kpt. dr inż. Piotr TOFIŁO
st. kpt. mgr inż. Marcin CISEK
Katedra Bezpieczeństwa Budowli, SGSP
Katedra Badań Bezpieczeństwa, SGSP

Selection of Evacuation Scenarios for Evacuation Simulations

The paper presents a more refined methodology that can be used to facilitate the analysis of RSET involving a range of defined scenarios differing with probability. The choice of values for each main scenario parameter is represented by conditional event tree functions. The probability of a given level for each variable is based on data obtained from research or actual events or failing that, on the expert judgment. Numerical analysis of all predefined evacuation scenarios (taking into account all possible combinations of input parameters) is carried out for a selected case study – a 3 storey school building. A variation of obtained evacuation times is presented. Variables having the greatest impact on the final outcome of the simulation are discussed. Results are further expressed by a Weibull cumulative probability distribution function. The use of the analytical methodology with the use of event trees is discussed as a tool in the process of negotiations involving the evacuation scenario with the verifying and approving institutions.

1. Introduction and Background

Performance based design is gradually being adopted in Poland and the fire regulations contain clauses allowing non-standard solutions. Problems in developing scenarios for modelling fires and evacuation are commonly observed in fire engineered proposals submitted for approval. Reasons for that are mostly related to the vague procedural framework and lack of good Polish guidance documentation on performance based methods. Some of the problems related to the aspect of evacuation design within the performance based option stem from the state of formal relations between the designers and verifiers. These relations usually come down to the final assessment of the submitted design by the state fire brigade which is not preceded by any discussion or exchange of views on the principles of the design or its main concepts and major assumptions requiring mutual understanding and consensus approach.

Usually the verifiers are reviewing the final report and in some cases point out the most questionable assumptions but often omit smaller mistakes. This is due to lack of good guidance documentation and low risk awareness of both designers and verifiers and lack of more systematic approach. There are no local regulations for preparing/requiring the fire engineering brief or qualitative design review reports. At the same time internationally respected standards and regulations advocate a more disciplined approach. The other side of the problem is that fire officers are not supposed to take part in the design as their role is to approve or disapprove, so they cannot take any responsibility for preparing the design.

The designers are usually people who are more involved in ASET (Available Safe Egress Time) analysis and fire modelling and the evacuation analysis is a smaller part of their report. This is understandable, as in many cases simple calculations suffice and effectively the evacuation simulations are not often performed yet. When performed usually they involve a single simple scenario considered representative by the designer, while a wider range of possible situations are not considered and assumptions are often simplified. Part of the problem is the scarcity of preprocessed statistical data. Existing literature data is often misused, taken out of context, misinterpreted and inappropriately extrapolated. Consequently the safety margins and uncertainty issues are usually poorly addressed.

However the bigger and more complex buildings with mixed or varied uses definitely require more insight. The performance based design often includes assumptions that are very strategic to the design while being effectively an engineering judgment. The assessment of such assumptions is very difficult as often these are speculative in nature and in practice there are many scenario variables that are chosen authoritatively without discussing the reasons.

Sometimes it is indeed a very difficult task to develop scenarios for simulation to evaluate a required safe egress time. In verifier's view the scenario should be the worst possible to achieve highest level of safety and to avoid risk and therefore responsibility. Designer is often motivated by economical optimization of the engineered solution. Consequently it is often difficult to make conclusive decisions on the selection of the scenario and both sides end up having different views on what should be considered as the worst case scenario.

Event tree methodologies are not often adopted as probability based approach is still often seen as too difficult and confusing among fire engineering community in Poland.

The aim of this paper is to present a plausible methodology that could be adopted for better communication between the designer and the verifier on the selection of the RSET (Required Safe Egress Time) time and the safety margins in the ASET/RSET analysis.

2. Analysis of a Selected Case

An existing school building was selected to perform an analysis in attempt to develop evacuation scenarios and to produce a wide range of possible evacuation times in order to make an educated judgment on the most appropriate evacuation time to be selected for ASET/RSET analysis.

Schools are potentially a type of buildings that may cause problems during the performance based design. A number of factors may become difficult to come to agreement on. This could be a question on whether the school is used all the time in a way that is typical for a school or perhaps there are other uses that are rare but imaginable and relatively probable. This could be various function events, parents day or as a very rare and unusual but in some areas quite plausible – the event when school can serve as a shelter for people who had to leave their homes due to some tragedy, in which case the school would operate as a dormitory. Unusual uses should be considered in the design stage. An open question is also whether pupils react in similar way to alarm during the class and during the break where the background noise is bigger and while teachers are away. A similar variation was used for a special day where the scenarios involved either day or night situations. In both cases adequate pre-movement times were chosen. The last question is whether any escape routes are blocked by fire or smoke. The issue of discounting of some parts of escape routes may be seen differently in various countries and this is usually a question that raises a lot of concern and confusion. The school plans with the location of blockages are shown on Figure 1.

