between 5 to 10 and the night-time staff, between 2 and 5 on each ward. Calculations are performed for each number of staff present, in all the basic scenarios. There are never more staff than patients in the room.

After the fire is detected by either the automatic fire alarm or manually, the staff spend a certain amount of time in reacting and interpreting the situation. As the staff are trained to respond to various kinds of signals, the reaction time is set rather low. The reaction time, R, in the calculations is normally distributed N(10,3) seconds, i.e. the mean value is 10 seconds and the standard deviation is 3 seconds.

After the reaction phase the staff will move towards the patients. This movement time, t_{StafM}, is assumed to follow a normal distribution N(20,10) seconds for daytime and N(30,10) seconds for night-time.

7.3 Fire specifications

The energy release rate from the fire is assumed to follow an αt^2 relationship, see figure 6. The fire is always in a patient room and does not spread to a neighbouring room or corridor during the time of interest. The time to reach untenable conditions in the fire room or the corridor is only depending on the growth rate of the fire, α. Therefore, the distribution for this variable has to be determined.

It is reasonable to assume a low value of the growth rate. Tests on the fire behaviour of hospital beds, Holmstedt and Kaiser (1983), indicates an α-value of approximately 0.01 kW/s^2. The bed used for that test was a standard bed used in hospitals until a couple of years ago. Newer beds are specially designed to be difficult to ignite and to have a substantially slower growth rate in the beginning of the fire development. After the fire in Hillhaven nursing home in Norfolk, Virginia, USA in 1989, Nelson and Tu (1991), it was determined that the bed ignited had a growth rate of approximately 0.01 kW/s^2. Tests simulating patient room fires Notarianni (1993) used growth rates in the region of 0.0001 - 0.00025 kW/s^2 which is very slow. A fire in a waste paper basket, Särdqvist (1993), could grow with a factor of 0.002 kW/s^2. The peak heat release rate is then as low as 20 kW.

After examining similar fires it was decided to use a growth characteristic for the fire following a log-normal distribution LN(0.005,0.01) kW/s^2. This will result in time to untenable conditions in the fire room within a few minutes, which is in good agreement with experiments and post-fire investigations. In some calculations a more severe distribution is used to see the differences. The other distribution is log-normally distributed LN(0.01,0.01) kW/s^2.

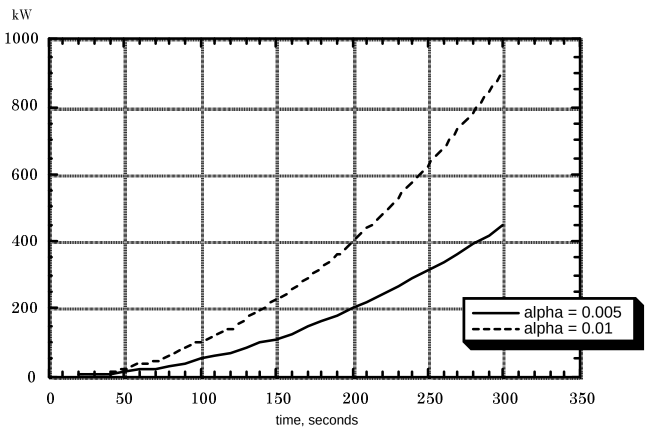

Figure 6. Energy release rates using the mean values of the fire growth rates.

All the fires concerned in this report are growing flaming fires. It is assumed that a smouldering fire will not create any untenable conditions in the time period considered. A small investigation was performed to see how the conditions in a room subjected to a smouldering fire was developing. The fire growth rate, described here as the fuel mass loss rate, is very low. It is chosen according to an equation by Quintiere et al. (1982).

$$\frac{dm}{dt} = 0.10 \cdot t + 0.0185 \cdot t^2 \text{ g/min} \qquad 0<t<60 \text{ min} \qquad (8)$$

$$\frac{dm}{dt} = 73 \text{ g/min} \qquad 60<t<120 \text{ min} \qquad (9)$$

In determining the time to untenable conditions the production term of CO is chosen very conservatively. Even so, there are no possibilities that untenable conditions will arise in the fire room based on the results from the calculations. Results from experiments and calculations, Quintiere et al. (1982), show that hazardous conditions due to inhalation of carbon monoxide happens more than one hour after ignition. Therefore, deaths in smouldering fires are unlikely in a health care facility. These are the reasons for omitting all the smouldering fires from the analysis and only looking at the growing flaming fires, even if it might be a simplification. The knowledge of consequences of smouldering fires is small.

7.4 Untenable conditions

The evacuation from the patient room and from the corridor must be finished before untenable conditions in those parts arises. The time to reach untenable conditions is determined by maximum levels of radiation, elevated temperature and toxic gases that people on the ward can be subjected to. Patients in a ward are probably more sensitive to those factors than the population in general. Elderly people and handicapped are more frequent in hospitals than others.

In the current calculations no special care has been taken to this fact. The tenable conditions are chosen so they will be valid for an average person, but the chosen values are rather conservative and on the safe side. Therefore, they can be used even for the hospital patients. Work by Purser (1988) are used in deriving untenable conditions. The limits used for determining untenable conditions are shown in table 4. Two different sets have been used for a sensitivity analysis. This set with extended levels is marked with ‘High level’ in table 4.

Table 4. Untenable conditions.

The condition first reached determine the time to untenable condition. Toxicity is measured in terms of the Fractional Effective Dose, FED, which is a measure that takes the effect of some toxic gases into account, Purser (1988).

7.5 Time to untenable conditions

The time to reach untenable conditions is derived using the computer model CFAST, Peacock et al. (1994). CFAST calculates temperature, smoke layer height, radiation etc. in every room in the scenario. The user has to define the scenario with room structure and layout. In the calculation, a user-defined fire specification has to be entered. One simulation with CFAST takes around 1 minute to perform and it is therefore not suitable for direct use in the reliability work.

The program CFAST has been used to derive a regression equation, or response equation, describing the time to reach untenable conditions as a function of the growth rate of the fire, α. For each scenario and opening condition of the door to the patient room, six calculations with different values of a was performed. The time to reach untenable conditions was determined in each case. With values of a and untenable time the regression equation was created by the method of least squares. This equation is used in the reliability treatment as a substitute for the actual CFAST results.

The event tree results in a number if different fire conditions each with a new regression equation. New regression equations have to be derived for the following conditions

- door to patient room is either open or closed after passage
- different breaking conditions for window in patient room
- sprinkler system operating.

7.5.1 Opening condition

The door between the corridor and a patient room can either be left open after patients have been removed or it can be closed thereafter. If the door is closed after passage of all patients, the conditions in the corridor will never reach untenable levels. It is assumed that the fire can be confined in the fire room. If the door is assumed to be left open after the patients have left the patient room, untenable conditions will take place in the corridor. Of course, untenable conditions will always be reached in the patient room independent of the opening condition of the door, but there is a small difference between the equations. If the door to the patient room is closed again after the passage the open/close condition of the door will follow the relation in figure 7. This information is used in CFAST. If the door is left open after passage the door condition will follow the relation shown in figure 8.

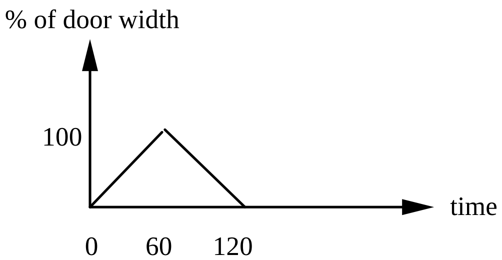

Figure 7. Time period when the door between patient room and corridor will be open, if it is closed after passage.

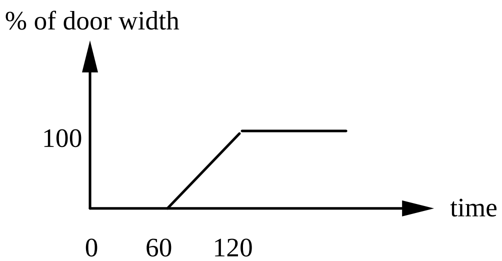

Figure 8. Time period when the door between patient room and corridor will be open, if it is left open after passage.

There is a small difference in the regression equations for the patient room depending on the open/close conditions. The two equations calculating the time to untenable conditions are

closing door: $S=16.0 \cdot a^{-0.41}$ seconds (10)

door left open: $S=19.3 \cdot a^{-0.37}$ seconds (11)

The conditions in the room are valid for cases without having a sprinkler system and using the normal values for tenable conditions according to table 4. The conditions in the corridor are as mentioned above depending on the door being left open. The time for tenable conditions in the corridor is also depending on the breaking conditions of the window in the patient room. This is discussed in the next section.

7.5.2 Different breaking conditions of the window

There is little known about when a window breaks and how much of the glass that will fall out. Therefore a sensitivity study was made to examine how different breaking conditions would change the calculated time to untenable conditions in the patient room and in the corridor. The breaking conditions used in the sensitivity study were respectively:

- 20 % open when gas-temperature reaches 250 ° C
- 50 % open when gas-temperature reaches 250 ° C
- 60 % open when gas-temperature reaches 250 ° C
- 50 % open when gas-temperature reaches 200 ° C
- 50 % open when gas-temperature reaches 150 ° C.

The time to untenable conditions in the patient room is not affected by the breakage of a window as untenable conditions occurs before the window breaks. The conditions in the corridor are affected by the breakage of the window when the door to the patient room is left open after passage. The differences in time to untenable conditions are small and the largest difference occurs at slow fire growth rates. The time to untenable conditions in the corridor for the different breaking conditions are shown in figure 9.

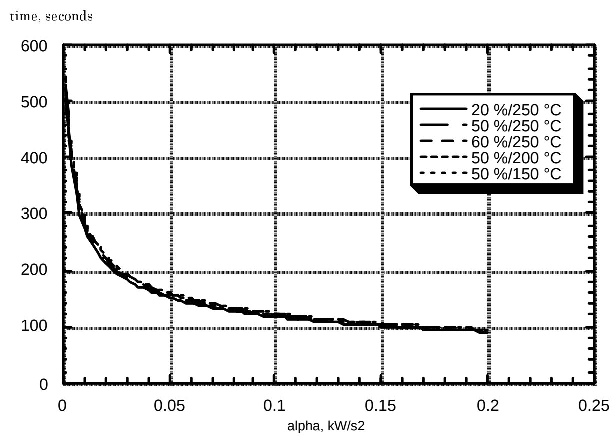

Figure 9. Time to untenable conditions in the corridor depending on the breaking conditions of the window in the patient room.

The equation chosen for the risk calculations relates to the condition; 60 % open when gas-temperature reaches 250 ° C. This line is in the middle of those presented in the figure above. The equation describing this line is

$$S=52.0 \cdot \alpha^{-0.37} \qquad (12)$$

This equation will of course only be valid if the door between the patient room and the corridor is left opened, i.e. following the curve in figure 8 above.

7.5.3 Sprinkler system

The ward is equipped with a sprinkler system designed to extinguish a fire in the premises. The sprinkler system is designed according to the Swedish regulation RUS 120:4. The sprinkler heads activates on a temperature of 68 ° C and are quick response sprinklers (RTI-value of 35 $\sqrt{m*s}$). The coverage area of a sprinkler head is 20 m^2 and the minimum water demand is 2.25 mm/min. The required duration is 30 minutes. These conditions result in two sprinkler heads per patient room which are located to give an optimal function.

Calculations were made on the activation time for the sprinkler system. The times were, for all scenarios, much longer than the time to untenable conditions in the patient room. Therefore, it is possible to state that a sprinkler system will not increase the safety level in a hospital ward for the patients there at the time of fire.

The sprinkler system will, however, most likely prevent the fire from spreading to other parts of the ward and the rest of the hospital. But the people safety on the ward of fire is not depending on a sprinkler system. There might, though, be some increase in the time to untenable conditions in the corridor, due to the sprinkler. This was not examined. The reliability that a sprinkler system will work and be able to extinguish a fire is assumed to correspond to a probability of operation of 0.96, according to judgement by Blomqvist (1996).

7.6 Extended tenability limits

A sensitivity analysis was made to see the influence in time to untenable conditions due to another choice of tenability limits. The limits used are the ones in table 4 under 'High level'. The condition changed is only the temperature criterion and it was elevated to 100 ° C. An equation describing the time to untenable conditions was derived in the same way as before. The calculated time is of course longer as the tenability is extended, but not so very much. The largest differences are the growth rate, a of the fire is low. Figure 10 shows the two graphs describing time to untenable conditions in the patient room, for the two tenability limits.

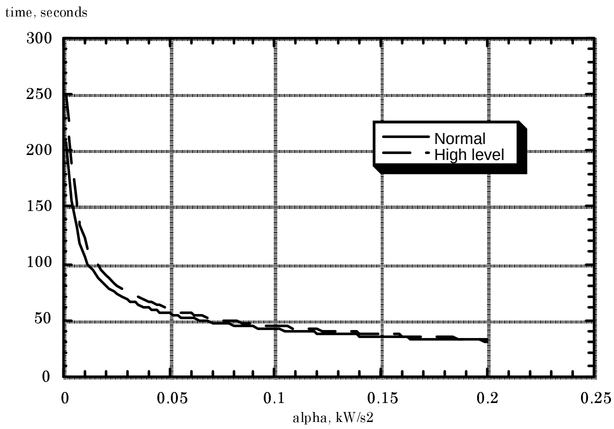

Figure 10. Comparison of time to untenable conditions using different tenability limits.

