LISA: A Systemic Model For The Evaluation of Life Safety in Building Fires

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The conceptual theory and qualitative structure of a model for the evaluation of life safety in building *fires is presented The model is based on a hierarchical framework, which is then overlain with an interactive network to represent the inter-relationships between the factors directly or indirectly determining life safety Representation of time in fire events is made using five discrete notional am stages corresponding to the characteristic Phases of escape.*

The model is a systemic approach to life safety in fires. It is applicable to any building/occupancy/fire definable scenario and at the design, in-use, or post-fire stages. In its current form LISA can be used for malting comparative safety evaluations, also assessments of the implications *of changes to design, occupancy, and/ or modes of use of buildings. LISA may hence be used as a design-optimisation tool.*

Qualitative and Quantitative Scope of LISA

Life Safety during building fires depends on the dynamic performance of a large number of identifiable and highly-interactive factors. These factors define and determine the capability of building occupants to escape the various manifestations of the fire threat. Hence the definition of these factors and their inter-relationships is a prerequisite for the realistic modelling of life safety in fires.

Whilst the physical progression of any single building fire is superficially unique, the operation of the under-lying life safety system conforms to a series of norms which are open to analysis. Hence fire-safe design can be described in terms of a limited range of Fire Safety Engineering norms. Successful creative design requires the safe balancing of such norms with other design criteria. LISA deals with the limited fire safety engineering norms for life safety in fires. Figure 1 indicates the nature of the factors identified at the top end of the hierarchy. In some areas of the system, interactive factors have been identified to level 13. Interactions operate irrespective of hierarchical levels, thus complicating the mathematical modelling of consistency within the network. Figure 2 indicates the nature of interaction between simple level 1 parent factors. These act as descriptors of the hierarchical sub-systems, and the interactions illustrated may operate at or between one or more levels of the six sub-systems. Separation into sub-systems is for modelling convenience only. In practice the life safety system, and the model operates as a single undivided system. LISA does not yet deal with conflicts arising from property protection goals. Dual-goal oriented design creates a different type of criticality and interface between the life safety and property protection systems. Such conflicts are rarely solved without detriment to one or both sub-systems.

Modelling of Interfaces Within Life Safety Systems

Unlike causal thinking, where the task is to identify pairs of factors between which there is a necessary connection, in systemic thinking the task is to identify the super-ordinate system to which they belong, and then to define their relationships within such a system. A prime requirement for such an appraisal is a qualitative model based on the identified factors and their potential inter-relationships. It is these which determine the safety of the building occupants during the various stages of a building fire.

The internal dynamics of the life safety system create varying degrees of synergism between conflicting or co-operating factors. In extreme cases the consequences of this synergism may interfere with the system so critically as to initiate its failure. Depending on the analytical context, this corresponds to safety, injury, or death.

Positive (pro-safety) interactions between factors are unlikely to compensate cleanly for negative (pro-threat) interactions. The dynamics of the interface are particularly critical. They correspond to the balance between the fire and smoke threat, and the response of, and use of the building by, the occupants (with or without assistance). The effectiveness of controlling measures to limit the growth and spread of the fire and smoke also require to be taken into account. Figure 3 illustrates potential interactions of the primary level factor escape route layout. Note that these are global interactions, which will operate at a variety of levels in the network according to the static and dynamic nature of the fire scenario.

Any interactions between the various factors may produce non-linear consequences. The greater the number of possible interactions, the more complex the sub-system involved. However, this does not necessarily translate into an increase in criticality, or even to make the target factor a more significant element in the general level of life safety. Figure 4 illustrates a sample network paradox of a simple but critical interaction (training on the usefulness of communication during the event) having a profound potential affect on many other factors. Training may constitute personal knowledge of the building built up through experience. Note that communication itself is determined directly by the sub-system of daughter factors.

Simple Applications of Life Safety Modelling

Take the simple scenario of a spreading smoke threat to escapees who are travelling along a corridor towards a final exit. See figure 5a. (Ignore also the direct effects of the fire, and assume a moderately-fit escapee population who are reasonably familiar with the building. Assume also no smoke control, and no fire brigade or other active assistance).

