From prescriptive arrival times to performance based fire service delivery – Parallels of Fire Service Planning and Fire Engineering

Adrian Ridder[*], Uli Barth
University of Wuppertal, Wuppertal, Germany

Abstract: The fire safety design process of buildings underwent a substantial shift in the last roughly two decades, switching from prescriptive building codes to performance-based, fire-engineered designs. A similar process can be observed with Strategic Fire Service Planning which defines "how much fire service" is necessary per municipality. The methods used there become more and more sophisticated as well. However, with increasing complexity it becomes harder to explain and interpret results to the decision-makers, which applies both to fire engineering and fire service planning. The need for further research is made clear as the major outcome of this paper.

Keywords: fire service, risk management, fire engineering, methodology

1. INTRODUCTION

For the decision-making process on how many resources, stations and personnel are necessary for the fire service of a local authority (town, city, county), several constrictions apply, the most important ones being limited available public funding and the statutory requirement to achieve a "deemed-to-satisfy" level of public safety (which usually is not quantitatively defined and therefore measurement of fulfillment is hard to achieve). A similar problem in quantifying the necessary level of safety exists in the design of buildings. This paper outlines some parallel developments in both fields, elaborates on similar problems in quantifying safety and delivering results that can both be validated and understood by the respective authority having jurisdiction.

2. FIRE ENGINEERING

In earlier times (and before the formal introduction of Fire Engineering in the second half of the 20th century), fire safety of buildings was based on prescriptive building-codes which contained the wisdom accumulated through lessons learned from fires over several decades or centuries in the respective country. Those concepts were hazard-based and prescribed in detail e.g. what building materials could be used, how far buildings must be separated and how thick a wall had to be. The cost of those very detailed, easy to apply rules in form of accepted solutions (called "deemed-to-satisfy" the objectives of the building codes) was limited flexibility and hampered progress in building design features.

With the emergence of Fire Engineering as respected science discipline and study course that changed. Deviations from prescriptive codes became allowed when the safety of a building could be assured otherwise. Building codes, e.g. the 2014 New Zealand Building Code [1], have been altered to include detailed quantitative "performance requirements". These can be achieved on numerous ways by architects and engineers and therefore allow for far more innovative designs than prescribed ready-made solutions where there remains not really any choice for architects and engineers except the one of implementing it or not.

To achieve the necessary safety level, the methods of Fire Engineering have been developed. In general they use acceptance criteria parameters to quantify general objectives like the protection of building occupants or easy fire service intervention. Through calculations and fire modelling the actual building in question is thoroughly analyzed as an individual case and the review shows if the building design can achieve parameters that are at least as safe as or safer than the performance requirements.

[*]Corresponding author: ridder@uni-wuppertal.de

This so-called performance-based concept is therefore risk-based, allows for more flexibility and at the same time – when carried out properly – ensures a high level of safety. Probably the findings of this process are more accurate than prescriptive solutions as the design is reviewed on an individual case basis and therefore "tailor-made", instead of generic prescriptive solutions which contain the risk of being not wholly applicable to the specific building. In accordance to that, it has been found that prescriptive solutions must not always be "safer" than performance-based ones. This discussion comes down to the fact that the level of safety of prescriptive requirements is not explicitly stated but it is rather assumed that by applying those measures, a design should be safe enough. That approach has lately been criticized as the level of safety of prescriptive requirements depends more on the building specifics than performance based designs do [2].
Methodologies and guidelines for the performance-based approach and relevant criteria parameters have been internationally developed, e.g. in the International Fire Engineering Guidelines IFEG [3], BS 7974 ([4] and the vfdb Fire Engineering Guideline [5]. Some of those documents also contain probabilistic risk assessment methodologies , e.g. [6].

3. STRATEGIC FIRE SERVICE PLANNING

Strategic Fire Service Planning has always existed where an organized approach existed to counteract the elementary hazard of fire. However, only very recently that area has been established as field of research. The resulting methodologies and algorithms strive to change fire service planning from experience and gut-feeling based towards a more scientific, fact-based and quantifiable approach (more often than not resulting from increasing pressures to justify fire service operations and the relating costs in the eye of the wider public and the politicians distributing funding).