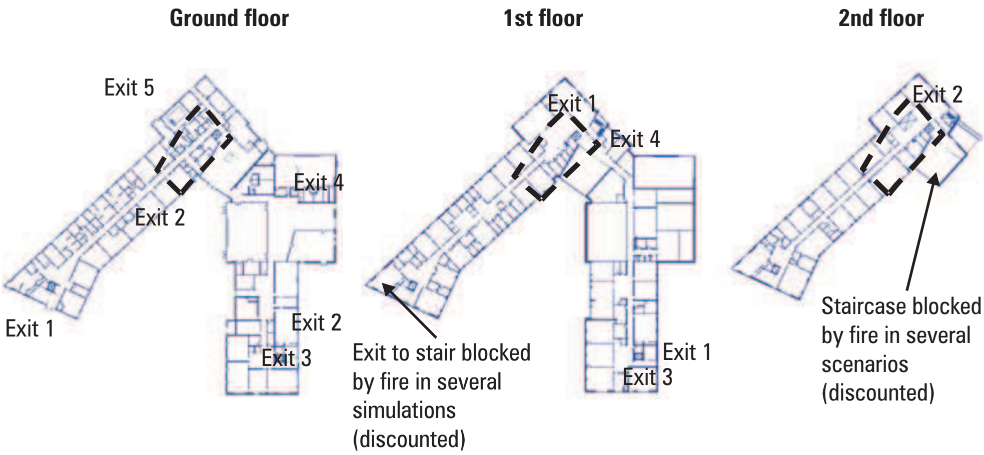

Fig. 1. *The school plans – details of scenarios with discounted escape routes*

The next step was to develop a numerical model and simulate the selected scenarios. This part was done using the STEPS evacuation modeling software. STEPS is a simulation tool designed to predict pedestrian movement under both normal and emergency conditions developed by Mott MacDonald Group Limited.

The assumptions for simulations are shown in Table 1. The results of the simulations are shown in Table 2 and Fig. 4a. The results could be further processed to depict the cumulative frequency of an evacuation time being shorter than a given time, which was plotted on Fig. 4b. Such a plot can be useful to obtain a predicted time of evacuation for say 95% or 90% of fires. This kind of information may be already used in discussions between designers and verifiers. The findings can be also presented as a plot typically used for risk profiles (Fig. 5a).

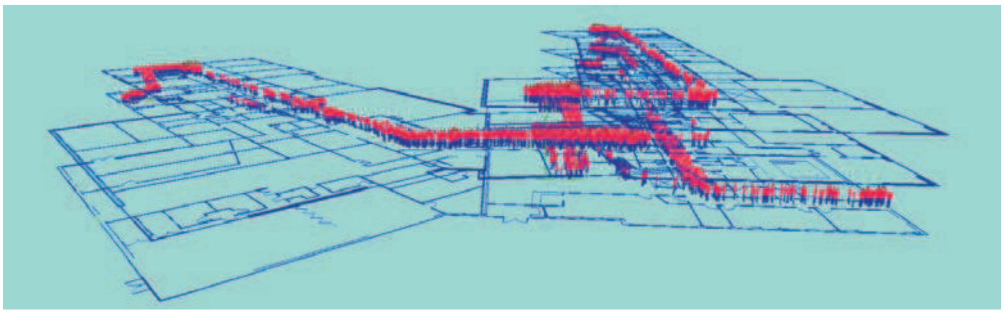

Fig. 2. *The view of the populated model*

Table 1. Assumed floor population and pre-movement time for defined scenarios

	Population on floors			Pre-movement time
	Ground floor	1^{st} floor	2^{nd} floor	
SC1	400	540	330	30-120s
SC2	400	540	330	30-120s
SC3	400	540	330	30-120s
SC4	400	540	330	60-240s
SC5	400	540	330	60-240s
SC6	400	540	330	60-240s
SC7	600	720	440	30-120s
SC8	600	720	440	30-120s
SC9	600	720	440	30-120s
SC10	600	720	440	60-240s
SC11	600	720	440	60-240s
SC12	600	720	440	60-240s
SC13	900	1080	660	30-120s
SC14	900	1080	660	30-120s
SC15	900	1080	660	30-120s
SC16	900	1080	660	60-240s
SC17	900	1080	660	60-240s
SC18	900	1080	660	60-240s
SC19	600	720	440	120-600s
SC20	600	720	440	120-600s
SC21	600	720	440	120-600s
SC22	600	720	440	60-240s
SC23	600	720	440	60-240s
SC24	600	720	440	60-240s