The resulting equation is calculated using the assumption that the door will close after the patients are in safety, i.e. the door will be open according to figure 7. The equation describing the time to untenable conditions in the patient room is

$$S=16.0\cdot\alpha^{-0.44}. \qquad (13)$$

7.7 Detection time

It is assumed that an automatic fire alarm system is present in the building. The alarm system is equipped with smoke detectors in every patient room and in common areas. The detectors are placed in the centre of the patient rooms. In some scenarios two detectors are mounted in each room. In those cases they are placed in an optimum way to cover the room in the best possible way. The alarm system is assumed to be using the best available equipment and the system is monitored for errors. In the calculations, the system can fail to detect either because there is an error in the system or if it is closed for maintenance. The non-functioning alarm system can also be regarded as a scenario without an installed fire alarm system.

The alarm system does not only indicate the presence of a fire but gives also an alarm to the staff and patients in the ward. The sounding of the alarm informs the staff that there is a fire in the ward. The staff recognise the alarm signal and make the correct interpretation because they are trained to respond and know the signal from previous training. It is therefore assumed that the signal is correctly interpreted. It is assumed that the alarm signal is possible to detect anywhere in the ward. As mentioned in section 7.2, the reaction time is normally distributed N(10, 3) seconds.

The model Detact-t2, Evans and Stroup (1985), was used to calculate detection times for smoke detectors for six different a-values. The Detact-t2 model calculates the activation time for a given fire and detector configuration. It takes the transport time for the smoke to travel from the fire to the detector into account. Using the same technique with regression analysis, as for the equation for time to untenable conditions, an equation was derived calculating the detection time as a function of the fire growth rate, α. The smoke detectors are assumed to behave like heat detectors but with a much faster response. The detectors have the following characteristics, RTI = 0.5 $\sqrt{m*s}$, activation temperature = 25 ° C. These data are chosen from the work in reviewing the Draft British Standard Code of Practice for The Application of Fire Safety Engineering Principles to Fire Safety in Buildings, Magnusson (1996). In the event tree there are branches distinguishing scenarios with one or two detectors in a patient room. This gives two equations;

one detector:	$D=20.6 \cdot a^{-0.31}$ seconds	(14)
two detectors:	$D=18.5 \cdot a^{-0.31}$ seconds.	(15)

The event that no smoke detectors are installed or working must also be addressed. The detection of the fire must in this case be done by someone observing the fire and alarming the staff on the ward. The manual detection time, t_{Det}, is assumed to be a random variable normally distributed N(150,75) seconds for daytime and with the parameters N(180,75) seconds for night-time. These two distributions are chosen purely by judgement. The night-time distribution results in longer detection times as the number of staff is less than during the day. Fewer persons able to observe the fire is therefore the reason for this longer time.

The reliability that an automatic fire detection system will work and be able to really detect a fire is assumed to correspond to a probability of operation of 0.95 if it is well maintained, according to judgement by Blomqvist (1996).

7.8 Model uncertainty

The ideal model would predict the reality without any deviation. However, limitations and simplifications are some factors which results in a deviation between the model result and the reality. Two computer models have been used in this study. CFAST is used for the prediction of the time available for evacuation or the time to untenable conditions. The other model is Detact-t2 for the prediction of activation times for detectors and sprinkler heads. There is a difference in result between the computer model and experiments. A model uncertainty factor has therefore been introduced. In a study by Bragason (1994) comparing CFAST results with experiments, the factor for time to untenable conditions, can be derived as a normal distribution with the following parameters N(1.35,0.11). In this variable the error of the regression equation is included. This error originates from deviations between the calculated CFAST results and the regression equation. Actually this error is much lower than the error between the calculations by CFAST and the experiments. The standard deviation between the experiments and CFAST calculations is also 0.11.

The model uncertainty for Detact-t2 is unknown. Activation time in a real room is very much depending on the configuration in the ceiling and other obstructions in the upper part of the room. The calculated detection times are then assumed to follow the theoretical relations in Detact-t2 without any correction, which probably is on the unsafe side.

7.9 Movement time

As two different evacuation situations are addressed, two simple equations will be used to describe the movement. The evacuation takes place from

- the patient room to the corridor and from
- the corridor to a safe place outside the ward.

Those two situations are treated separately in order to obtain a safety measure for both of them, i.e. a reliability index for the patient room and another reliability index for the corridor. The evacuation from the patient room can be derived using the following equation

$$E = t_{StafM} + t_{Care} \cdot (PatInRm / StafInRm). \qquad (16)$$

First after the staff have responded to the alarm, they move towards the patients during the time period, t_{StafM}. The time spent in moving patients out from the room is determined by the second part of equation 16. The variables PatInRm and StafInRm are indicating the number of patients and staff in the patient room during evacuation. The movement time is depending on the ratio of number of patient and staff and the time to prepare each patient before movement, t_{Care}. The reliability of the patient room evacuation is investigated by changing the number of staff in the room, StafInRm.

Evacuation of the corridor is similar. In that case the whole ward should be evacuated. The expression for is

$$E_{corr} = t_{StafM} + (t_{Care} + t_{PatM}) \cdot (NoPat / NoStaf). \qquad (17)$$

The time needed per patient is now the sum of the preparation time, t_{Care}, and the movement time to the safe place, t_{PatM}. The number of patients on the ward, NoPat is always 30 patients. The reliability of the corridor evacuation is investigated by changing the number of staff on the ward, NoStaf. The variations in the physical capabilities of the patients is considered in the preparation time, t_{Care} and the patient movement time, t_{PatM} according to table 3 in section 7.2.

8 Result and conclusion

The general limit state function for the risk calculations is

$$G = S \cdot U_s - D - R - E \text{ (or } E_{corr}\text{)} \qquad (4)$$

S =	time to untenable conditions (calculated)
U_s =	model uncertainty factor for CFAST (basic variable)
D =	detection time (basic variable t_{Det} or calculated)
R =	reaction and response of the staff (basic variable)
E =	movement time for patient room (calculated)
E_{corr} =	movement time for corridor (calculated).

The limit state function is the main equation used for all the final scenarios in the event tree but with different basic variables and equations describing the situations. All the resulting b-values from the scenarios are presented in figures B1 to B18 in appendix B. In the event tree (in appendix A), two columns with graph names are shown. The first column indicates the results for the patient room and the second column, for the corridor.

All the figures are presenting the β-value for different number of staff. Note that, in the calculations, the number of patients in a room is always six. Other patient/staff ratios can be obtained from the graphs, as for example, six patients and two staff are equal to three patients and one staff. The b-values for the patient room are with regard to the number of staff in the patient room. For the corridor results, the numbers on the x-axis indicates the number of staff in the whole ward.

It should also be noted that the presented β-values in these figures indicate the reliability on the condition that all the events indicated in the event tree have happened. This means that the branch probabilities have not been included in the presented β-values in the figures in appendix B.

The importance of the basic variables is calculated for some of the scenarios. The importance measure used is the direction cosine for each basic variable which indicates the direction of the vector β in the standardised space. The vector β is directed as defined by equation 18. The direction cosines, in the vector $\vec{a}_i$, are results from the FOSM (or SOSM) method. The direction cosines can vary between -1 to 1 and are subjected to the condition described by equation 19.

$$\vec{x}_i' = -\vec{a}_i \cdot \beta \qquad (18)$$

$$\sum_{i=1}^{n} a_i^2 = 1 \qquad (19)$$

where a_i indicates the different direction cosines and n is the number of basic variables in the limit state function. A high value of $|a|$ indicates a high importance for the basic variable. The scenarios are indicated in the figures with their names according to the event tree and the number of staff indicated between brackets. The scenario A43(5) defines room scenario 4 with patient category 3, with 5 staff present and evacuation during the day. The capital letter C indicates corridor, F indicates a higher mean value of the fire growth rate and T indicates a higher tenability limit.

8.1 Basic scenarios

The figures B1 to B18 presents the resulting b-curves so that all the six basic room and corridor scenarios, are shown in one figure having the same parameter values on the variables t_{Care} and t_{PatM}. The basic scenario is the one ending after the 'Door to patient room' option, see figure 3. It is clearly observable that the b-value is increasing with increasing number of staff. This indicates an increased safety level and reduced probability of failure of the evacuation system. For the scenarios where the detection system fails, this increase is not that clear. This has to do with the importance of the variable t_{Det} which is used as detection time in the scenarios with failing alarm, see figure B19-B21. The variable t_{Det} has a rather high importance in the determination of the β-value at the design point and the mean value is also higher than the calculated detection time for an automatic detection system. Using the design point value for a, in calculating the detection time for the smoke detectors, results in 105 seconds. This should be compared to the mean value of t_{Det} which is 150 seconds during the day. Also, the detection system affects the level of safety, which is considerably higher when the system is working.

Generally, the most important basic variable is the fire growth rate. Only in a few cases, other variables will have a higher significance on the β-value than the fire growth rate. Those cases are characterised by having only a few staff present, and patients demanding much help in evacuating, see scenario A33C(5) in figure B19. The significance of the fire growth rate is also decreased by specifying a higher mean value of this basic variable, i.e. having a faster fire growth rate. In these cases the patient related factor t_{PatM} will be more important. This trend will be further emphasised if the number of staff decreases, A31C(5) - A33C(5), A31C(10) - A33C(10) and A31CF(10) - A33CF(10) in figure B19.

The difference in safety level in the patient room is not too much depending on the opening conditions of the door to the corridor. The two equations describing the variable S, time to untenable conditions, are quite similar. However, if the door is kept open during the evacuation, the safety in the corridor will be drastically affected. Smoke will enter and eventually create untenable conditions in the corridor, increasing the difficulties in evacuating the other patients.

The importance of the time needed to prepare a patient for evacuation, t_{Care}, is less when the number of staff is increased. This is rather obvious but can be seen in comparing the scenarios A31(1) and A31(5) in figure B19. This means that the patient category will affect the safety level less, if the number of staff is higher. Similarly, looking at the conditions in the corridor the importance of t_{PatM} will decrease and t_{StafM} will increase as the number of staff on the ward increases from 5 to 10. The importance of the other basic variables are almost unaffected.

The figures B22-B24 show the differences in having one or two detectors in the patient room. The scenarios studied are otherwise having the same conditions and it is assumed that the fire occurs during the night. It is clear that the detection time is decreased by having an extra detector installed in each room. This results is a small improvement of the reliability index but the difference is small compared to the difference between a operating and non-operating detection system. The difference in reliability index is assumed to be less during day conditions because the similar importance of the basic variable a.

Figures B25-B30 show how the reliability index is varying for one scenario but with different patient characteristics. Only results from the first branch alternative A is presented.

8.2 Parameter study

Comparing calculations using different distributions of the random variables gives of course different results. Increasing the mean value of the basic variable a to log-normal(0.01,0.01) kW/s^2 will decrease the resulting b-value, figure B31-B33. Similarly using the higher tenability limits in deriving the regression equation for the time to untenable conditions will result in an increasing β-value, figure B34. The importance of the basic variables are also affected as discussed in the previous section.

8.3 The validity of the method

The risk method i.e. the β-method, has been used for almost 20 years in the area of structural engineering. This is one of the first attempts made to treat even person safety by the same method. Two other examples where the method has been used can be found in Magnusson et al. (1994) and Magnusson et al. (1995). The method has been proven to result in a consistent reliability independent on how the limit state function is formulated, see section 5.2. The method can be further used to derive safety factors or partial coefficients valid for a class of buildings, Frantzich et al. (1996) and NKB (1978). The procedure is to minimise the difference between a target β-value and the β-values for the scenarios in the class.

The advantage with the method is that it provides the design point, apart from the reliability index. The design point is a combination of values representing the basic variables that when used will lead to the desired reliability expressed as the β-value. In this report the information about the design point is never used.

The most obvious disadvantage is that the method does not provide information about the appearance of the distribution calculated by the limit state function. This information must be used to predict the risk to the society accurately. This can be achieved by using numerical sampling methods to calculate the evacuation time margin. A comparison between the two methods will be presented in a later report.

Finally, the procedure presented in this report describes a method that can be used to calculate the reliability of safety expressed as the ability to evacuate safely from a building in the case of a fire.

9 Acceptable risk

What is the acceptable risk level? This is a question that is most difficult to give a single answer. The acceptable risk is dependant to facts such as if the event is performed voluntarily or not and to public opinion. In Vrijling (1995), acceptable levels of risk is proposed from both individual and societal point of view. The work is focusing on the Dutch situation and general failure events. They discuss both the present Dutch regulations and a new approach to the acceptable risk measure. The individual risk of dying in an accident per year should not be exceeding

$$p_{fi} = C_{vol} \cdot 10^{-4}$$

where C_{vol} is the policy factor expressing the degree of voluntariness with which the activity is undertaken and with the benefit perceived. The factor ranges from 10 in the case of complete freedom of choice like mountainclimbing to 0.01 in the cases where the action cannot be controlled. The risk on the national level is derived in the same manner but includes a measure of the number of exposed persons. These two risk levels are including the probability that the event will take place, i.e. the initial probability.

To be able to compare the risk level for health care facilities, the probability of the event has to be considered as well as the probability of failure in the final scenarios. The individual risk can be calculated by combining those two for each scenario. But, as many of the probabilities in the event tree are uncertain and the risk comparison is outside the scope of the report only an example will be provided showing the methodology. The individual risk for the scenario will be compared to the Dutch proposed acceptable level.

