Towards an Integrated Egress/Evacuation Model Using an Open Systems Approach

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ABSTRACT

Egress Research is fragmented through being too narrowly focussed. This research can be categorised into Behaviour and Movement. The Paper discusses the various evacuation models available and how they have not made the necessary allowances for all the aspects of egress. A new model in the process of development is briefly discussed that will use an open systems approach to egress from buildings.

INTRODUCTION

Egress research appears to have been focused into narrow compartments (Pauls 1984). Stahl and Archea (1977) identified these areas prior to this as being;

1. Field studies of the use of circulation facilities in non emergency conditions;
2. Laboratory studies (eg. sign visibility in smoke);
3. Post incident surveys of human behaviour in emergencies.

The results of the studies are well recorded in the literature. They are still somewhat fragmented, but have been reviewed and compared with codes by such writers and researchers such as Stahl and Archea (1977), Pauls (1984), and Stahl, Crosson and Margulis (1982). Fragmentation can be overcome via integration. Certain models have already been developed, but the writer would maintain that the only valid ones will be those which view egress and/or evacuation as an open system so that all aspects of egress in an emergency environment can be assessed. The Search and Rescue Model (Alvord-1983) developed by the National Bureau of Standards seems to have adopted this approach in part. Stahl's model B Fires II (1980) adopts a slightly different approach. Its implemtnation is somewhat complex because of the number of variables.

The author is in the process of developing a total model which will be known as the P.M.S. Model. The latter has been outlined in at least three papers (MacLennan 1984, 1985a, 1985b). It is being developed as part of a research programme for the Australian Uniform Building Regulation Co-ordinating Council and also as part of MacLennan's doctoral programme at Portsmouth Polytechnic. The Model will also incorporate additional areas of research such as;

1. Exit Affiliation Sime (1984a, 1984b)
2. Orientation and Wayfinding (Weisman Ozel, 1984)
3. Aspects of Visual Access which could be adapted from the work of Archea (1984)

4. Implications of behavioural research that will permit confident generalisations to be made especially in terms of sequence Keating and Loftus (1984) and as described by Sime (1984b) re the contribution of his former colleague Breaux.
5. Importance and relevance of Perceived Time Needed and Perceived Time Available Sime (1984b).

The main problem of the behavioural component of the Model is one of sequence and the prediction of times. A possible answer will be presented in a later section of this paper.

Models Available

A number of egress models have already been developed viz;

1.	Evacnet :	R.L. Francis of the University of Florida
2.	Search and Rescue:	D.M. Alvard; National Bureau of Standards
3.	B Fires II :	F.I. Stahl formerly of the National Bureau of Standards
4.	Descriptive Model: for Movement	E. Kendik
5.	Effective Width Model :	J.L. Pauls, National Research Council of Canada.

The most powerful of these models in terms of movement is Evacnet. In the writer's opinion it only deals with part of the problem, seeing it does not really cater for human behaviour in terms of time. Human Behaviours such as perception of cues, investigation for the purpose of seeking information and general coping behaviour that may not involve actual movement towards exits or along egress routes are not really included. The time associated with these behaviours could be classified as start up time (ST). Once the decision has been made to evacuate an area then individuals or groups of individuals would move towards the exits. This time could be termed (MT). The latter could be defined as the time taken for occupants to reach an exit. There are however, still problems associated with;

(a) Orientation and wayfinding (Weisman/Ozel 1984)
(b) Exit affiliation (Movement towards the familiar) (Sime 1984a) and hence exit choice
(c) Perceived time needed and available that could affect both (ST) and (MT)

The time from initial perception to exit access could be summarised as being the clearance time for an area (CT). Evacnet could be modified to cater for this in certain occupancies such as assembly buildings. This is, however, an oversimplification of the problem. It does not allow for the cyclic relationship between behaviour and movement. Movement through exit systems has been well researched by Pauls, Fruin and others. The Search and Rescue Model has partly overcome the problem, but it is only really suitable at present for Board and Care Homes. It too has potential for other occupancy types, where there is an evacuation plan and team. B. Fires II is a simulation model but its main problem is complexity in terms of the number of variables. Kendik and Pauls' models only address movement through exits in the main. The writer would maintain that there is a need for a model that is based on a systems approach as developed in management science. The egress problem can be visualised as being a management exercise be it self management or group management. The impact of the environment at large together with the emergency environment must be catered for and identified.