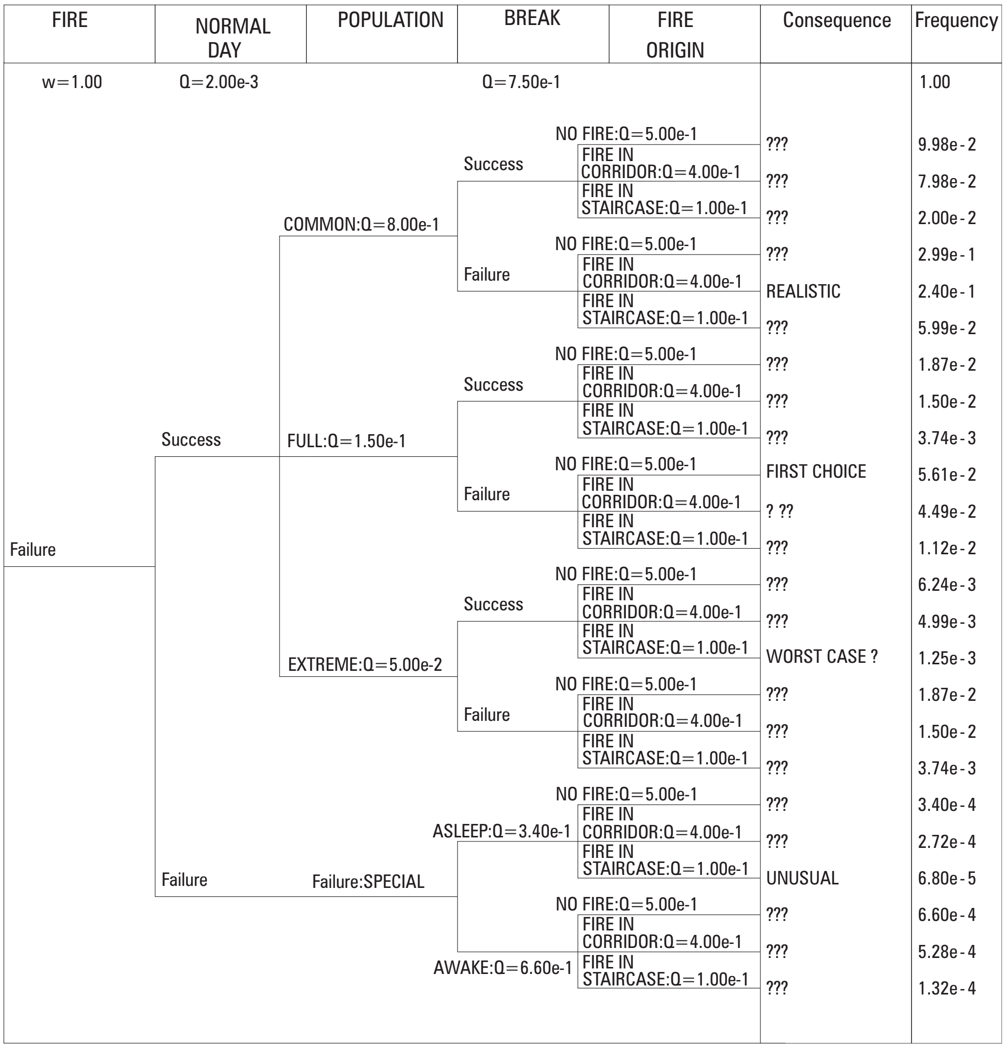

Fig. 3. *Event tree with a description of variables taken for consideration*

Table 2. Parameters for defined scenarios and results of simulations

	Normal day / Special day frequency	Population frequency	Break or Class freq. (day/night for sp. day)	Blockage by fire – frequency	Total frequency	Time to safety	Total evacuation time
SC1	0.95	0.8	0.25	0.5	0.095	297	342
SC2	0.95	0.8	0.25	0.4	0.076	331	389
SC3	0.95	0.8	0.25	0.1	0.019	308	379
SC4	0.95	0.8	0.75	0.5	0.285	199	237
SC5	0.95	0.8	0.75	0.4	0.228	220	301
SC6	0.95	0.8	0.75	0.1	0.057	213	337
SC7	0.95	0.15	0.25	0.5	0.018	309	378
SC8	0.95	0.15	0.25	0.4	0.014	324	367
SC9	0.95	0.15	0.25	0.1	0.004	316	443
SC10	0.95	0.15	0.75	0.5	0.053	236	320
SC11	0.95	0.15	0.75	0.4	0.043	276	343
SC12	0.95	0.15	0.75	0.1	0.011	298	422
SC13	0.95	0.05	0.25	0.5	0.006	327	428
SC14	0.95	0.05	0.25	0.4	0.005	417	481
SC15	0.95	0.05	0.25	0.1	0.001	478	598
SC16	0.95	0.05	0.75	0.5	0.018	352	428
SC17	0.95	0.05	0.75	0.4	0.014	404	480
SC18	0.95	0.05	0.75	0.1	0.004	435	552
SC19	0.05	1	0.34	0.5	0.009	640	680
SC20	0.05	1	0.34	0.4	0.007	722	784
SC21	0.05	1	0.34	0.1	0.002	665	703
SC22	0.05	1	0.66	0.5	0.017	522	560
SC23	0.05	1	0.66	0.4	0.013	540	579
SC24	0.05	1	0.66	0.1	0.003	584	664

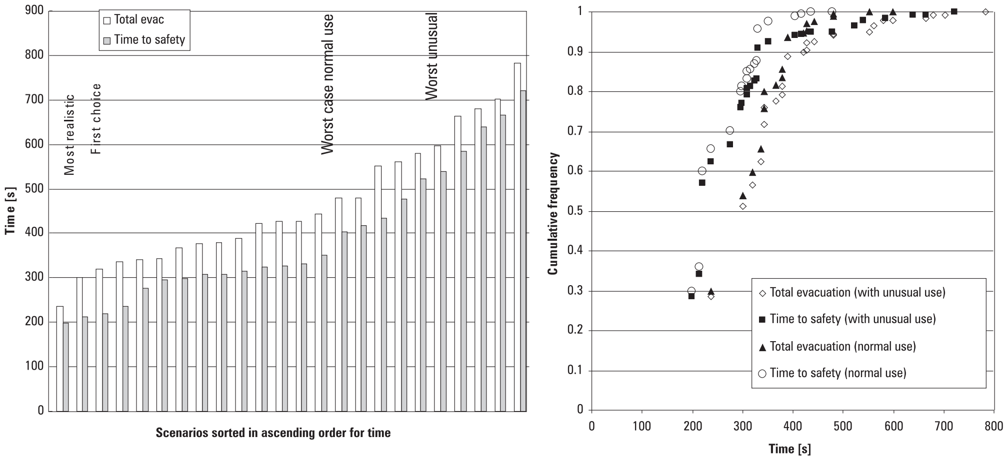