Consider the final scenario A31 with 4 staff present in the patient room. The reliability index for this final scenario is according to figure B1 equal to 1.75. This corresponds to a probability of failure of 0.0401, derived by using equation 6. Assuming that the fire on the ward starts during the day and no staff are able to extinguish it the probability of the event is $0.07 \cdot 0.67 \cdot 0.05 = 0.0023$ per year. The numbers used are probabilities for the start of the fire, the condition that it occurs during the day and that the staff are unable to extinguish it. The values are chosen according to the previous discussion in sections 6.1 and 6.2. The total individual risk is equal to $0.0401 \cdot 0.0023 = 0.94 \cdot 10^{-4}$ per year. This value can be compared to the acceptable risk according to the Dutch level. Using a policy factor of 1 leads to acceptance of the risk. The acceptable level is, however, very sensitive to the chosen policy factor. Using a lower policy factor or decreasing the number of staff results in a unacceptable risk.
The risk in health care facilities should perhaps be compared to the present safety level in those premises. The present risk level could be used as a indication of acceptable level. The problem is that much of the data are lacking. It is not possible, on a national level in Sweden, to determine the actual safety level on an average. A rough estimate of the required reliability index for a scenario can be derived for dwellings. The number of fires in dwellings are collected on a national basis. In 1993, 11 370 fires occurred in dwellings, SRV (1994). From the same source 575 persons were killed or injured due to fires in the whole country. Assume that half of those

were harmed in dwelling fires. The probability of getting hurt or die due to a fire in a dwelling during a year is

$$\frac{575}{2 \cdot 11\,370} = 25.3 \cdot 10^{-3}$$

The condition is that a fire has started and not been extinguished. With this value the corresponding reliability index β can be derived as equal to 1.95. This value could be compared to the final scenario b-values for dwellings.

For health care facilities this information is not accessible, but the value for dwellings gives a hint on the magnitude of the b-value. It is, however, not possible to say if it is higher or lower than the rough value for dwellings.

It must be one of the important matters for the future work to evaluate the average national reliability index for health care facilities. This work must address all uncertainty variables in the design process and assign them with accurate values and information about the uncertainty.

10 Limitations

The calculations are subjected to a number of limitations.

The calculations will be limited to one health care ward. The effects on other places in the building due to a fire in the specific ward has not been discussed.

The spread of fire is limited to the room of origin. This means that spread of smoke or fire through the ventilation ducts or from one floor to another are neglected. It is also assumed that the walls within the ward will withstand the fire and smoke at least as long as the room in occupied.

The fire is only treated as a growing fire. Objects in a patient room may result in other heat release rate curves. This is a simplification but some experiments are validating this assumption. The use of sprinkler system is limited to only influence patient safety. Therefore no benefits resulting from this installation can be observed. Of course the fire will be affected by the sprinkler but that will happen later in the sequence when the patients are in safety. The sprinkler will make it easier to control the fire and perhaps also extinguish it. The damage cost will probably be lower and the ward can be used more quickly again after a fire. This period in the fire event is not addressed.

The evacuation is treated rather simple with the same patient treatment of all patient rooms. The patients all have the same characteristics in a single calculation run and the deviations comes from the number of different calculations. The conditions of the patients are still subjected to uncertainty.

The reliability index for the patient room assumes that the patients are in relative safety when they have reached the corridor. The b-value therefore indicates the safety of the patients in the fire room only.

The time to untenable conditions and the detection time are, in the reliability calculations, derived by using response equations. This means that the actual computer output from the two programs, CFAST and Detact-t2, have been fitted to an equation with the fire growth factor as the varying parameter. The fitting is done by the method of least squares. There will, inevitable, be a difference between the fitted responses from the equation and the actual computer output. This means that the actual times calculated with the computer programs will be approximated by the response equation. The error between the output and the equation is minimised, but it exists and contributes to the overall uncertainty. As only one varying parameter is used in the response equation the error is small.

The location of the fire is constant throughout all the calculations. This means that different evacuation strategies have not been investigated. If the fire should occur in a room in the middle of the corridor another evacuation procedure would have been needed. The stair, close to the fire room, would have been forced to be used with more problem as a result. Also, the fire only occurs in a patient room. Other scenarios where the fire is located in the corridor could have been investigated. The result from the computer simulations can, however, be used also for this scenario. A fire in a room connected to the corridor without a door separating the two rooms, can be assumed to result in almost the same conditions as the used fire on the condition that the door is kept open.

The method used to calculate risk or evacuation reliability is also subjected to some limitations. The result from this calculation is only one value, the β-value. No information is available of how the resulting distribution of the evacuation margin will appear. By calculating the probability of an unsuccessful evacuation it is assumed that the margin is normally distributed. For many cases this is a good approximation, i.e. when the probability is small. In many cases the probability of unsuccessful evacuation is relative large, above app. 20 % (β=0.8) for the basic case. Large deviations from the normal distribution can then be expected. However, as the variables in the limit state function are summarised the margin will tend to look like a normal distribution. The actual shape of the margin distributions have not been investigated.

By including also the branch probabilities the error in approximating the margin with the normal distribution is reduced. This is the reason for still being confident in the results even with low b-values for the basic scenarios.

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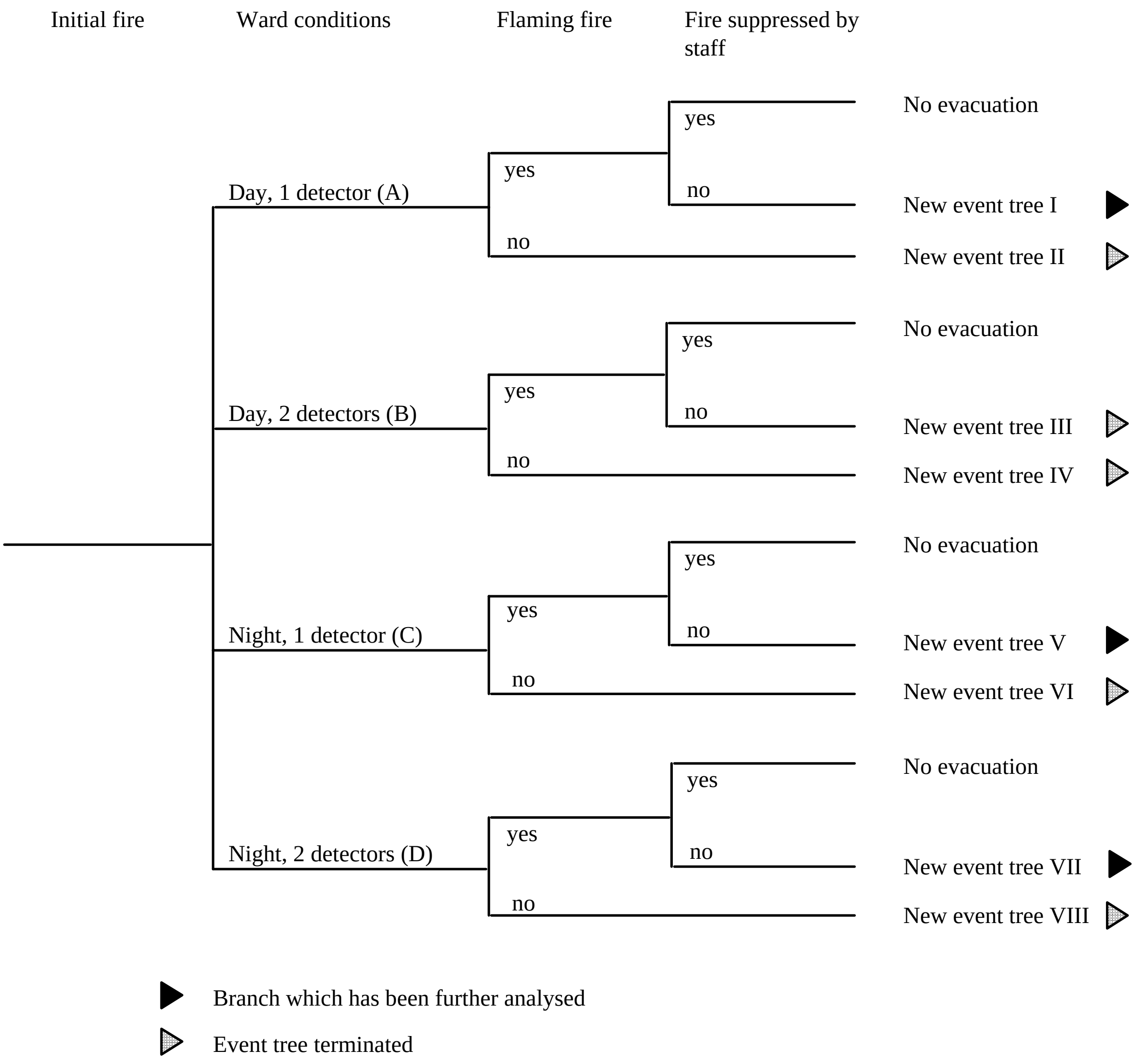
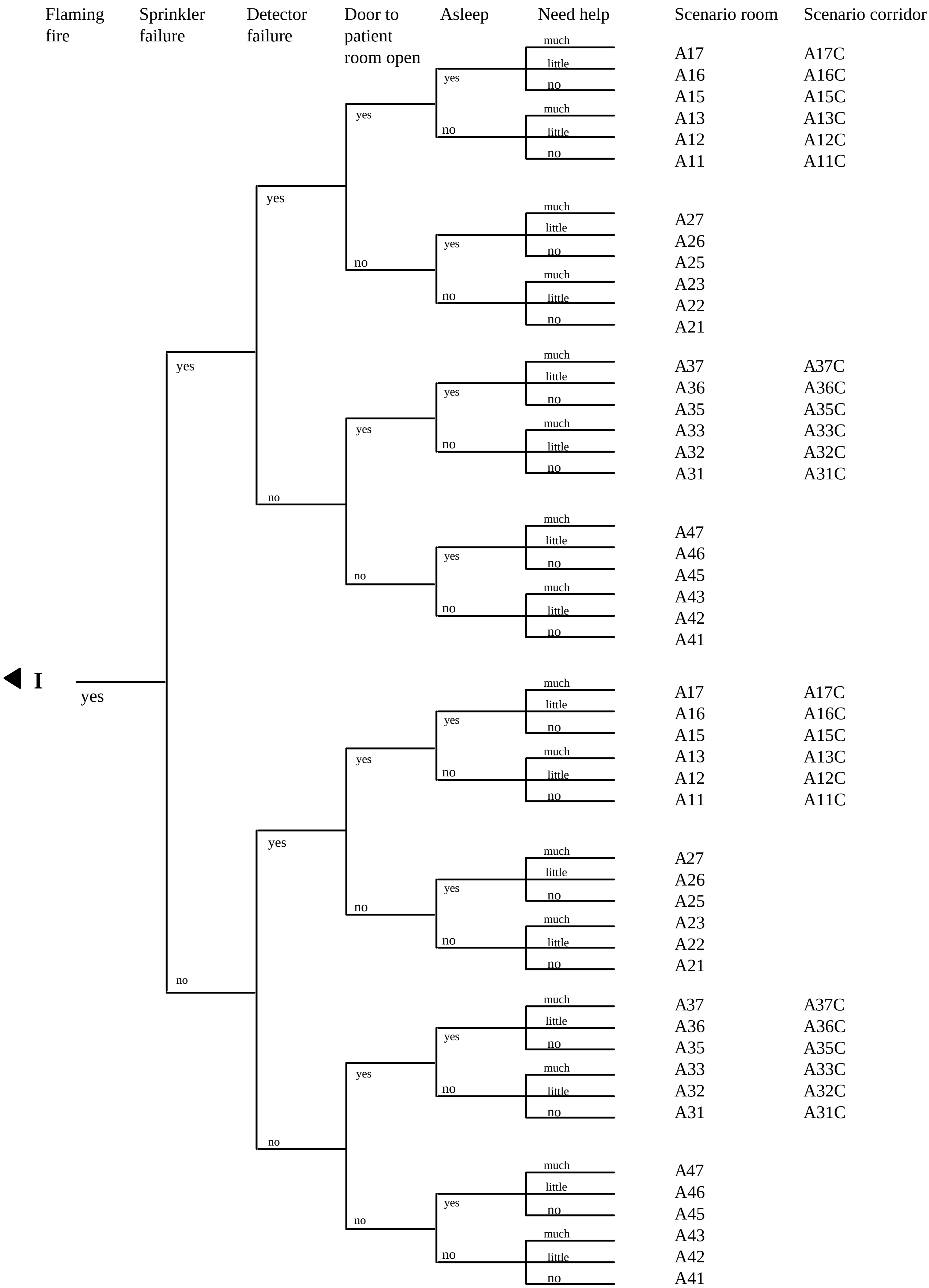
Appendix A. Four figures illustrating the event tree used for the calculations.



The roman numbers I - VIII have been used to connect this figure to the continuing events in the following figures in this appendix.