3.1. Historical developments

In the past, many countries worldwide (e.g. Sweden, the Netherlands, UK, New Zealand, USA, Germany) chose prescriptive fire service arrival times as a substitute benchmark to answer the question if adequate safety has been achieved. That is, regulations or laws defined that the fire service had to arrive at the incident scene in a certain amount of time, usually somewhere between 8 and 15 minutes after the emergency call has been received by the dispatch center. Those times were universal or at best split in categories like "within city limits" and "outside city limits", therefore allowing for only small deviations [7], [8], [9], [10], [11].
In literature, that response or arrival time is seen as the dominating characteristic for quantification purposes of fire service delivery [12]. Though several attempts have been made, no validated correlation between a fire growth or fire toxicity curve to the specification of fire service arrival times can be found in international literature [7]. Existing time goals are therefore to be considered as expressions of the political will and the financial clout of the municipality at hand. However, it is obvious that shorter response times are favourable cp.[13].
The importance of the arrival time has to be put in context also with the question how much resources are put into action after that time, how well equipped and how competent they are in what they are required to do (cp. [13], [12], [14].

With the advent of increasing computation power, computer models have been used to calculate optimum locations for stations based on the existing workload (emergency calls). Also the other way around has been used, picking existing stations and calculating how far a fire truck can travel in a given time, with varying degree of detail (the type of road, quality of the road, traffic conditions, daytime, season etc.).
Today, the arrival time approach is still widely used in European countries and all over the world. The obvious advantage is the fact that it can easily be defined and controlled. But it comes with the disadvantage that it is not possible to derive what kind of equipment and trucks should be allocated to different stations. In that generic form it also fails to allow for more detailed responses, e.g. faster fire service response in areas with a higher risk (however, for example in the Netherlands approaches like that with varying response times in accordance to the type of object and time of day are already used).

In the EU, seven countries use such an approach, whereas seven others use a scenario-driven approach and nine countries use a risk-based approach (not all EU member countries have a written methodology for fire service planning)[15]. The so-called risk-based approach is a relevant recent development and started only in the early 2000s. It is hoped to include the probability of a fire incident in those methods and therefore allow for a more detailed allocation of resources (instead of spreading the fire service evenly over a city, some areas with less associated risk could get fewer stations or slower responses while high-risk areas would receive a faster response with probably more resources as well).

3.2. Current developments

The risk-based approach is to be considered the latest development in fire service planning. It is hoped that more sophisticated risk analysis methods and analysis of risk-related data will in the future allow for "tailor-made" allocation of fire service resources, without over-protecting (and therefore over-paying) but still guaranteeing an adequate safety level.

Methodologies used today are based on assumptions made based on the type of buildings in a given area (height, occupancy, construction type etc.), the number of population in the area (population density), the demand to the fire service measured in fire calls and rescues/injuries/deaths or a combination thereof [16], [17], [18], [19]).
However, more research needs to be done to create a more empiric foundation of those methods instead of pure assumptions and operational experiences. Newer research has shown a strong connection between socio-demographic factors and fire risk. A strong association between deprivation and other social factors with the occurrence of fire has been found [20].

Increasingly, different data sources from both inside and outside a fire service are used in conjunction with Geographical-Information-Systems (GIS), which allow for a convenient depiction of a large number of different datasets on a map. Data sources inside the fire service may be incident action reports containing the equipment used, the time spent at one incident, the number of injured persons etc.; data on availability of fire trucks due to maintenance and workshop-stays; availability of personnel (depending on percentage of sick leave, training, absolute number of personnel etc.); fire investigation reports and a lot more. Outside data sources may be the ambulance service (where separate from the fire service) contributing numbers of injuries of different severity and fatalities, Public Housing and Statistics departments contributing data on population distribution, type, age and occupation/zoning of buildings, Traffic departments delivering data on traffic density, blockages and road network changes, and many more. First works have been done on merging those different data sources in a uniform data warehouse per fire service [21] which facilitates the analysis enormously.
The move towards a more performance-based approach to fire service planning brings about and coincides with a similar movement to introduce performance measurement and performance management techniques and methodologies in the fire services [22], something private industry has done many years ago. Both need more and more sophisticated data collection pools and analysis tools to allow for the more detailed outcomes which are increasingly expected from authorities having jurisdiction. Therefore it has already been found that a risk based approach offered significant potential for the application of performance measurement in the fire services [20].

4. SIMILARITIES AND INTERDEPENDENCIES BETWEEN BOTH DISCIPLINES

Both Fire Engineering and Fire service planning share one common important question to answer: How safe is safe enough? And directly correlated to it is the more profane question, how much money must be spend to achieve an adequate safety level? Both questions have been widely discussed and elaborated on in the risk and safety literature [23], [24]. A more practical way to put that question is rather than considering absolute safety levels it should be considered what value is placed on a specified change in survival probability [24]. A holistic answer to that fundamental question of safety science has not been found yet, but it is important to communicate shortcomings in the risk assessment and risk management process to the relevant stakeholders, which mainly are the developer, owner and user of buildings in the case of Fire Engineering and the citizens and politicians in the case of Fire Service Planning. Uncertainties must be made public as to not create a false feeling of safety.