Prediction of the Required Safe Time for Egress (RSET)

Available Time for Egress. Cooper (1983) postulated that the available safe egress time (ASET) in enclosure fires is defined as the time between fire detection and the onset of conditions which are hazardous to continued human occupancy. The other side of the equation is RSET. Cooper (1983) defines this as being the length of time, subsequent to alarm, which is actually required for safe occupant egress from threatened spaces. This definition is valid however in certain occupancy types such as assembly building where the population density and the evacuation plan are such that egress is almost entirely movement controlled eg. stadia. Sime (1984b) is concerned with detection in terms of time. He discusses the problem of perception in terms of the time that people think they have available PTA and the time they think they need to evacuate the building safety (PTN). These times can be related directly to cues especially in terms of whether they are ambiguous or unambiguous. It is therefore imperative that RSET be related to ASET in terms of cues. Cooper's model deals mainly with single room or compartment fires.

There are other models that have been developed that go beyond ASET such as FAST (Model for the Transport of Fire Smoke and Toxic Gases (Jones 1984). Jones maintains that it is necessary from a life safety and operational standpoint to be able to make accurate predictions of the spread of fire, smoke and toxic gases. This will in turn provide valuable inputs for an egress model in terms of time available in spatial terms. This can then be related to the actual layout and/or configuration of various building types together with the resultant egress behaviour. FAST also opens up possibilities according to Jones for combatting the various problems that may arise as well as taking preventive measures. Much of this can be achieved through design intervention and "evacuation" planning. Other models have been developed such the Multi Room Fire Spread Model by Tanaka (1983) and a Two Room/Compartment Model by Zukowski and Kubota (1980). The Centre for Fire Research is currently developing a "family" of models that will eventually address most instances and provide the necessary input for the various forms of egress/evacuation models in the form of constraints. The simple concept of the designed safe egress criterion basically still stands viz -

RSET (t_{hazard} - $t_{detection}$) < ASET

The problem is therefore one of confidently predicting RSET. The one component of RSET namely human behaviour is the one that poses the problem (Sime 1984b).

Generalisations about Human Behaviour that will permit Sequence and Time Predictions. The main researchers into Human Behaviour have been Wood, Canter, Bryan and Keating. The work of Wood (1972, 1980) and Bryan in Project People and Project People II are perhaps the most widely read and quoted. They provided the necessary start and in fact identified most of the actions and/or responses. Sime, Canter and Breaux also made valuable contributions (1980), and Sime demonstrated (1984b) the relevance of this work in terms of RSET. Their "decomposition" diagrams (1980) provided a valuable insight into the relationship between behaviours in emergencies. Sime also raised problems associated with time and perception in terms of egress.

Keating and Loftus (1984) have developed a new interviewing technique known as the Behavioural Sequence Interview Technique. The main benefit of this work is that it will provide real world answers and a data base which will eventually be large enough to allow confident generalisations about human reactions and behaviour during fires. When this technique is coupled with the work carried out by Sime, Breaux and Canter (1980) and Sime (1984a) together with work of Bryan and Wood then the behavioural

component will start to take shape. The writer intends to use this technique in a modified form to design questionnaires for use in evacuation drills that he will be carrying out as part of a research project (MacLennan 1984).

Movement. Movement of people along egress routes and through exits has provided sufficient data for the prediction of the movement phase of an egress model. Stahl and Archea 1977, Stahl, Crosson and Margulis (1982) and Pauls (1984) have already appraised the literature. Kendik (1984) has developed a model based on the work of Predtechenskii and Milinski (1978). This "model" has vast potential for use within an integrated model. Kendik will be also examining the Evacnet and Effective Width Models as well this year, so that there could be further developments in this area. MacLennan intends to incorporate the results of this research into his model.