Flaming fire
Sprinkler failure
Detector failure
Door to patient room open
Asleep
Need help
Scenario room
Scenario corridor
I
yes
yes
no
yes
no
yes
no
yes
no
yes
no
much
little
no
A17
A16
A15
A13
A12
A11
A27
A26
A25
A23
A22
A21
A37
A36
A35
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A42
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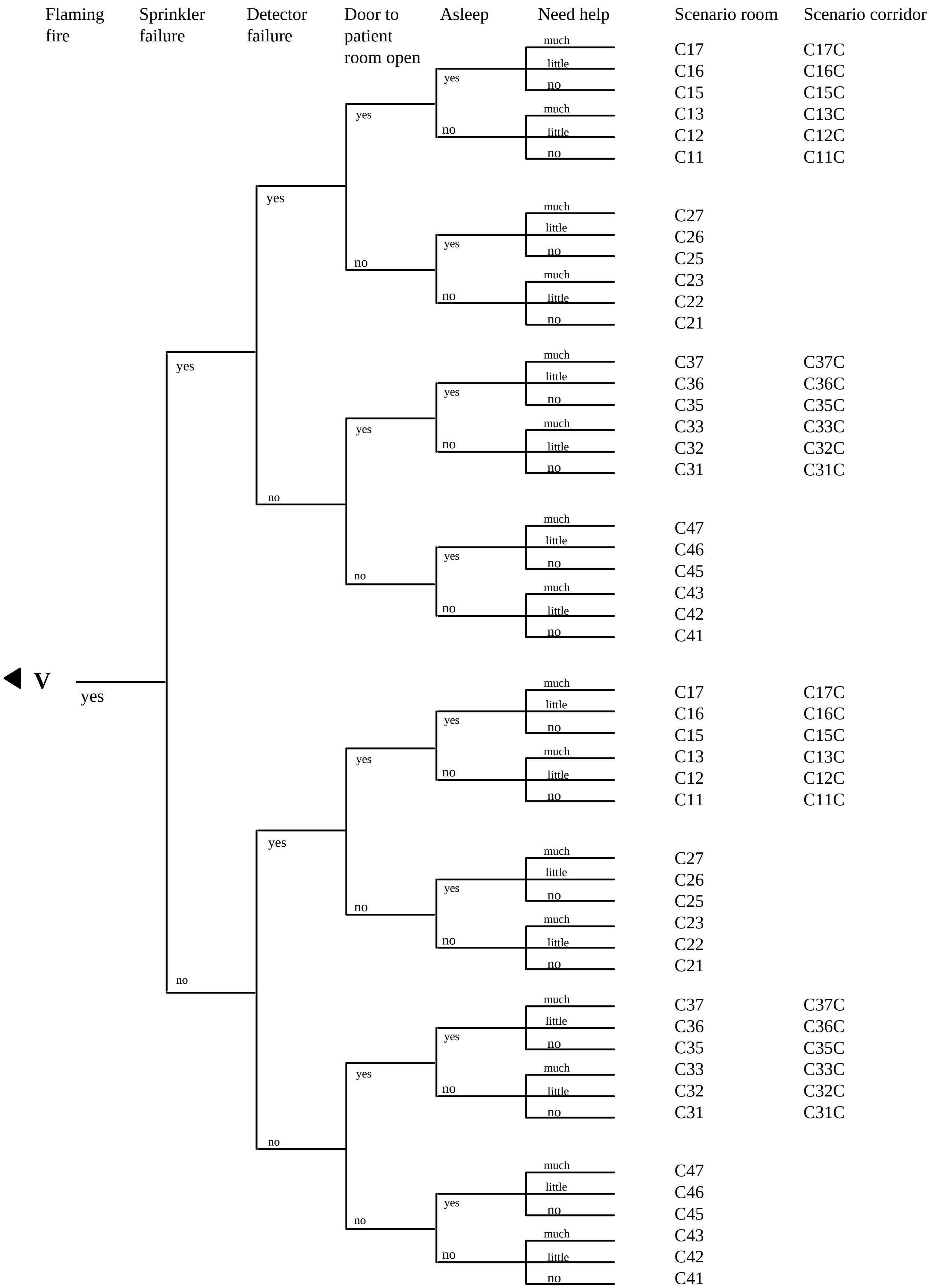
A33C
A32C
A31C



Flaming fire
Sprinkler failure
Detector failure
Door to patient room open
Asleep
Need help
Scenario room
Scenario corridor
V
yes
yes
no
much
little
no
C17 C17C
C16 C16C
C15 C15C
C13 C13C
C12 C12C
C11 C11C
C27
C26
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C23
C22
C21
C37 C37C
C36 C36C
C35 C35C
C33 C33C
C32 C32C
C31 C31C
C47
C46
C45
C43
C42
C41
C17 C17C
C16 C16C
C15 C15C
C13 C13C
C12 C12C
C11 C11C
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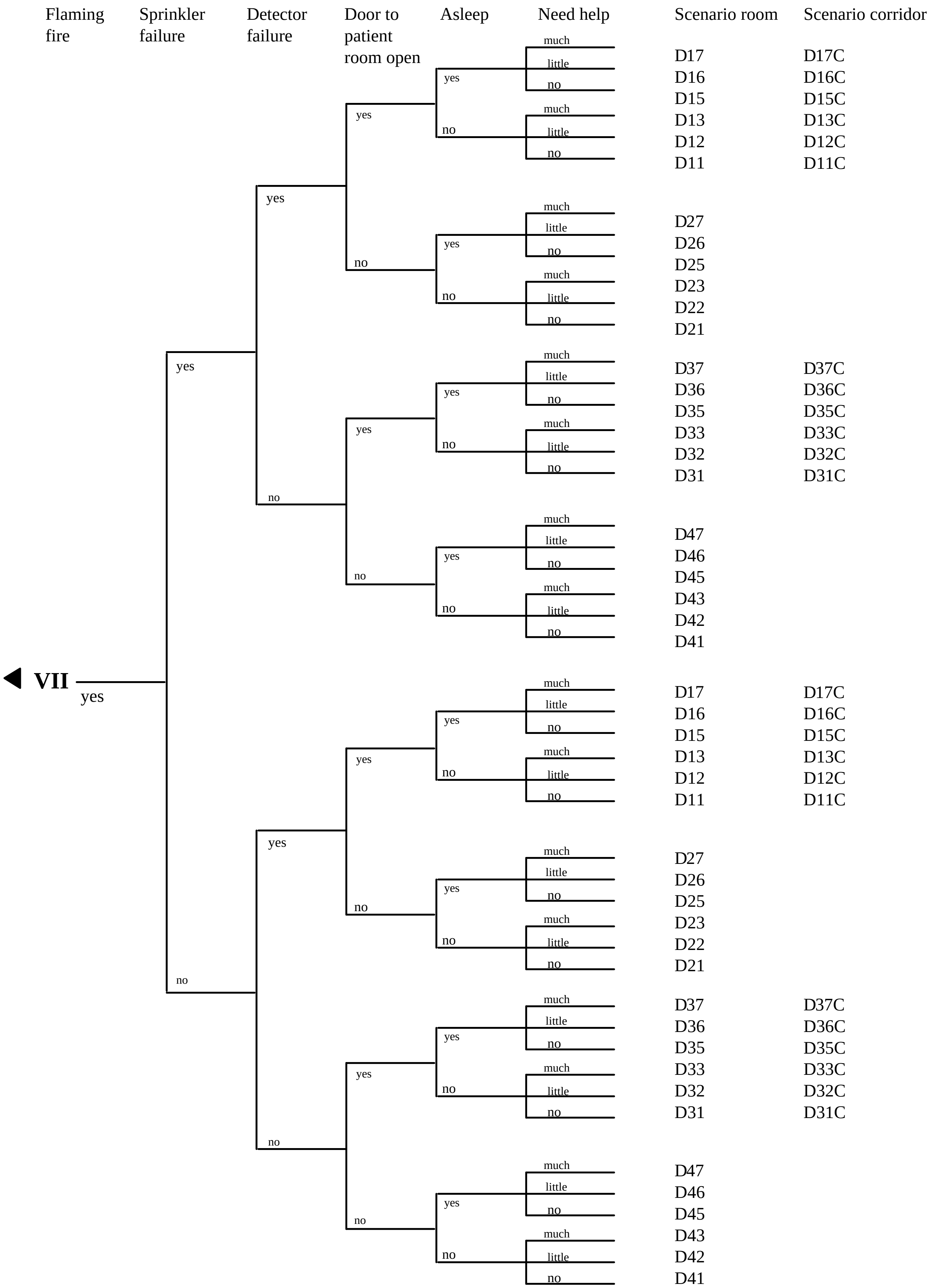

Flaming fire
Sprinkler failure
Detector failure
Door to patient room open
Asleep
Need help
Scenario room
Scenario corridor
VII
yes
yes
no
much
little
D17 D17C
D16 D16C
D15 D15C
D13 D13C
D12 D12C
D11 D11C
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D25
D23
D22
D21
D37 D37C
D36 D36C
D35 D35C
D33 D33C
D32 D32C
D31 D31C
D47
D46
D45
D43
D42
D41
D17 D17C
D16 D16C
D15 D15C
D13 D13C
D12 D12C
D11 D11C
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D37 D37C
D36 D36C
D35 D35C
D33 D33C
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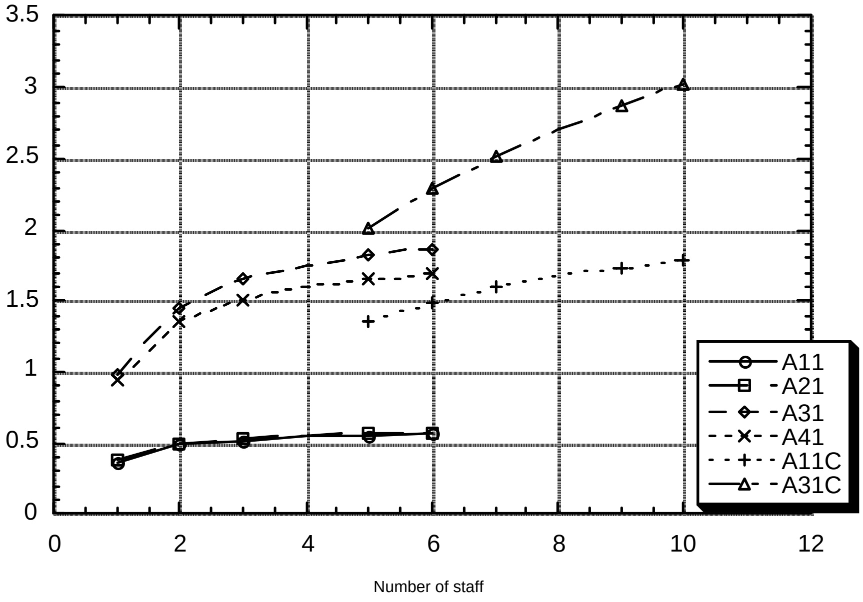
D41

Appendix B. Figures showing the reliability index β for the limit state function for the scenarios in the event tree.



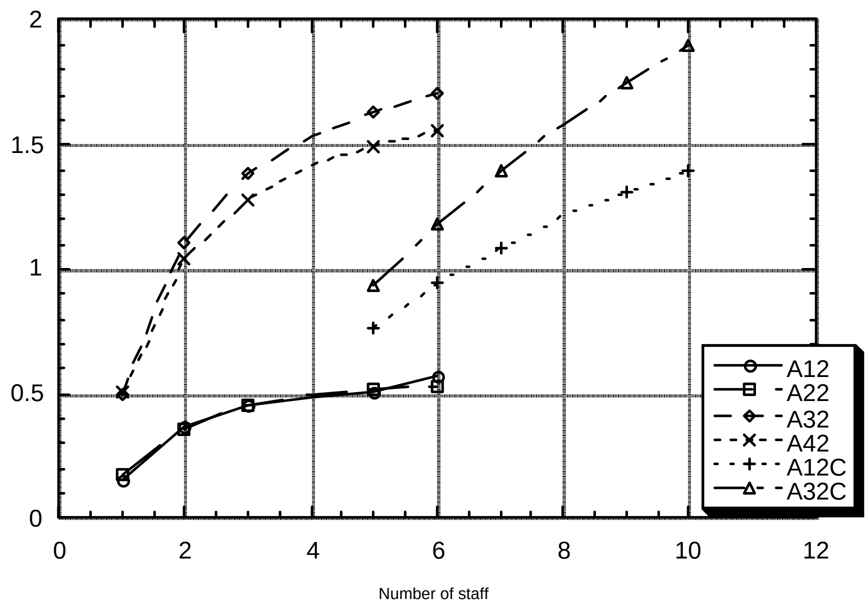
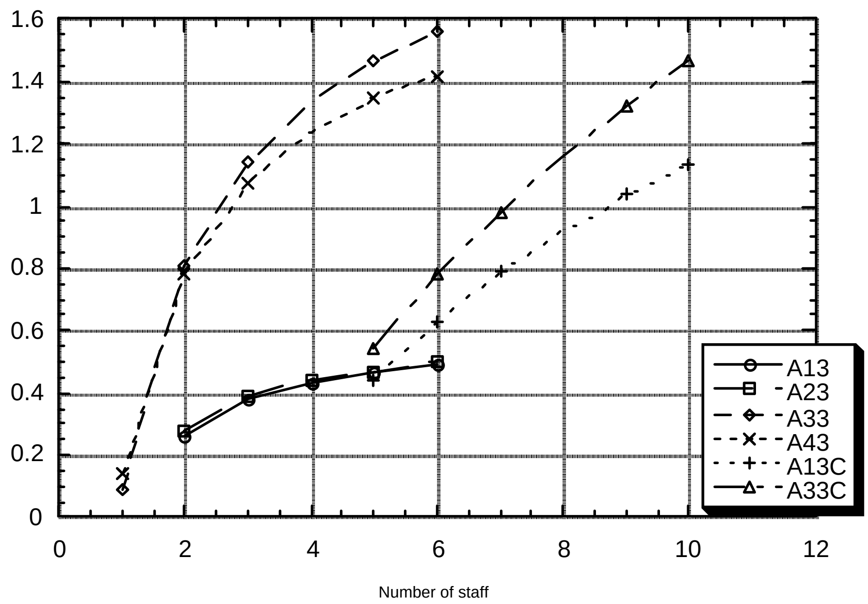


Figure B1 and B2. Branch alternative A and patient categories 1 and 2.