Modern design approaches aim to eliminate this possibility of smoke spread by use of passively or actively protected routes, older building designs may not. Without knowing the exact nature of the building design, the actual significance of the threat cannot be tightly qualified (beyond being *undesirable*). Evidently, elements of the design are playing a part in the safety system, even if they are overlooked by the escapees or the evaluator. Further information is needed to make a design judgement, which will require a degree of professional intuition to assess the relevance of the implications of its interaction.

Now revoke the assumption of fitness of the individual, as indicated in figure 5b. This represents a material change in the nature of the occupancy. Any physical frailty or temporary exhaustion will drastically affect the potential contribution escapees can make to regaining their own safety (or impeding others).

Consider also hesitance (as distinct from the populist theory of 'panic'). It follows that the appropriateness of behaviour when an individual is faced by the threat of the partial smoke blockage to the escape route will be critical to their safe (unaided) escape. As expected, the interface between the threat and their power to overcome it is critical. It is also dynamic, and already becoming obviously dependent on the outcome of interactions between several factors. There are still significant residual limiting assumptions in place however.

Now consider the issue of smoke spread further - any tacit or overt smoke control sub-system has evidently failed, so this element of the safety system is *de facto* significantly deficient if it allows the smoke threat to predominate. It is also potentially critical to the escapees' safety. Any delays in decision-making by the escapees may be construed as representing only a marginal change in the appropriateness of response, but can produce a catastrophic change in the output of the system - such as death instead of injury or safety. Refer figure 5c for schematic relationships between parent and daughter factors. A weakness in any sub-factors of escape capability produces a knock-on (negative) effect on the contribution of escape route layout to safety. This is a critical interface, which can theoretically be compensated for by designing the escape route to suit the limitations of the occupants, and/or by providing smoke control measures to counteract smoke movement. If this is done, the full system will have to be modelled to avoid the potential oversight of consequential low-level interactions, which could create indirect criticality deep in the system. Generally, the lower the level the interactions operate at, the more pervasive their effects, since the system tends to operate in a bottom-up manner. By extension, this may be the most effective and efficient area of the system to plan compensatory measures.

Compensatory Design Modelling : Applications of LISA

Where there is a predictably immobile or otherwise frail population this may be 'compensated' for by alterations to other elements of the design safety system. The aim is to prevent potentially critical or dangerous interactions between factors predominating in a fire event. Straightforward examples include smoke control and the provision of refuges, the introduction of active fire protection or provisions for assisted escape.

Figure 6 represents the use of such compensatory design measures to counteract potential criticality. Note that this will introduce a new and probably more complex criticality network. Simple and fundamental is best!

Whilst the systemic mechanism of compensation is very complex, the traditional modifications have worked, because they tackled the critical elements of the system. In novel applications or where the packaging of compensatory measures is carried out at the boundaries of fire safety engineering, the margin of dynamic safety may be eroded in an unanticipated or even incalculable manner.

Qualitative Modelling with LISA

Qualitative modelling of the contribution of behaviour and/or the acceptability of the building provisions for safe passage or refuge involves the simulation of the conflicting contributions that all factors (critical or otherwise) make at various key stages throughout the fire event.

Fire events can be sub-divided according to a number of sequential activities that escapees carry out. The relationship of these notional time stages for people or the fire to real time are entirely flexible. This is significant and is particularly important to address correctly in a life safety model.

Figure 7 illustrates the conventional time stages for a fire event. Stages may be short or long, but they are usually sequential. Generally speaking, short stages associated with the available safe time for escape, and long stages associated with the required safe time for escape will yield an imbalance of a potentially hazardous nature. It is essential to appreciate that time stages represent the result of systemic activity, hence they are wholly the result of the dynamic interactions between factors contributing to the threat and safety of the escapees.

The potential safety consequences of most interrelationships between factors differ between the various time stages. The contribution of a factor may be critical in only one or some stages of a fire event. For instance, the value of a piercing fire alarm quickly wanes once you are aware of the fire and are trying to escape. In such instances a factor may even contribute to safety during one stage of the fire event, yet detract from it during another. In contrast, smoke spread into an escape route may not directly influence the behaviour or safety of escapees if they are asleep in a protected zone. Figure 8 shows the potential interfaces between factors used for compensation. Note that the factors such as smoke control do not operate until stage 2 (assuming initiation is automatic), and that the balance between escape route provision and escape capability is not relevant until escape action begins. The benefits of smoke control may tail off in the latter stages of the escape if the final escape route section is a protected route without pressurisation. As a consequence of this there is a potentially very short time window when the full benefits of a compensatory design package will operate. This may be easily overlooked at design stage. Note also that the relationship between threat and safety interfaces do not balance in the conventional sense. Safety measures have to catch up and overhaul the threat already present on their activation or use. Depending on the length of time between the various stages, this may be impracticable. Here also the criticality is an implicit result of varying systemic outputs at different stages in the fire event - the use of LISA to show up such implications requires considerable familiarity with the architecture of the modelling system.