Other perameters have to be catered for such as the problems of orientation and wayfinding, group behaviour perception of additional cues and most important of all exit choice. The latter is a function of exit affiliation viz. movement towards the familiar (Sime 1984a). The study of orientation and wayfinding (Weisman, Ozel 1984) is in its infancy, but studies in non emergency conditions will (Passini) provide valuable information and data. Visual access is equally as important (Archea 1984) in terms of what features of building a person can see from a certain station within that building. When this is coupled with cognitive mapping and wayfinding then the problem with the spatial form and distribution of exits in relation to the normal circulation spaces could be more clearly stated.

Integrated Model for the Prediction of RSET. The author is currently developing a model which will be known as the P.M.S. Model (Perception - Movement Safety). Any model in this vein could be seen as being futile where it failed to view egress/evacuation as a system. The model views the occupants of a building as a form of organisation in event of an emergency. Certain types of building occupancy such as shops are frequented by the public who may not be familiar with the building. Occupants of office buildings could quite well be familiar with the building. This poses structural problems about the result "emergency organisation".

The environment at large is turbulent. "The environment" within a building during an emergency such as fire is constantly changing so that it too is turbulent. "Organisations" within the building can no longer be isolated from each other and other external organisations which go to constitute the environmental world of interactions. The organisation must therefore be studied as a system especially in terms of:

1. Its component parts (incl. interaction)
2. Reaction/Interaction with the Environment and the resultant change
3. Setting of Objectives
4. Input - Throughput - Output in terms of management effort to achieve objectives.

Organisations if they are to operate within a changing environment, must interact positively with that environment and modify their modus operandi as a result thereof. They must therefore be viewed as open systems seeing they are also similar to living systems in that in order to maintain themselves or "survive" (especially in emergencies) they must be constantly exchanging material, energy and information with the environment and modifying their goals (in part), behaviour, strategy, structure etc. Goals are extremely important in terms of reaction to and with the environment. They must be compatible if the organisation is to survive and hence the individuals within that organisation.

The occupants of buildings comprise individuals. The latter may exist in groups comprising organisations or as members of the public. There is no set ratio between the two other than a broad range that would relate to the occupancy type. Even the number of organisations occupying an office building could vary depending on the tenancy strategy of building owner. The latter may even occupy the whole building in the form of one organisation. Whatever the profile may be, this may be modified in event of an emergency.

In an emergency such as a fire the "environment" is immediately modified. The occupants of the building are therefore collectively "threatened". They receive certain cues, start to investigate them, seek information from others, carry out other coping actions, decide to evacuate, try to find their way to exits, encounter further cues, investigate further, assist others and the like. These behaviours may be structured depending on prior training and emergency management practices. The occupants in relating to one another and to the environment have common objectives;

1. To find out what is "going on"
2. To escape safely or be assured that they will be safe as result of following a set of instructions which they perceive to be correct.

The occupants are spatially related. They therefore comprise an organisation. The evacuation of or egress from a building involves its occupants either individually or in groups reacting to cues from an emergency generated environment. The main objective for each occupant or for each group and in fact for all groups is life safety. The achievement of such an objective is series of problem solving exercises. Problem solving is synonyuous with management practice. The writer is of the opinion that the systems approach can be used to accomplish this end i.e. organisations can be viewed as open systems.

The subsystems of an emergency organisation are seen as being;

1. Goals and Values: that of the "organisation" and its members related to emergencies which would be concerned with safety.
2. Structures: i.e. structuring of relationships, patterns of communication and information gathering plus the processing thereof, line of authority, level of responsibility and the like. Existing organisational hierarchies must therefore be considered.
3. Psychosocial: individual needs, motivation, behaviour, values, participation, perception of the environment, group dynamics and the like related to emergencies.
4. Technical: level of knowledge in the main. This also relates to safety education and prior evacuation training. Specialist advice may often therefore be required.
5. Managerial: need for management and coordination of the organisation to achieve objectives e.g. safety "Throughput" is therefore critical. See Figure 2a.