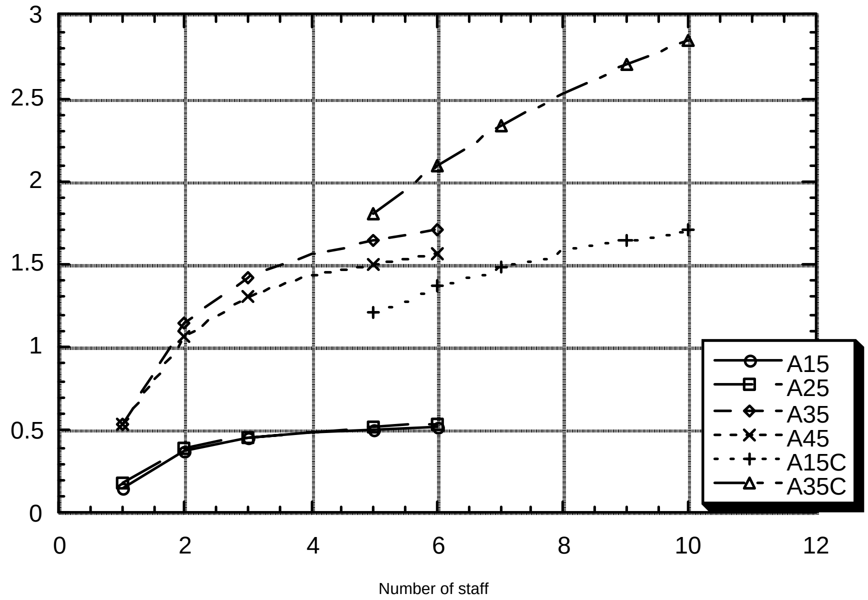
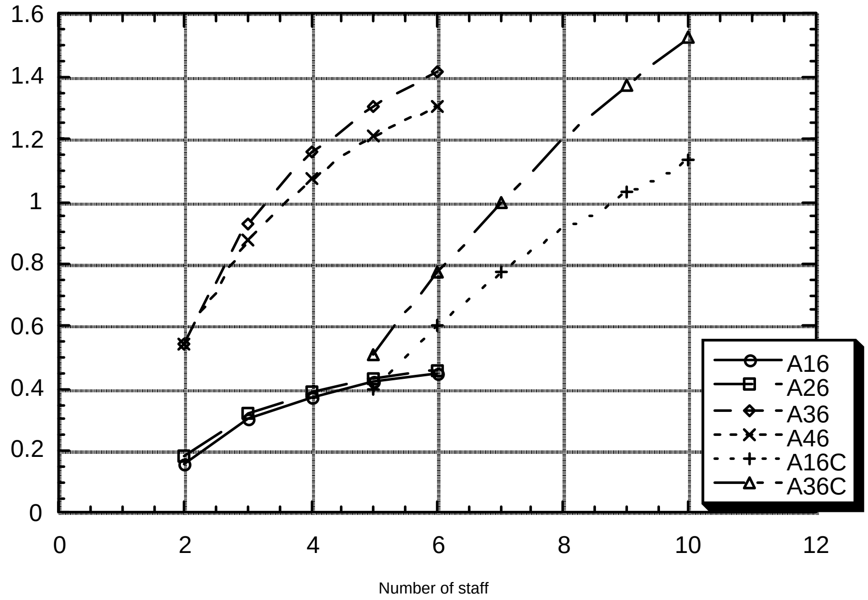


Figure B3 and B4. Branch alternative A and patient categories 3 and 5.



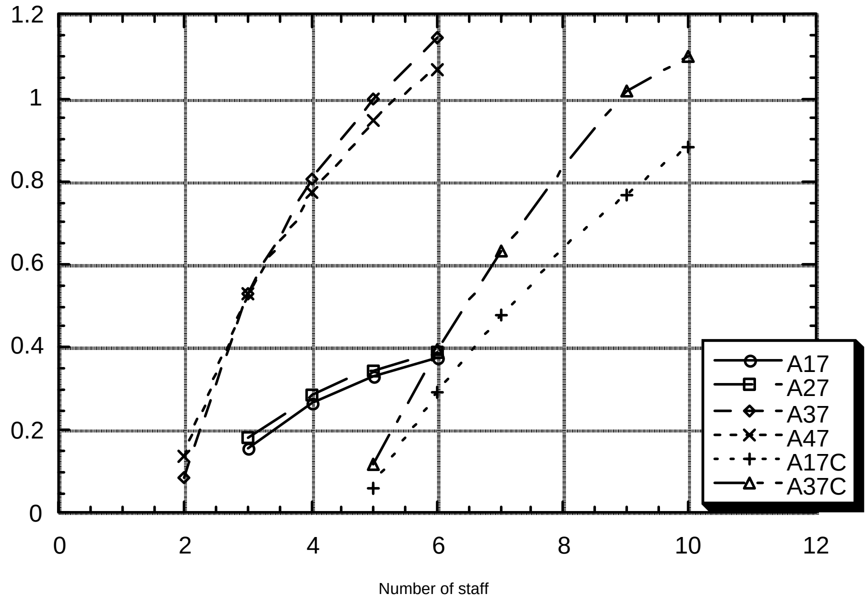
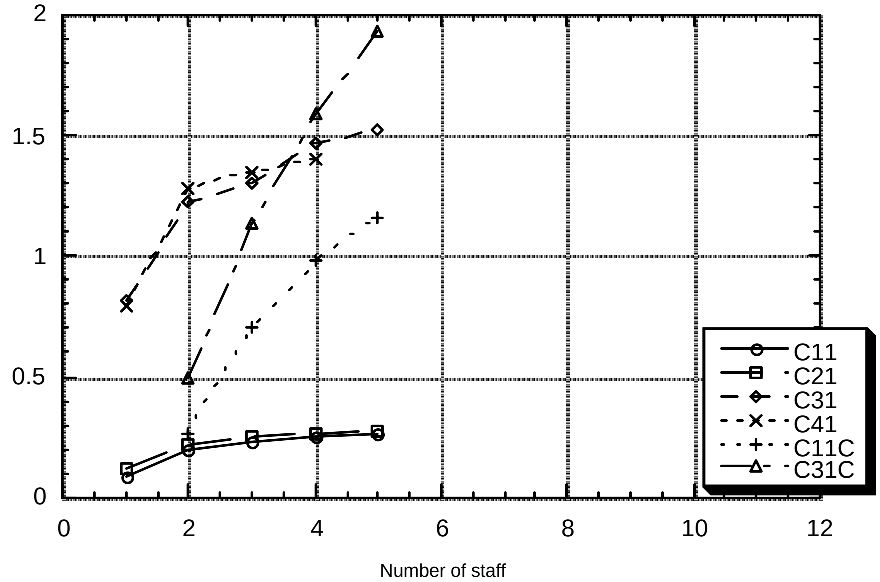


Figure B5 and B6. Branch alternative A and patient categories 6 and 7.



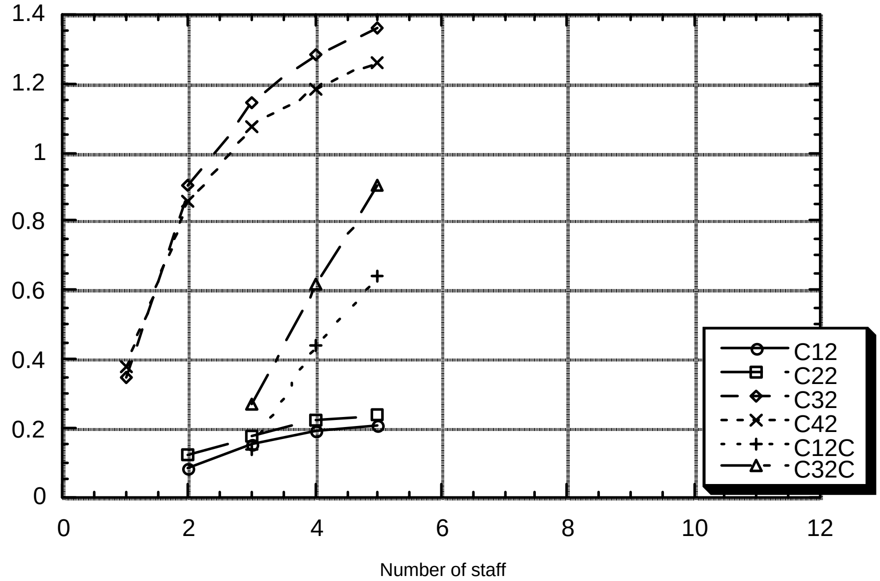
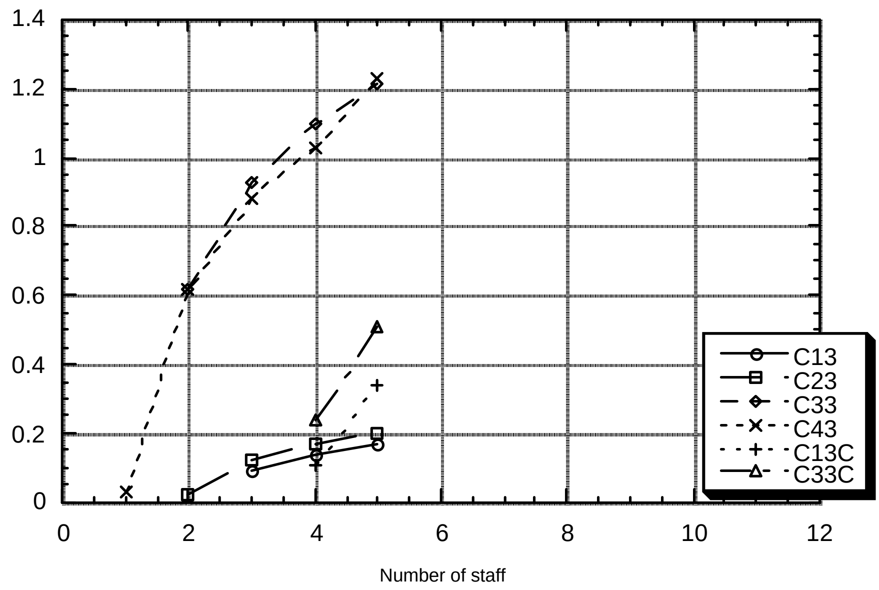


Figure B7 and B8. Branch alternative C and patient categories 1 and 2.



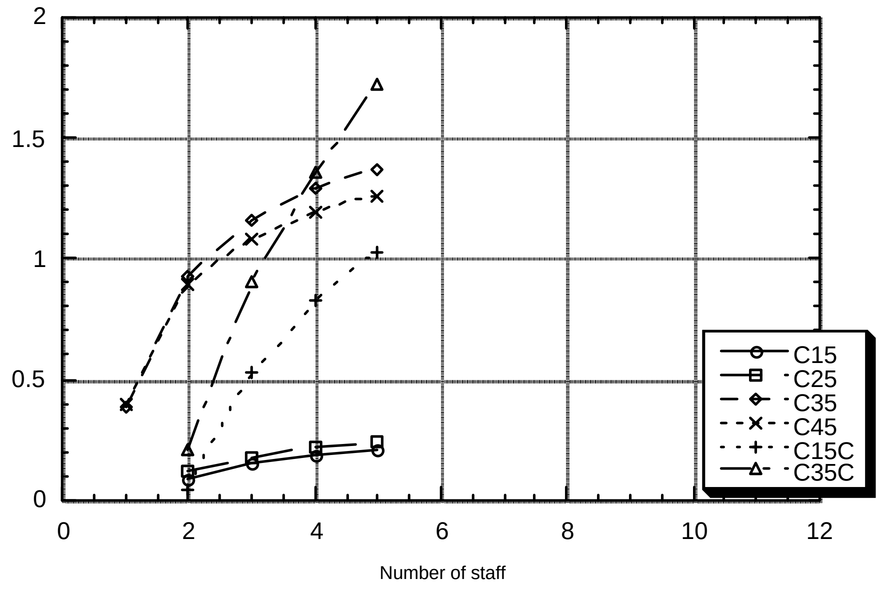
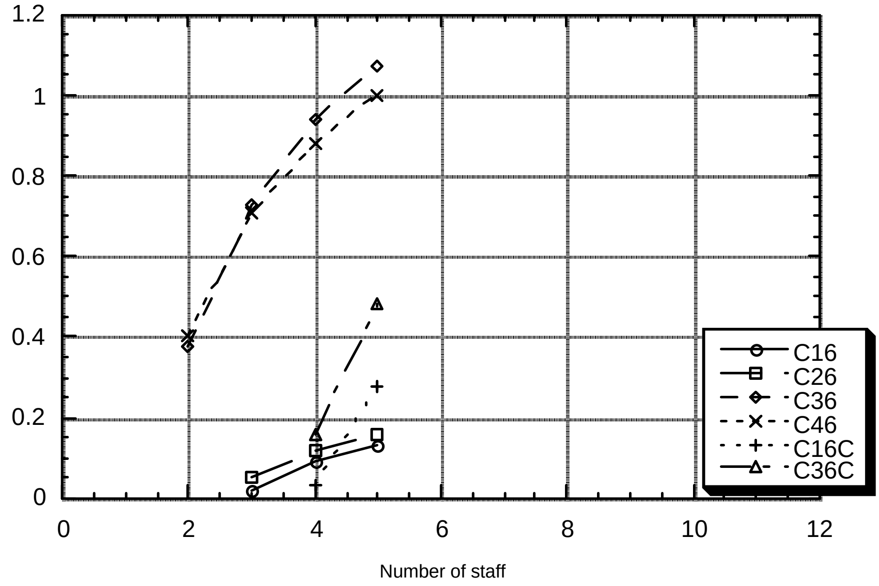


Figure B9 and B10. Branch alternative C and patient categories 3 and 5.