Clearly the practice of 'trading-off' of design options requires careful discrimination, since the appropriateness of a 'trade-off' at one stage does not automatically translate to all stages. In this sense LISA represents a physical embodiment of the design decision process, and operates as a realistic design-aid tool.

To make consistent comparative judgements on building safety, which surpass the exercising of professional intuition, demands a reliable and realistic quantified relational network. Some experts hold and use some of this quantifiable knowledge, fire safety models support the estimation of other quantifiable elements of the safety system. Neither is truly systemic in its coverage or breadth of applicability. The alert expert is as aware of the overlaps and contradictions is knowledge as the gaps. The broader the applicability of a systemic model such as LISA, the more general and all-embracing its underlying framework must be, and the more alert and expert the user. Ironically, the more complex the systemic model, the more confounding is its quantification, and fires involving people are astoundingly complex to model realistically. LISA does not represent any more of a substitute for experience than the plethora of other models available. It doesn't promise it however.

Turning to the data required to move beyond qualitative intuition: Post-fire analysis is characterised by a scarcity of reliable data, particularly in the area of human behaviour and its contribution to safe escape. Hence quantitative comparisons between the contributions of human behaviour to safety and, say, smoke spread are not immediately obvious or attainable. The exact balance of the qualitative scenario illustrated in figure 7 depends upon the quantitative contributions of factors at each stage. More importantly, the sensitivity of each to marginal change is unclear. Meanwhile the frequency and relative importance of such interfaces effectively determine the safety of individuals in building fires. Focusing on the critical factors allows potentially problematic changes in design, occupancy or use to be readily identified and analysed. This is the essence of the expertise in the use of models such as LISA.

The paucity of data about fires is generally restrictive for modelling purposes. To overcome the data problems, a Delphi technique for data collection from experts was used to establish relative measures for the general contributions of various conflicting factors to life safety. Specific building fire scenarios were then modelled using this data for the underlying safety framework, overlain by subjective survey data for the comparative analysis of a specific scenario (supplied by the evaluator). LISA operated well in tests but was onerously dependent on the skill and familiarity of the user. This is symptomatic of the significant obstacles facing safe, widespread use for models generally. For further details about the quantification process, or the IKBS development of LISA, FRISK, contact the author.

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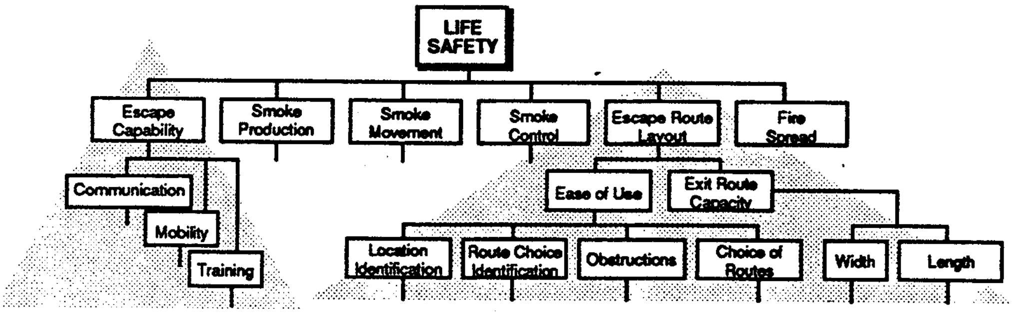