All of the above subsystems are part of the "whole" i.e. the organisation. Each subsystem is related to the other. Systems theory allows these relationships to be clearly identified and analysed. Emergency situations seldom occur and exist within the life of a building. The occupants of a building therefore have little opportunity of functioning as an emergency organisation in a condition of emergency. Training is therefore an essential part of the management of emergency organisations.

Another problem that exists with buildings is in the design thereof. Architects and their consultants may not be entirely aware of the makeup

of the "end users" of the building they are designing. If they carry out market research and determine their client's needs properly, then building safety can be taken into account. Building Owners and Designers often consider that it is sufficient to merely comply with the provisions of the various Codes. This could hardly be seen as being "design intervention". Each building is unique within itself together with its resultant impact on the end user.

The results of research in the area of egress and fire provide valuable input for any model concerned with life safety. These highlight the need for designers to cater for the needs of people. Fire protection and detection systems, smoke control systems, evacuation plans and procedures, location and use of exits, internal subdivision need to be designed around the use of the building and to satisfy the needs of the future occupants of the building. The P.M.S. model is being developed to allow both the owner and the designer to develop a full life safety strategy based on the analysis of a special "organisation" functioning in an emergency environment. It will also allow for a similar type of analysis for existing buildings where life safety is inadequate.

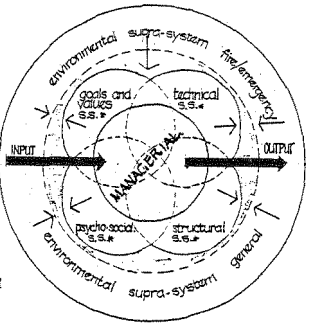
The PMS Model is shown in systems format in figure one. It has been based on a similar management model developed by Kast and Rosenzweig (1978). The throughput has been analysed and summarised in a collapsed form in figures 2a and 2b. The operational flow is cyclic in nature as shown and has been developed as a result of discussions held in Ottawa at the National Research Council of Canada between Messrs. Pauls and MacLennan and Dr. Sime. The components of the flow have been identified as Cues, Relatively Complex Behaviour, Direct Movement to and through exit and Safety. The diagram is simplistic and is virtually self explanatory. It will allow for the complete integration of the results of research of egress and the fire scenario within the various environmental constraints. The results of research clearly indicate the need for both management and responsible design intervention strategies to cater for life safety. There is a need for total involvement of people. If an organisation is seen as being dynamic then the open systems approach can be used and the psychosocial subsystem catered for. The Goals of the emergency organisation can be aligned with those of its members via an integrated Management approach such as "Management by Objectives". The "emergency organisation" would then be established and the individuals in that organisation motivated to be concerned with safety via a safety committee. Training via drills and education in the aspects of emergency scenarios such as fire would then be invaluable. Failure to adopt this approach could result in confusion. This would increase the overall time required for safe egress to the point where it exceeded the time available.

Relatively complex behaviour as a component of the throughput includes the detection of a cue, investigation and the seeking of further information, other forms of coping behaviour including fire fighting, the decision to evacuate and assisting and warning others. The Direct Movement to Exits Component includes the movement aspect, orientation and wayfinding, exit choice and affiliation, visual access, receipt of further cues which would alter the flow as shown in figure 2a and eventually movement along egress routes through exits to safety. It also highlights the fact that evacuation may not be the safest solution and that the objective of safety may be accomplished by other means such as rescue. The flow for any situation could be set down in a predetermined safety or emergency plan. The flow of information within the organisation and hence through the building in spatial terms is therefore vital. The Model is therefore seen as being an integrated approach for the achievement of the life safety objective and hence the prediction of RSET as applicable.

INPUT: FALLS INTO TWO CATEGORIES

1. FROM GENERAL ENVIRONMENT
   - KNOWLEDGE RE FIRE SCENARIO
   - PRIOR TRAINING
   - FIRE PROTECTION / DETECTION / SAFETY
   - OTHER
2. FROM EMERGENCY ENVIRONMENT

REFERS TO ACTUAL INTERNAL ENVIRONMENT DURING THE EMERGENCY; CHANGES RAPIDLY ESPECIALLY IN EVENT OF FIRE; IT PROVIDES THE INITIAL CUES.