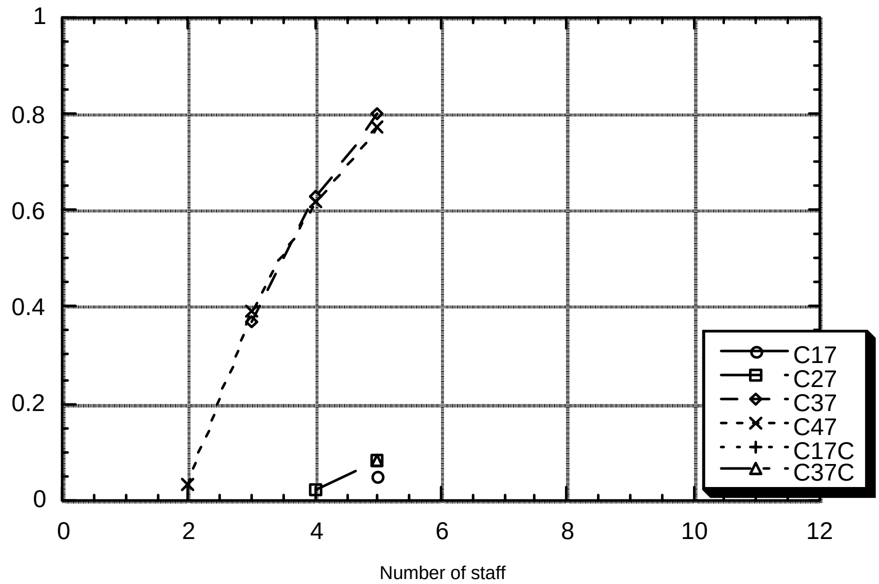
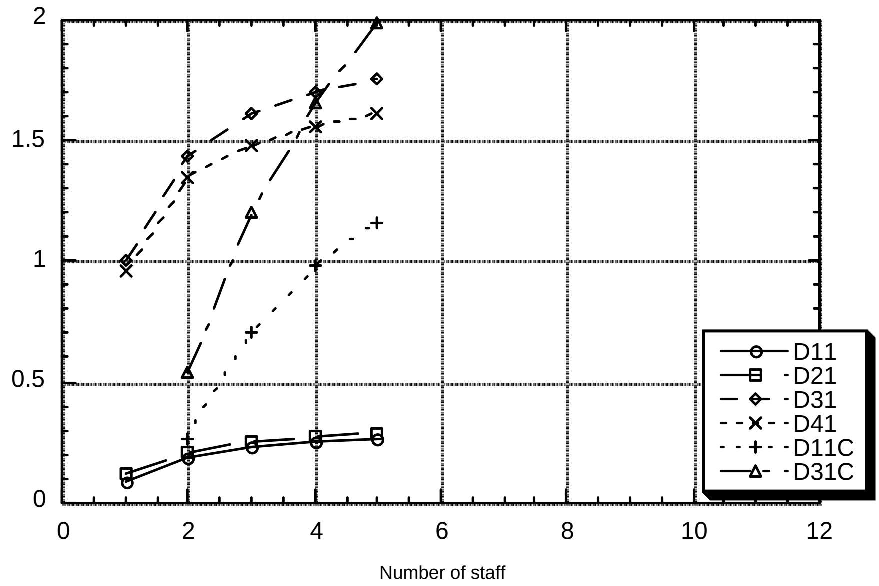
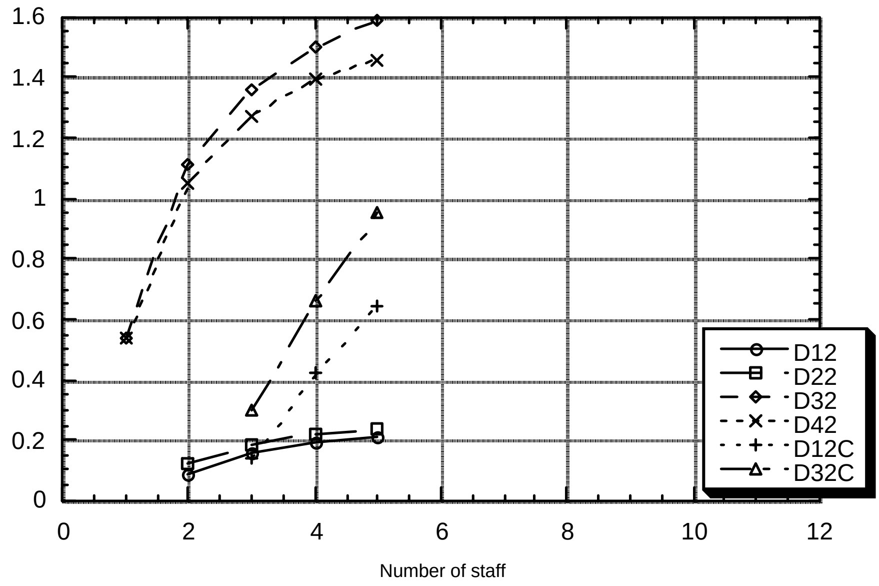


Figure B11 and B12. Branch alternative C and patient categories 6 and 7.

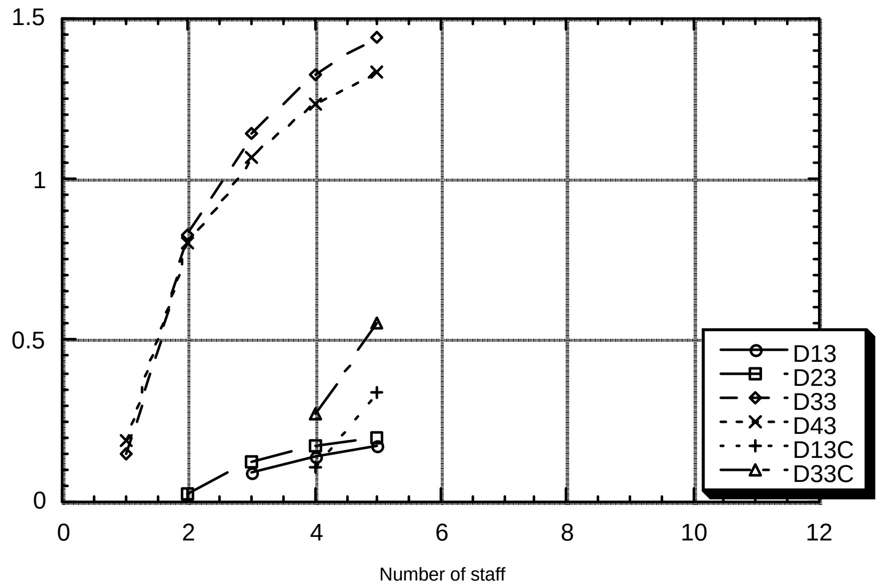


2
1.5
1
0.5
0
0
2
4
6
8
10
12
Number of staff
D11
D21
D31
D41
D11C
D31C



1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Number of staff
D12
D22
D32
D42
D12C
D32C

Figure B13 and B14. Branch alternative D and patient categories 1 and 2.



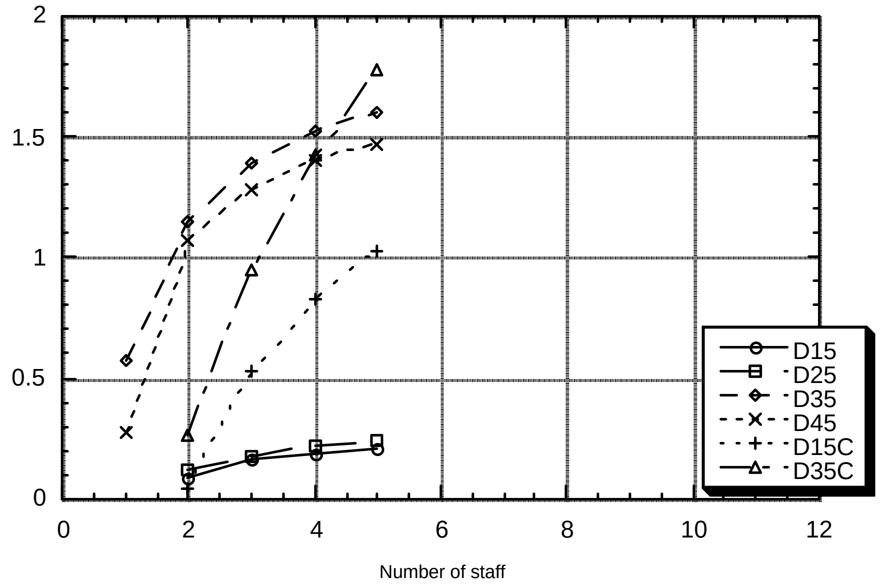
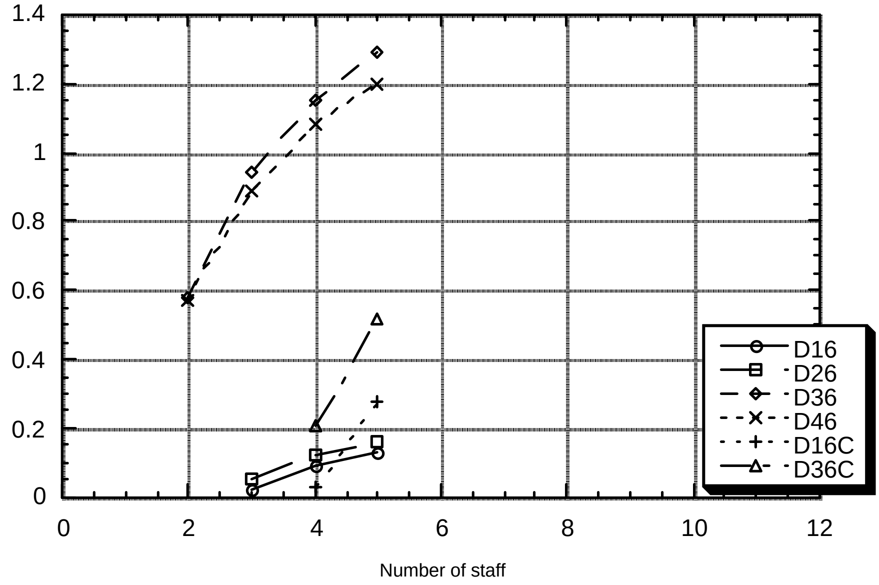


Figure B15 and B16. Branch alternative D and patient categories 3 and 5.



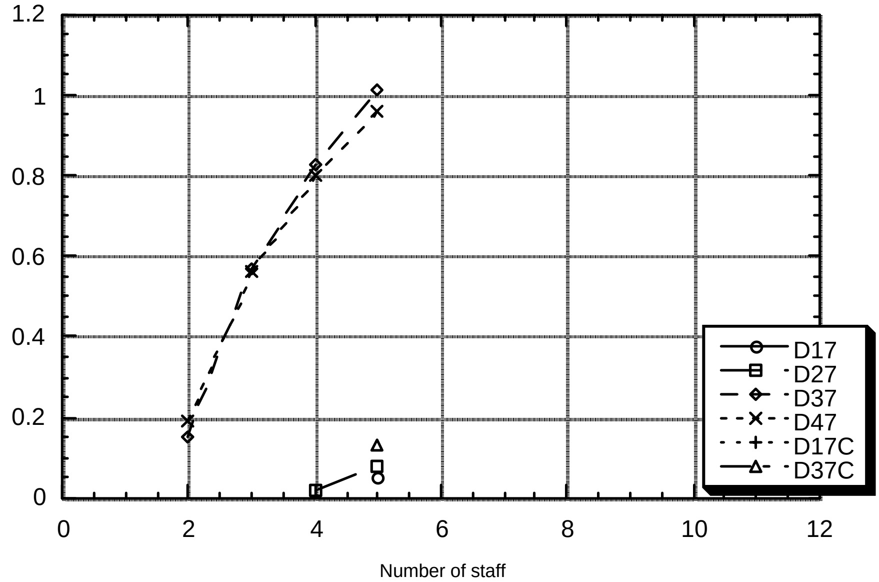


Figure B17 and B18. Branch alternative D and patient categories 6 and 7.

Description of scenarios for the folowing importance-data figures

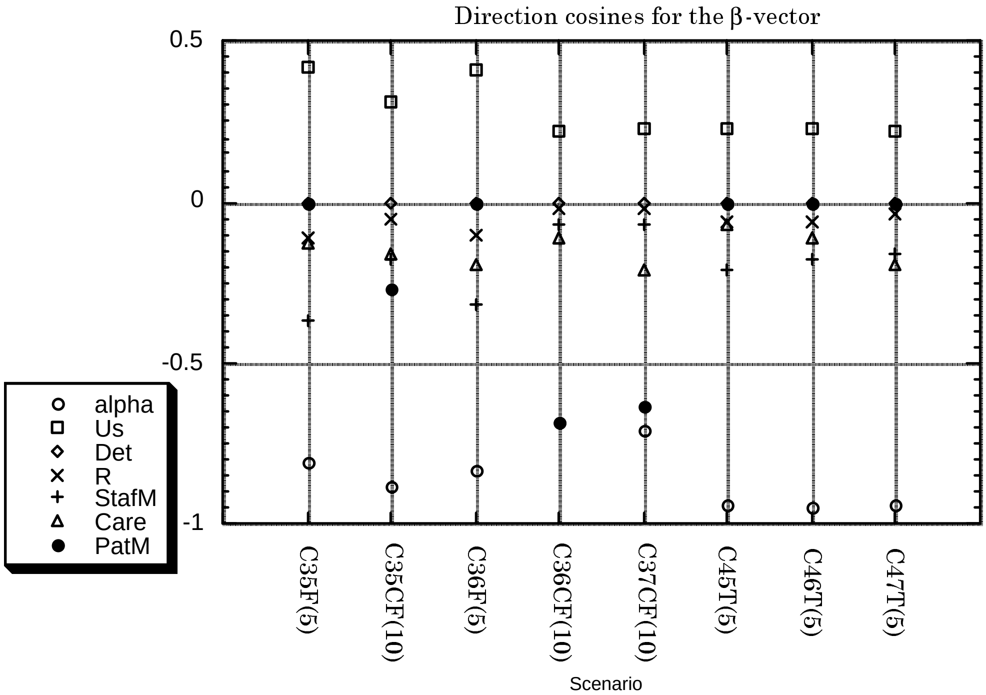
A31(1)	Room, day, alarm, open door, 1 staff, pat. cat. 1
A32(1)	Room, day, alarm, open door, 1 staff, pat. cat. 2
A33(1)	Room, day, alarm, open door, 1 staff, pat. cat. 3
A31(5)	Room, day, alarm, open door, 5 staff, pat. cat. 1
A32(5)	Room, day, alarm, open door, 5 staff, pat. cat. 2
A33(5)	Room, day, alarm, open door, 5 staff, pat. cat. 3
A31C(5)	Corridor, day, alarm, open door, 5 staff, pat. cat. 1
A32C(5)	Corridor, day, alarm, open door, 5 staff, pat. cat. 2
A33C(5)	Corridor, day, alarm, open door, 5 staff, pat. cat. 3
A31C(10)	Corridor, day, alarm, open door, 10 staff, pat. cat. 1
A32C(10)	Corridor, day, alarm, open door, 10 staff, pat. cat. 2
A33C(10)	Corridor, day, alarm, open door, 10 staff, pat. cat.3
A11(5)	Room, day, no alarm, open door, 5 staff, pat. cat. 1
A11C(10)	Corridor, day, no alarm, open door, 10 staff, pat. cat. 1
A31F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 1
A31CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 1
A32F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 2
A32CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 2
A33F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 3
A33CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 3
A35F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 5
A35CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 5
A36F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 6
A36CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 6
A37F(5)	Room, day, alarm, open door, fast fire, 5 staff, pat. cat. 7
A37CF(10)	Corridor, day, alarm, open door, fast fire, 10 staff, pat. cat. 7
A41T(5)	Room, day, alarm, closed door, high tenab. level, 5 staff, pat.cat 1
A42T(5)	Room, day, alarm, closed door, high tenab. level, 5 staff, pat.cat 2
A43T(5)	Room, day, alarm, closed door, high tenab. level, 5 staff, pat.cat 3