Figure 1

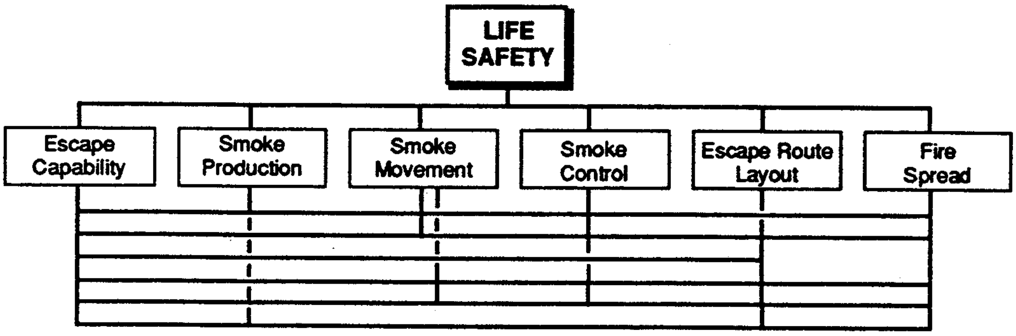
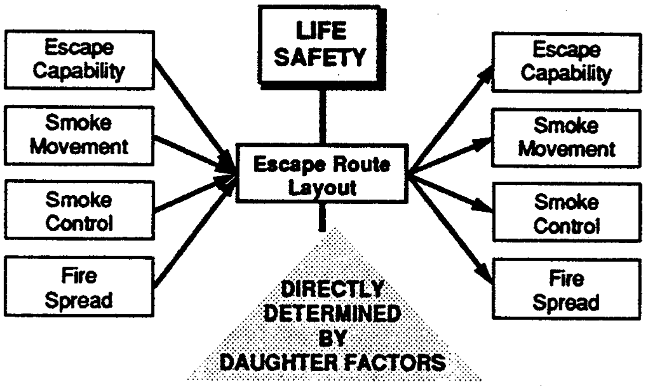


Figure 2



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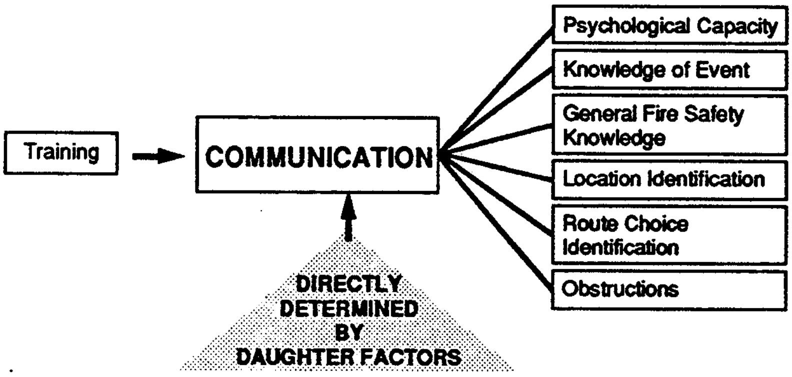