INPUT-OUTPUT → ←
FLOW OF ENERGY, INFORMATION AND RESPONSE.-
EXTERNAL PRESSURES

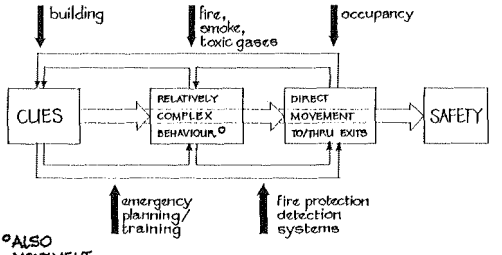
THROUGHPUT.

OUTPUT: ACHIEVEMENT OF SAFETY OBJECTIVE.

1. ESCAPE TO OPEN SPACE
2. ESCAPE TO AREA OF REFUGE
3. NO ACTION; EMERGENCY BROUGHT UNDER CONTROL OR RESCUE EFFECTED.

THE P.M.S. MODEL.
(PERCEPTION/MOVEMENT/SAFETY)

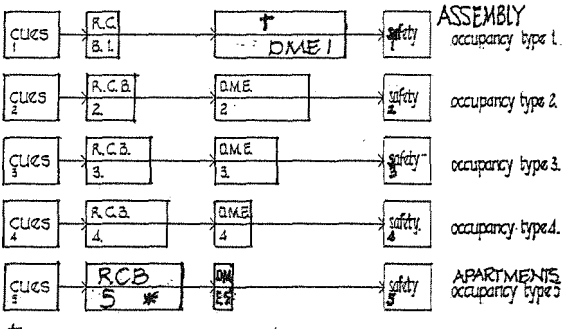
Figure 1



°ALSO MOVEMENT RELATED

Figure 2A
Depiction of Throughput PMS Model

Figure 2b
Time Variability by Component and Occupancy Type- PMS Throughput Model.



† DIRECT MOVEMENT TO/THRU EXITS
* RELATIVELY - COMPLEX BEHAVIOUR

The Estimation of Times for the RCB and DME Portions of the Throughput of the PMS Model. The current data available from Research into Human Behaviour cannot be used to make accurate generalised predictions. BSIT as developed by Loftus and Keating (1984) could overcome this problem when viewed in conjunction with work carried out by Canter Breaux and Sime (1980) (Sime 1984b). It identifies sequence hence permitting data derived from this technique to be used in making accurate generalised predictions re sequence. Activities could be "sequenced", but there will still be the problem with estimating times. The Australian Research study will utilise this approach in the design of evacuation drills. MacLennan is aware that these drills will not be under emergency conditions, but each building that is to be evacuated will be operated in "fire mode". Sime, Pauls and MacLennan are in the process of developing a questionnaire that will follow the concept of BSIT. The net result will be the development of data that can be analysed in association with other existing data and that can be used to estimate times for each generalised activity. These sequences will then be integrated to derive an overall time which will be matched against the appropriate fire growth or smoke production/filling/movement models.

This problem does not exist to the same extent with the DME portion of the throughput, as previously discussed. Effects of orientation and wayfinding, exit affiliation, visual access and the like will also be identified together with the effect of faulty design intervention strategies on the questionnaire. Direct observation techniques such as those used by Pauls (1980) will be used to reinforce and/or supplement the questionnaire.

The objectives of the throughput should be;

1. The prediction of a total RSET.
2. The comparison of RSET with "ASET" at strategic points (not necessarily Cooper's version).
3. The evaluation of the degree of safety associated with each building analysed.
4. The identification of areas requiring design intervention and adoption/modification of emergency management and training procedures.
5. Adequacy of Building Codes re Life Safety.
6. Framework for the improved design of egress systems and management.

CONCLUSION

Research will be constantly making progress with each year. Data will and is becoming more reliable especially in the area of human behaviour. Models will be able to utilise this data coupled with that of the movement phase of egress so that the prediction of a total egress time can be made. The P.M.S. Model will endeavour to achieve this end seeing it uses a systems approach.

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