Both areas of research are directly linked when it comes to the question of how long a building's structural integrity must be maintained in order to allow for efficient fire service operations, an objective found in many building codes around the world. One approach for that is incorporated in the IFEG in form of a time-line approach for the fire service intervention based on the Australian Fire Brigade Intervention Model (FBIM, [25]). That shows how deeply interconnected both disciplines are: Building designers have to know how capable and fast the local fire service can deploy so that they can correctly calculate the buildings resistance against fire. Similar time-lines have been developed all over the world, e.g. [26]. In Germany a similar strong connection between fire brigade intervention and design of the building is only applied to industrial buildings, where the minimal fire resistance time determines the mandatory response time of the fire service [27].

Both disciplines also share common problems and shortcomings, which are discussed below.

4.1 Methodological Voids and Deficits

In both areas, the scientific work on the relevant topics is quite young, while Fire Engineering has at least some 50 years under its belt, Strategic Fire Service Planning in a methodological and scientific manner is even younger. Resulting from this fact, many assumptions are still used in state-of-the-art models, as simply the complex systems of compartment fires and fire service operations have not been fully understood yet. Additional fundamental research is necessary to understand the different parts and components of both systems, let alone the complex interactions between different subsystems (for Fire Engineering e.g. pyrolysis of wood and plastics, heat fluxes radiating back on surfaces, flashover-behavior in complex room geometries with various fuel-loads, toxicity of gases like HCN, CO, H_2S and their solitary and combination effects under varying ambient conditions; for Fire Service Planning e.g. the influence of competencies and training on outcomes of operations and the quantification of it, the efficiency and effectiveness of varying crew sizes and equipment as well as that of different firefighting agents (water, Class-A foam, compressed air foam etc.) and the influence of risk factors like building and population characteristics and many more).

Prescriptive arrival times did not consider local risk distributions, specific risk resulting from particular industrial complexes, residential buildings or transportation infrastructures. Therefore only rough estimations on the service delivery of a fire service could be calculated. The same can be said about prescriptive building-codes, which could only be used for off-the-shelf buildings and therefore hampered the development of more sophisticated designs. Hence both concepts became to rely on the risk concept.

But dealing with risks in both disciplines carries specific difficulties, too. Especially the probabilistic handling of fire service incidents in general and of structural fires as topic of fire engineering in particular highlight a methodological conflict associated with the risk concept. The important events of interest are of a low probability and high impact nature. Therefore it is difficult to not misrepresent those seldom but severe events as with simple mathematical multiplications those events are somewhat "adumbrated" by the far higher number of incidents with less or no damage at all (e.g. false automatic fire alarms). That makes those risks somewhat hard to statistically analyze and risk aversion factors and similar concepts must be used to counter that. The distinction between the probability of high risks and the pure frequency of all kinds of incidents also makes it hard to explain to laymen like citizens and politicians why some sort of "overhead" with the fire service resources has to be maintained in order to be able to respond to the larger, but more seldom events, although the daily call load could more often than not easily be handled with a fraction of fire service resources. Probabilistic models must therefore account for this specific fire service related aspects. Taking this approach one step further, fire services as the usually only “all-round” first responder agency in a town have to be able to deal with not only rare incidents but also totally unexpected ones. Therefore the quite new concepts of black swans [28], [29] and resilience-based contingency [30], [31] should be considered as well as.

Assuming a risk assessment could be executed, in both areas it is very tricky – and nonetheless important - to set the threshold for “acceptable” risks. Performance criteria contained in building codes can be a solution for this in terms of Fire Engineering. For Fire Service Planning suitable indicators and measuring parameters for acceptable risks have to be found. The author proposes the number of incidents where the loss could be stopped after arrival of the fire service as indicator for the protection of property and the percentage of rescued persons out of the total number of affected persons the fire service had a chance to rescue as performance indicator for life safety.

4.2 Validation & Verification and Credibility to Reviewers

Fire Engineering heavily relies on computational fluid dynamics, for which several software packages exist. The parameters and models used in those simulations must be validated and verified in order to prove that they actually represent realistic scenarios and can predict the probable course of events in case of a fire. It has been shown that actually the current state of development of the software packages in combination with the varying skills of the users (fire engineers, consultants, and technicians) does not allow for accurate a priori predictions of fire growth in realistic complex scenarios and contain a large margin of error [32].