C35F(5)	Room, night, alarm, open door, fast fire, 5 staff, pat. cat. 5
C35CF(10)	Corridor, night, alarm, open door, fast fire, 10 staff, pat. cat. 5
C36F(5)	Room, night, alarm, open door, fast fire, 5 staff, pat. cat. 6
C36CF(10)	Corridor, night, alarm, open door, fast fire, 10 staff, pat. cat. 6
C37CF(10)	Corridor, night, alarm, open door, fast fire, 10 staff, pat. cat. 7
C45T(5)	Room, night, alarm, closed door, high tenab. level, 5 staff, pat.cat 5
C46T(5)	Room, night, alarm, closed door, high tenab. level, 5 staff, pat.cat 6
C47T(5)	Room, night, alarm, closed door, high tenab. level, 5 staff, pat.cat 7

D31(1)	Room, night, 2 det. alarm, open door, 1 staff, pat. cat. 1
D35(1)	Room, night, 2 det. alarm, open door, 1 staff, pat. cat. 5

D37(1)	Room, night, 2 det. alarm, open door, 1 staff, pat. cat. 7
D31(5)	Room, night, 2 det. alarm, open door, 5 staff, pat. cat. 1
D35(5)	Room, night, 2 det. alarm, open door, 5 staff, pat. cat. 5
D37(5)	Room, night, 2 det. alarm, open door, 5 staff, pat. cat. 7
D35C(5)	Corridor, night, 2 det. alarm, open door, 5 staff, pat. cat. 5
D37C(5)	Corridor, night, 2 det. alarm, open door, 5 staff, pat. cat. 7
D35C(10)	Corridor, night, 2 det. alarm, open door, 10 staff, pat. cat. 5
D37C(10)	Corridor, night, 2 det. alarm, open door, 10 staff, pat. cat. 7
D15(5)	Room, night, no alarm, open door, 5 staff, pat. cat. 5
D15C(10)	Corridor, night, no alarm, open door, 10 staff, pat. cat. 5

Figure B19. Importance of basic variables in branch alternative A.
(Not available in electronic format)



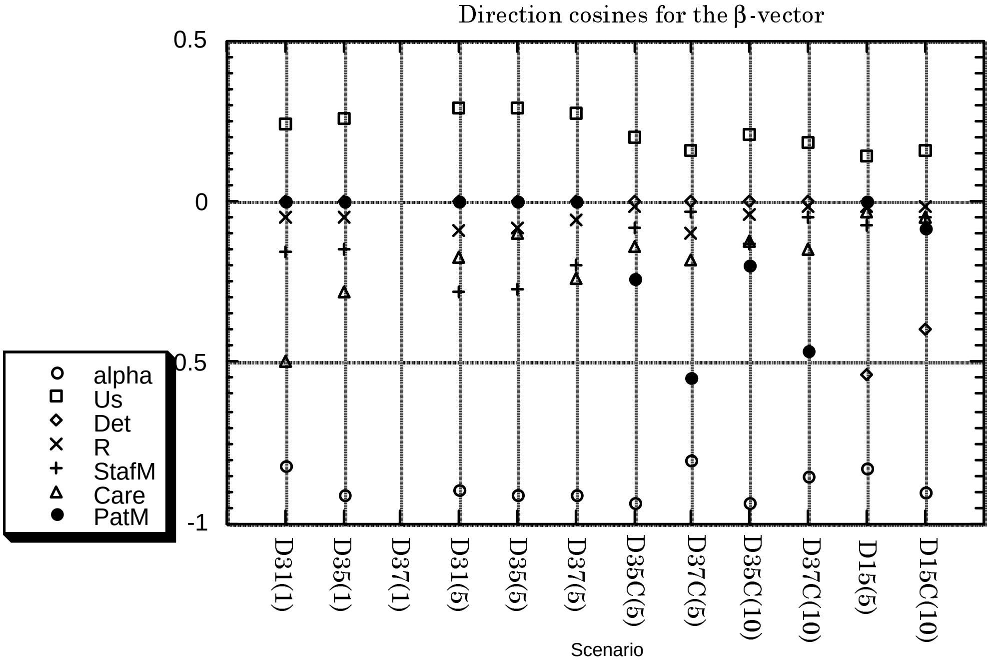


Figure B20 and B21. Importance of basic variables in main scenarios C and D.

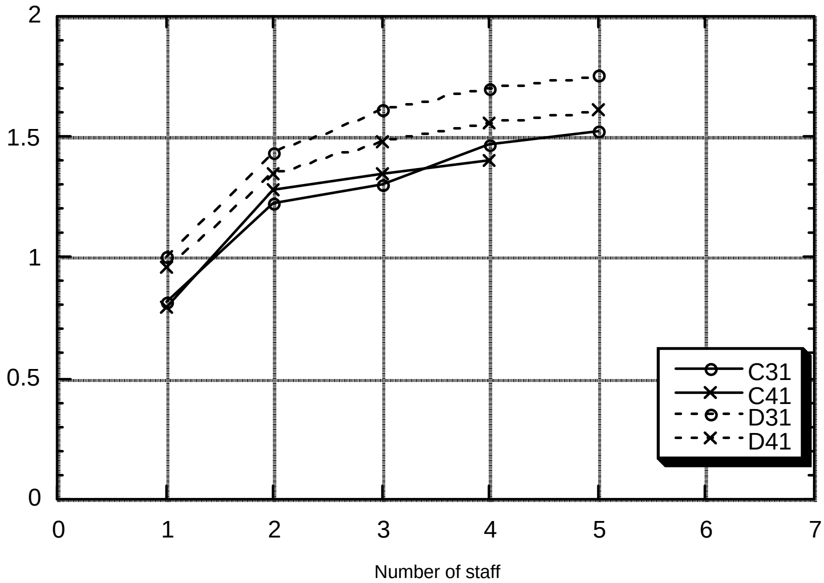


Figure B22. Comparison between β-value in room-scenario with one and two detectors. Patient category 1.

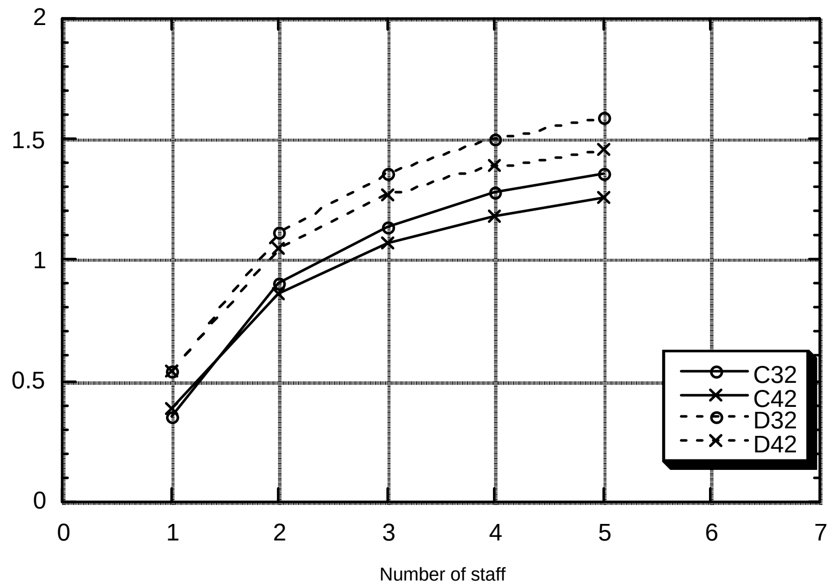


Figure B23. Comparison between β-value in room-scenario with one and two detectors. Patient category 2.

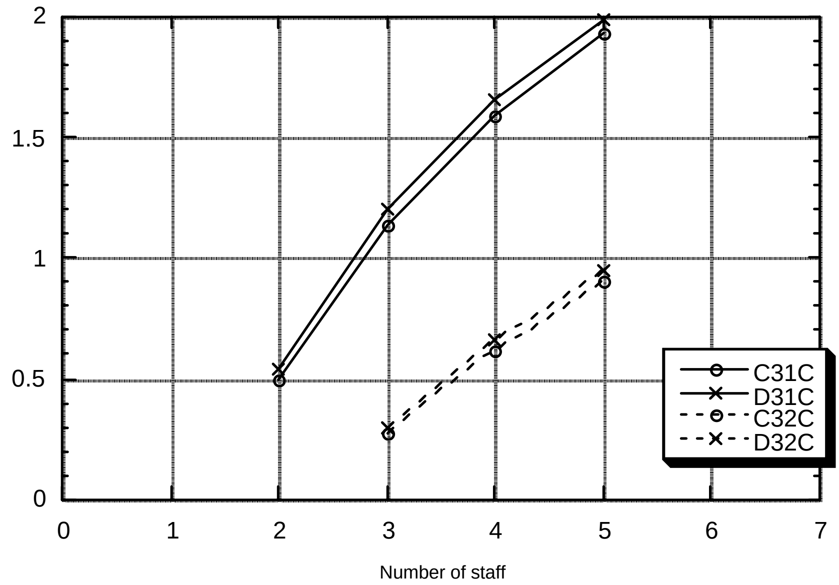


Figure B24. Comparison between β-value in corridor-scenario with one and two detectors. Patient categories 1 and 2.

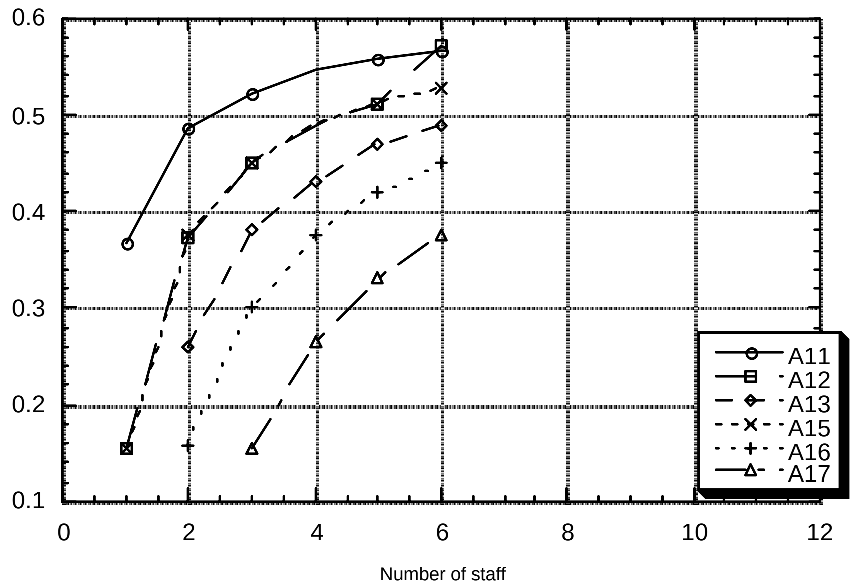


Figure B25. Reliability index β for different patient categories in room scenario with open door and detector failure.

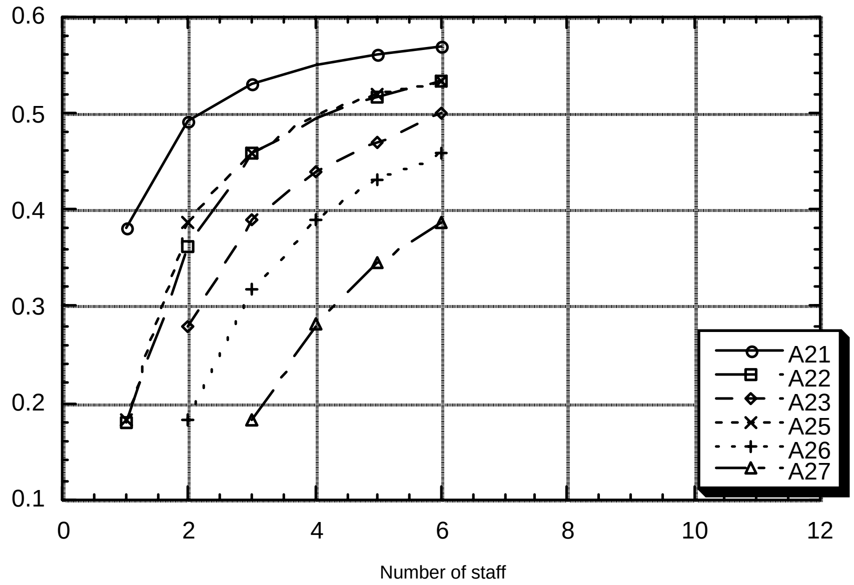


Figure B26. Reliability index β for different patient categories in room scenario with closed door and detector failure.