Fig. 4. Results of simulations: a) evacuation times (total evacuation and time to safety), b) results presented for cumulative frequency vs. time

The whole set of results can be represented as a single expression that can be then used to obtain the required escape time based on any frequency provided as input. First however, the results have to be curve-fitted for the Weibull cumulative distribution function using any method available. For this study a spreadsheet solver and the least squares method was used. The resulting curves can be seen on Fig. 5b.

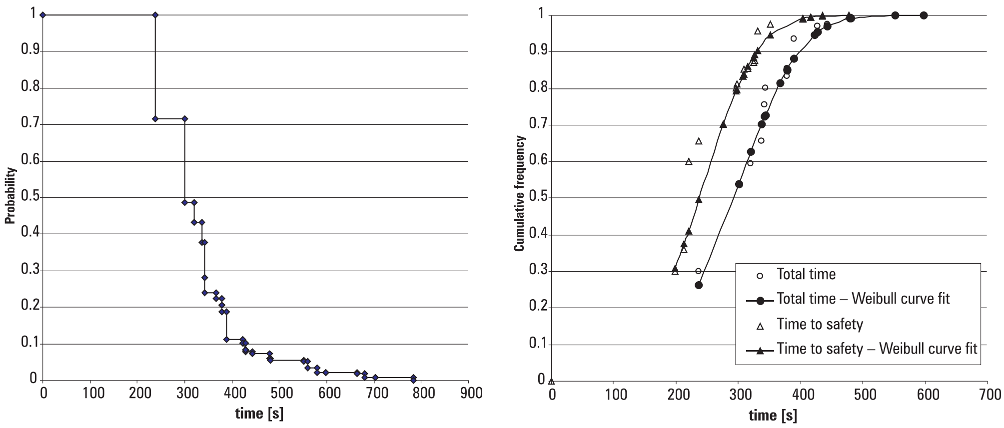

Fig. 5. Results presented as: a) plot showing the results in a style typically used for risk profiles, b) as a cumulative frequency (with Weibull cumulative probability function curve fit)

After curve-fitting the parameters of the Weibull cumulative probability distribution function $P = f(t_{RSET}, \alpha, \beta)$ are obtained. The function is described with the following equation:

$$P = 1 - e^{\left(\frac{t_{RSET}}{\beta}\right)^{\alpha}} \quad \text{(Eq. 1)}$$

The equation 2 can be solved for t_{RSET} as shown below:

$$t_{RSET} = -\beta\left[\ln(1-P)\right]^{1/\alpha} \quad \text{(Eq. 2)}$$

So to find a required safe egress time t_{RSET} three parameters are necessary: $P, \ \alpha, \ \beta$.