Figure 4

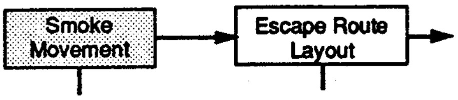

Figure 5a

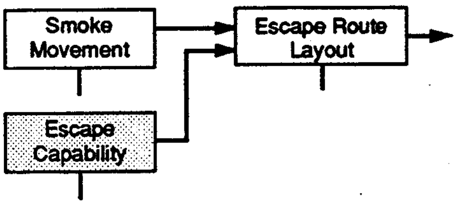

Figure 5b

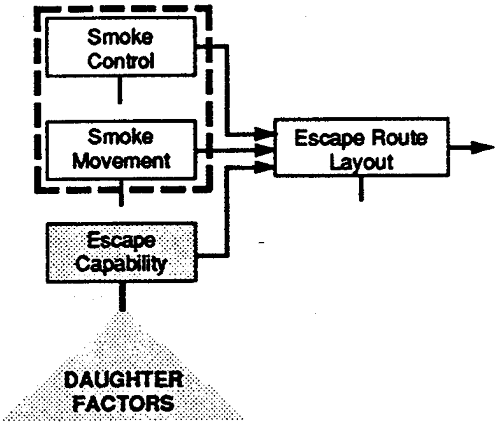

Figure 5c

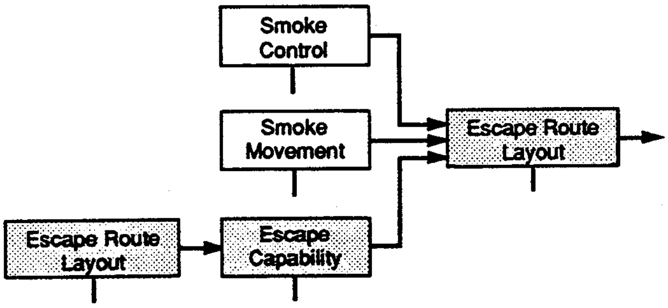

Figure 6

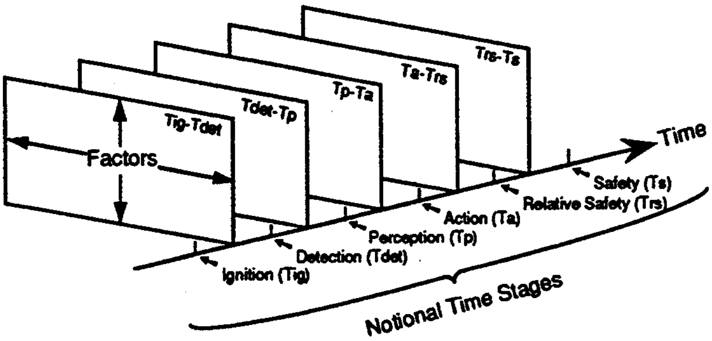

Figure 7

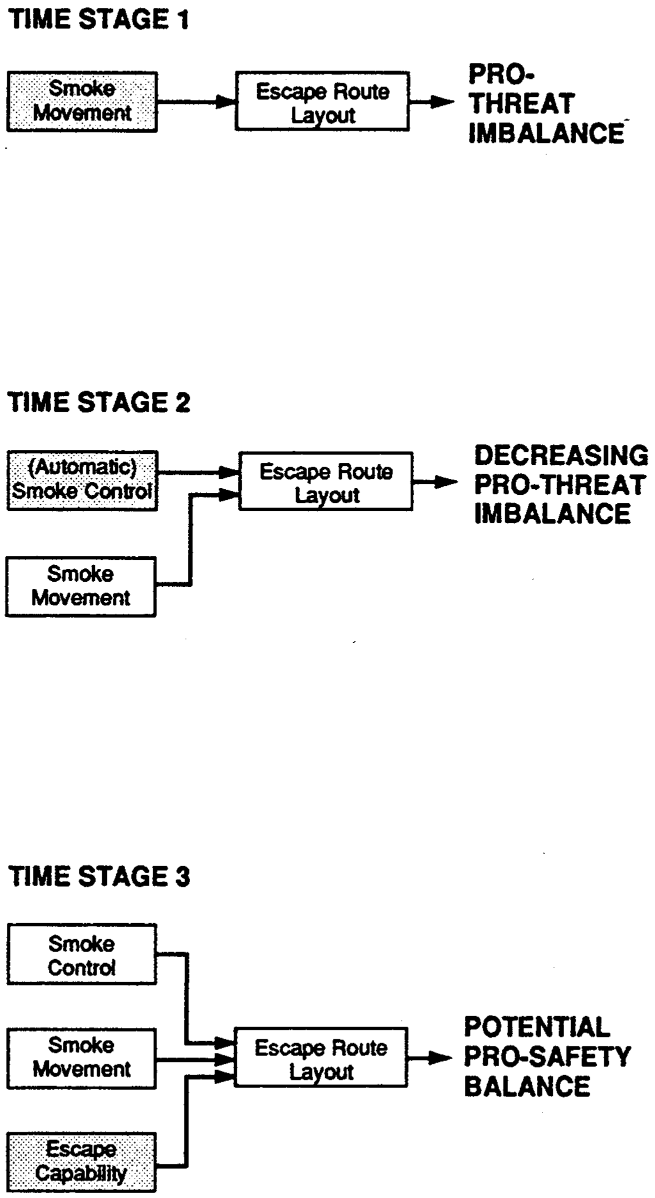
TIME STAGE 1
Smoke Movement
Escape Route Layout
PRO-THREAT IMBALANCE
TIME STAGE 2
(Automatic) Smoke Control
Escape Route Layout
DECREASING PRO-THREAT IMBALANCE
Smoke Movement
TIME STAGE 3
Smoke Control
Smoke Movement
Escape Route Layout
POTENTIAL PRO-SAFETY BALANCE
Escape Capability

Figure 8