Similarly to the CFD software used in Fire Engineering, increasingly GIS-based software systems and specific software packages receive attention by planning departments of fire services. However, looking at literature and current best practice one can easily get the impression that too much emphasis and trust is placed on the outcomes of those software packages, neglecting the application boundaries and working assumptions used in those models. One has to bear in mind that software packages can only be as good as the underlying models which should be based on empiric evidence rather on assumptions and “operational experience” only. However, operational experience comes in handy to cross-check the plausibility of simulation outcomes.

In terms of validation and verification, similar problems exist in both fields: All too often the authority having jurisdiction to decide on proposed fire service planning and fire engineering concepts lack the knowledge, manpower and capabilities to scrutinize the proposed solutions to the degree necessary. The increasing complexity of the used models drives that trend, as more and more specialists are also necessary to check the proposals. Especially with a fire service structure as in Germany, where roughly 11.000 independent municipalities exists which all have at least one independent fire department, one can imagine that is impossible to amass the necessary expertise at all of those municipalities and fire services. Besides more streamlined and more easily understandable models, probably also organizational changes towards larger fire services (as practiced currently in the UK, Australia and New Zealand for example) offer some advantages related to the economy of scale concept.

In addition, practical guidelines should be developed for both areas which authorities having jurisdiction could use for assessing the completeness, quality, and scientific validity of the models, parameters and assumptions used. For both areas those guidelines should be as uniform and transparent as possible in order to allow for comparisons and to reduce the additional workload for consultants and other involved stakeholders working for and with different authorities having jurisdiction. One best practice example for Fire Engineering is the Acceptable Solutions and Verification Methods of the NZ Building Code [1].

In both disciplines it is of paramount importance that the relevant outcomes of design and planning processes are not obstructed by a vast array of formulae, numbers, different models and codes etc.

Rather every consultant, engineer and planner should be able to explain his work in a way that is easily understandable by the relevant stakeholders and the authorities having jurisdiction.

5. CONCLUSION

Fire Engineering and Strategic Fire Service Planning face similar problems as identified in the literature review. Those problems are under scrutiny in a current work-in-progress project on developing a risk-based fire service planning methodology for Germany. That project called “TIBRO” (German acronym for tactical-strategic innovative fire service and risk-based optimizations) was started in February 2012 and is scheduled for its final report in the first quarter of 2015. The aim of the project is to outline the fundamentals of a comprehensive methodology to derive necessary fire service resources in accordance with the legal tasks to be fulfilled by the fire service.
It has been pointed out that more sophisticated models don’t necessarily bring more clarity and accuracy in predicting the behavior of a building in case of fire or the operational performance of a fire service in the future. All current predictions and simulations are to be taken with a pinch of salt and should be compared to existing best practices and operational experiences where existent. More research in both areas is paramount to propel both young scientific disciplines to further levels of detail and validity.

Acknowledgements

The TIBRO research project on which this report is based has been funded from the German Federal Ministry of Education and Research (grant ID 13N12174). The authors are responsible for the content of this paper.

References

[1] Ministry of Business, Innovation & Employment, New Zealand Building Code Handbook, Wellington/NZ, 14.2.14.
[2] G. de Sanctis, Assessing the Level of Safety for Performance Based and Prescriptive Structural Fire Design of Steel Structures. 11th International Symposium of Fire Safety Science, 21.2.14, Christchurch, New Zealand, 21.2.14.
[3] National Research Council of Canada (NRC), International Code Council (ICC), United States of America, Department of Building and Housing, New Zealand (DBH) and the Australian Building Codes Board (ABCB), International Fire Engineering Guidelines, 2005th ed., Australian Building Codes Board, Canberra, ACT, 2005.
[4] British Standards, Application of fire safety engineering principles to the desgin of buildings. Code of practice, 2001.
[5] Vereinigung zur Förderung des deutschen Brandschutzes e.V., Leitfaden Ingenieurmethoden des Brandschutzes. vfdb TB 04-01, Altenberge, 2013.
[6] British Standards, Application of fire safety engineering principles to the design of buildings - Part 7: Probabilistic risk assessment, 2003 13.220.20; 91.120.
[7] W.J. van Dijk, RemBrand Fase 1. Niet harder rijden, maar voorkomen en slimmer bestrijden - quick research scan naar een model voor de operationelen maatschappelijke prestaties gericht op brandveiligheid. TNO-rapport RA053.02994, TNO, Den Haag, 2013.
[8] National Fire Protection Association, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, 2010 Edition, NFPA, Quincy/MA (USA), 2010.