3. Discussion and Conclusions

The analysis and methodology presented above can be useful and should be considered in cases where a serious disagreement and difference of opinion exists or is expected to occur between the designing and verifying parties as regards to the selection of evacuation scenarios and the required safe egress times. In such cases both parties should first agree on the accepted probability levels, a range of variable scenarios assumptions and the parameters of the event tree including the frequencies attributed for all branches. With this stage completed the remaining work does not involve critical decision making and is mostly technical. Such approach can reduce the margin for disagreement and confusion. It is quite likely that the methodology can be criticized because of the big increase in the number of scenarios that are usually performed. However the above analysis of a hypothetical case was not a big effort because the evacuation modeling is getting simpler and quicker these days. The software packages often enable batch processing and automation so a number of simulations can be developed and run with some parameters varied. Most evacuation modelers confirm that the biggest effort usually is to develop the model itself. Other critical voices may refer to the uncertainty of the models. Indeed the evacuation modeling software packages often contain many other parameters that are arbitrary in nature that affect the results of the simulation. Those parameters can be for example the grid size, decision process parameters or movement algorithm variables. Experience in using particular software usually helps to narrow down the extents of those variables and consequently the software related distribution of the evacuation time, but even then for correctness the result of a single simulation should be expressed in a form of a probability distribution [6]. To include the software related variations may however be too problematic during the design stage where time constraints for analytical work on a single project are often a big problem in the building design process. The methodology presented here provides a more informed selection of required safe egress time and is realistically feasible in real design situations.

Refrences

[1] BS 7974:2001 – Application of fire safety engineering principles to the design of buildings – Code of practice.
[2] Life Safety Code NFPA 101 2006 – Performance Based Option.
[3] Notarianni K.A., Perry G.W., Uncertainty: SFPE Fire Protection Engineering Handbook, 4th Ed, 2008 SFPE.
[4] Hurley M.J., Rosenbaum E.R., Performance Based Design: SFPE Fire Protection Engineering Handbook 4th Ed, 2008 SFPE.
[5] Hadjisophocleous G.V, Mehaffey J.R., Fire Scenarios: SFPE Fire Protection Engineering Handbook, 4th Ed, 2008 SFPE.
[6] Lord J., Meacham B., Moore A., Guide for evaluating the predictive capabilities of computer egress models – NIST GCR 06-886, 2005.

Summary

Piotr TOFIŁO
Marcin CISEK

Selection of Evacuation Scenarios for Evacuation Simulations

The current practice of fire safety engineering analysis often comes down to the comparison of the available safe evacuation time (ASET) and the required safe evacuation time (RSET) in order to determine whether the criterion of acceptability in a form of an adequate safety margin of time has been met. Analysis of fire dynamics and evacuation usually takes place separately although there are also tools to simultaneously simulate the development of fire and evacuation of people. In both cases however it is essential to develop such an evacuation scenario that is the most unfavorable but nonetheless plausible and representative for the building in question. The worst case scenario is understood here as the most unfavorable combination of the input parameters. Assuming such a scenario for analysis is most probably putting the designer on the safe side, usually however the selection of scenario parameters and assumptions is often accompanied by disputes and controversies between the designing and the verifying parties regarding the realism of the assumed scenario. The paper presents a more refined methodology that can be used to facilitate the analysis of RSET involving a range of defined scenarios differing with probability. The choice of values for each main scenario parameter is represented by conditional event tree functions. The probability of

a given level for each variable is based on data obtained from research or actual events or failing that, on the expert judgment. Numerical analysis of all predefined evacuation scenarios (taking into account all possible combinations of input parameters) is carried out for a selected case study – a 3 storey school building. A variation of obtained evacuation times is presented. Variables having the greatest impact on the final outcome of the simulation are discussed. Results are further expressed by a Weibull cumulative probability distribution function. The use of the analytical methodology with the use of event trees is discussed as a tool in the process of negotiations involving the evacuation scenario with the verifying and approving institutions.