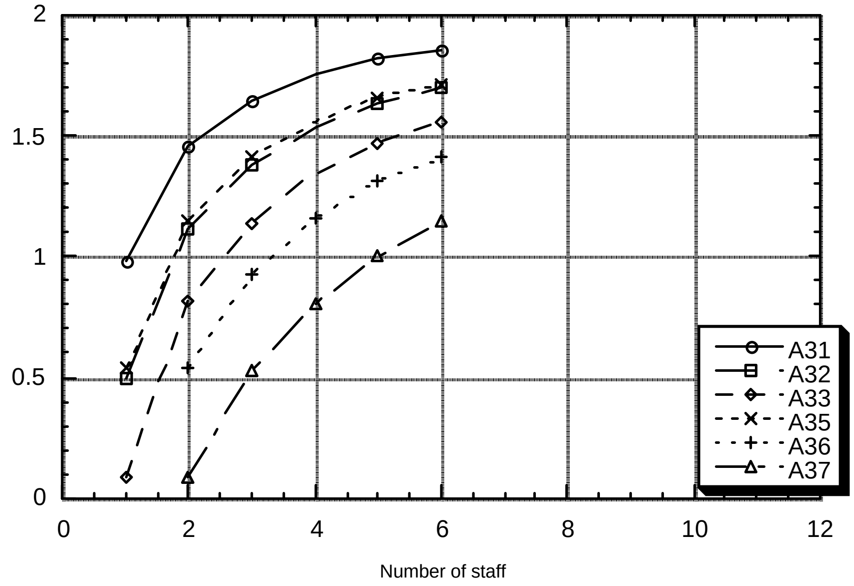


Figure B27. Reliability index β for different patient categories in room scenario with open door and detector operating.

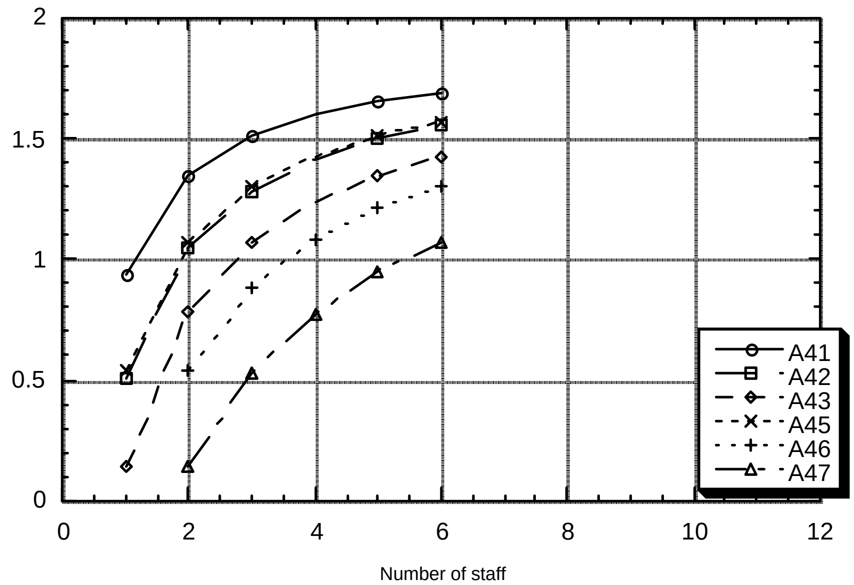


Figure B28. Reliability index β for different patient categories in room scenario with closed door and detector operating.

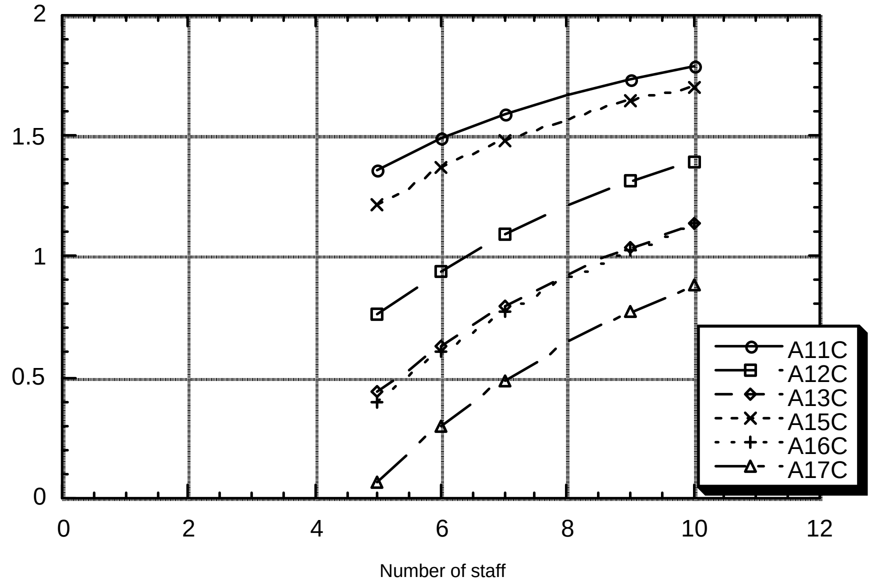


Figure B29. Reliability index β for different patient categories in corridor scenario with open door and detector failure.

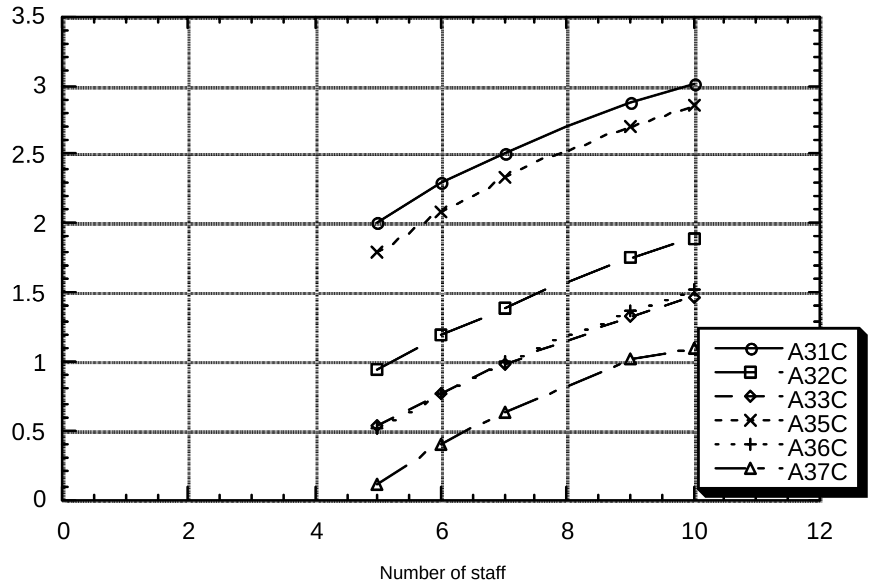


Figure B30. Reliability index β for different patient categories in corridor scenario with open door and detector operating.

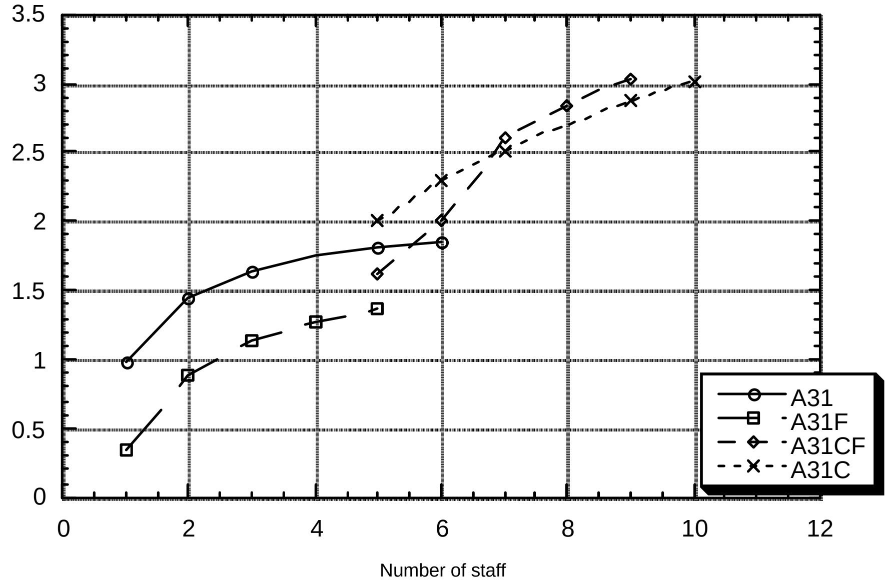


Figure B31. The effect on the reliability index on increased mean value of the fire growth rate α.

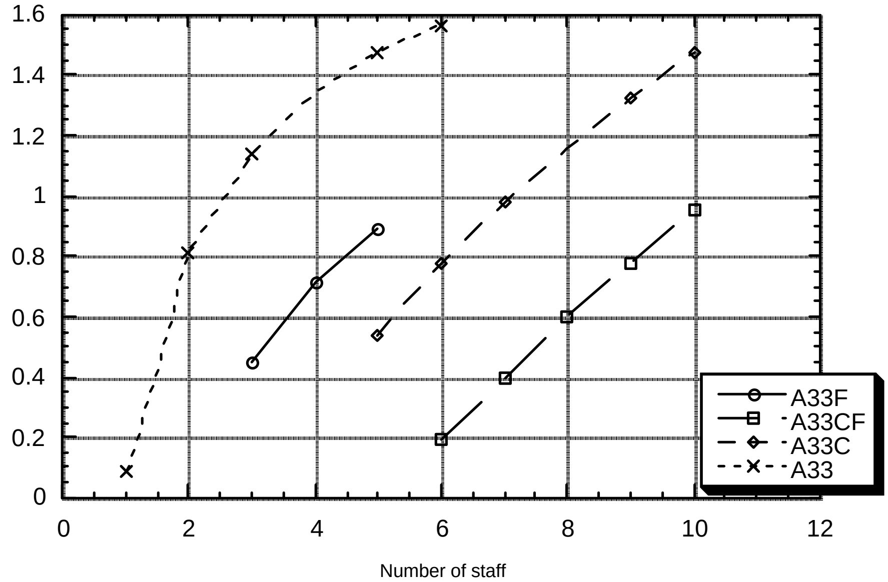


Figure B32. The effect on the reliability index on increased mean value of the fire growth rate α.

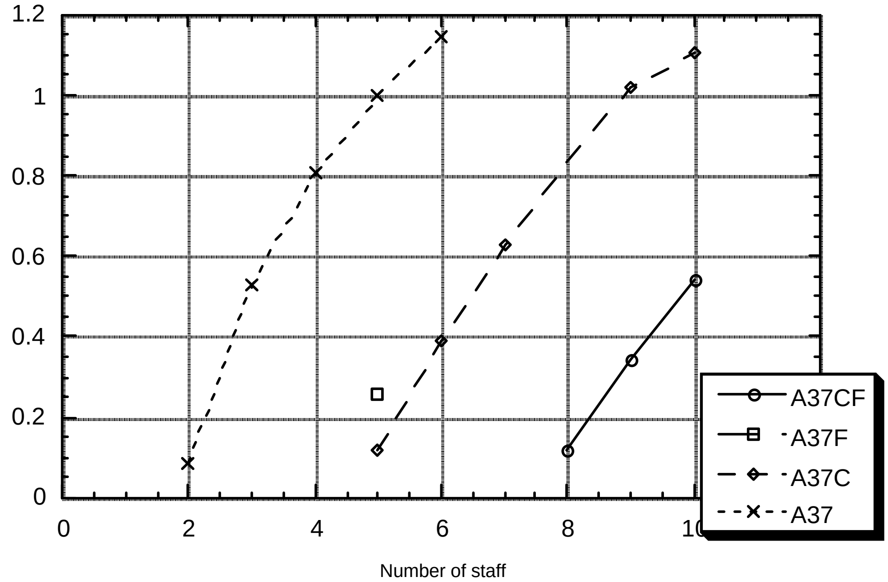


Figure B33. The effect on the reliability index on increased mean value of the fire growth rate α.

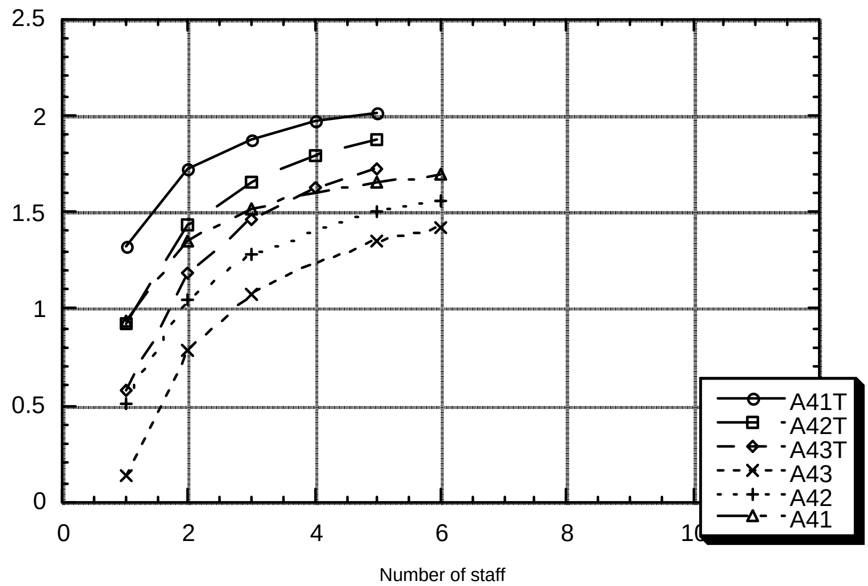


Figure B34. The effect on the reliability index on increased tenability levels for the people on the ward.