[9] National Fire Protection Association, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments, 2010 Edition, NFPA, Quincy/MA (USA), 2010.
[10] S. Svensson, A shift in focus. Perspectives on Fire Cover. Second International Conference on Fire Servcie Deployment Analysis, 12 March 2002, Indianapolis, Indiana/USA, 2002.
[11] C. Reynolds, J. Pedroza, Fire cover modelling for brigades, Home Office - Fire Research and Development Group, London, 1998.
[12] S. Svensson, Quantifying efficiency in fire fighting operations, in: Interflam 10. Proceedings: 12th International Fire Science & Engineering Conference, London, 2010.
[13] H. Jaldell, Essays on the performance of fire and rescue services. Dissertation, Kompendiet, Göteborg, 2002.
[14] R. Ahlbrandt, Efficiency in the provision of fire services, Public Choice 16 (1973) 1–15. http://link.springer.com/content/pdf/10.1007%2FBF01718802.
[15] M. Weber, Brandschutzbedarfsplanung im europäischen Vergleich. Facharbeit in der Ausbildung zum höheren feuerwehrtechnischen Dienst, Lehmen, 2012.
[16] J. van der Schaaf, J. Jeulink, Handleiding Brandweerzorg. Systeem voor de beoordeling van de gemeentelijke brandweerzorg, Ministerie van Binnenlandse Zaken, Directie Brandweer, Den Haag, 1992.
[17] H.-G. Faasch, Strukturuntersuchung des Einsatzdienstes der Feuerwehr Hamburg, BrandSchutz - Deutsche Feuerwehrzeitung (1972) 355–358.
[18] R. Grabski, Erarbeitung einer Risikoanalyse für die Ausrüstung sowie die Anzahl der zu besetzenden Funktionen einer Gemeindefeuerwehr. Instituts-Bericht Nr. 437, Institut der Feuerwehr Sachsen-Anhalt, Heyrothsberge, 2007.
[19] DCLG, Fire Service Emergency Cover Toolkit. Executive Summary. Fire Research Report 01/2008. Fire Research Series 01/2008, Department for Communities and Local Government, London, 2008.
[20] DCLG, Risk Based Performance Measurement in the Fire and Rescue Services. Final Report. Fire Research Series 10/2008, Department for Communities and Local Government.
[21] von der Lieth, David, Neue Methode zur Erhebung und Analyse steuerungsrelevanter Kennzahlen. BRENNPUNKT, 25.10.12, Wuppertal, 25.10.12.
[22] D. Hilgers, Performance Management, Betriebswirtschaftlicher Verlag Dr. Th. Gabler / GWV Fachverlage GmbH Wiesbaden, Wiesbaden, 2008.
[23] C. Starr, Social Benefit versus Technological Risk, Science 165 (1969) 1232–1238.
[24] P. Slovic, The perception of risk, Earthscan Publications, London, 2002.
[25] Australasian Fire Authorities Council AFAC, Fire Brigade Intervention Model. V 2.2, Melbourne, 2004.
[26] AGBF Bund, Empfehlungen der Arbeitsgemeinschaft der Leiter der Berufsfeuerwehren für Qualitätskriterien für die Bedarfsplanung von Feuerwehren in Städten, Arbeitsgemeinschaft der Leiter der Berufsfeuerwehren in der Bundesrepublik Deutschland, 1998.
[27] Deutsches Institut für Normung, Baulicher Brandschutz im Industriebau - Teil 1: Rechnerisch erforderliche Feuerwiderstandsdauer, Beuth Verlag, Berlin, 2010 13.220.99.
[28] N. Taleb, The black swan. The impact of the highly improbable, 2nd ed., Penguin, London, 2010.
[29] T. Bjerga, R. Flage, On black swans in relation to some common uncertainty classification system, in: Safety, Reliability and Risk Management: Beyond the Horizon. ESREL 2013, Taylor & Francis Group Ltd, London, 2013, pp. 3197–3202.
[30] J. van Trijp, A. Breur, First overview of the relationship between quantitative dynamic operational resilience and the Dutch Fire Services occupational safety and quality management program Cicero, in: Safety, Reliability and Risk Management: Beyond the Horizon. ESREL 2013, Taylor & Francis Group Ltd, London, 2013, pp. 1671–1676.
[31] O. Renn, P.-J. Schweizer, M. Dreyer, A. Klinke, Risiko. Über den gesellschaftlichen Umgang mit Unsicherheit, Oekom-Verlag, München, 2007.
[32] G. Rein, J.L. Torero, W. Jahn, J. Stern-Gottfried, N.L. Ryder, S. Desanghere, M. Lázaro, F. Mowrer, A. Coles, D. Joyeux, D. Alvear, J.A. Capote, A. Jowsey, C. Abecassis-Empis, P. Reszka, Round-robin study of a priori modelling predictions of the Dalmarnock Fire Test One, Fire Safety Journal 44 (2009) 590–602.