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# BOUNDING DEFAULTS IN EGRESS MODELS

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## ABSTRACT

Egress model developers are in a difficult position. It is in their interest to develop models that are simplified representations of reality and at the same time reduce inadvertent misuse. While default values enable immediate (i.e., out-of-the-box) use of models without in-depth familiarization with modelling concepts and assumptions, defaults often represent optimistic and/or even unrealistic evacuee behaviours. In this paper, the term 'default' relates to a pre-set, fixed setting or value (or distribution) for a parameter or algorithm. Most egress models provide default values for five core behavioural elements: pre-evacuation time, travel speeds, route usage, route availability, and flow conditions. These behavioural elements typically need to be represented in order for the model to function. The authors suggest that bounding default settings, rather than more optimistic values, should be provided for each behavioural element. Here, a bounding default setting is a value derived from relevant empirical data that prolongs the overall evacuation time produced for a particular design. If the model user wishes to decrease the conservative nature of a particular estimate, he/she would be required to explicitly justify the modification of the bounding default value(s). This approach allows the immediate use of the model, but forces the user to modify the settings to obtain credible design scenarios.

**KEYWORDS:** egress modelling, emergency evacuation, model defaults, human behaviour in fire

## INTRODUCTION

The developers of egress models used to simulate the evacuation from fire events are in a difficult position. On one hand, it is in their interest to develop models that are quick and easy to employ, especially given the profusion of models and the expansion of applications. On the other hand, model developers need to protect model misuse by inexpert users; i.e., those likely to derive results without paying proper attention to the origin and limitations of the agent behavioural functionality and underlying data. One example of such model misuse (where results are produced through the use of inappropriate data and/or behavioural settings) is when a user configures the model based on overly optimistic assumptions, producing results that are not representative of reality, and which are then used as part of engineering analyses. A contributing factor to this issue is the relative inexperience of the users in the field, along with the scarcity of supporting documentation, the array of techniques employed, and a lack of readily available validation activities. Ronchi and Kinsey [1] found that most egress model users have less than five years' experience using such models. (Although it is not immediately clear what level of experience would be necessary and whether this alone would be sufficient to ensure responsible use.) Although model misuse is not ultimately the model developers' responsibility, it can certainly be their problem. The misuse of their model can produce inappropriate results that can (unfairly) tarnish the image of the model and, more importantly, reduce safety levels in the designs examined. These problems can then contribute to scepticism regarding model use in general and egress models in particular. No model design can satisfactorily compensate for a lack of user expertise or deliberate model misuse. Indeed, at their best, models are only able to contribute data to inform engineering decision-making rather than delivering a definitive solution (a limitation often missed by naïve users). However, there are opportunities for ensuring that the likelihood of accidental model misuse is minimized.

Model developers may not be mandated by regulations to ensure the expertise of their users. However, in other environments, the provision of suitable documentation on the use and development of the model is a requirement, implying that the exchange of information will engender expertise [2]. As mentioned previously, even if it is not the model developer's responsibility to promote user expertise and good practice, it is certainly in his/her interest to ensure credible use of the model and at least prevent outright erroneous practice.

It is beneficial (in terms of user experience and model usability) for model developers to include model defaults to enable out-of-the-box use of their model. However, previous work by Gwynne and Kuligowski [3] considered the availability of default values in simulation tools, and in particular egress models, and their potential for contributing to model misuse. Here, the term 'default' relates to a pre-set, fixed value (or distribution) for a parameter (e.g., the value for unimpeded walking speed) or the application of a specific behavioural algorithm in the model (e.g., agents travel along the path to their nearest exit). Default values are often provided in egress models to allow for ease of use of the model; however, they often represent optimistic and even unrealistic evacuation conditions or occupant behaviour (e.g., immediate response, optimal use of routes available, etc.), which can lead to inappropriate results (e.g., artificially short overall egress times). However, in this earlier work, no suggestions were made as to what default values or algorithms should actually be implemented by a model developer [4].

In this paper, the use of default values in egress models is further explored and specific values are proposed to suggest ways to combat issues of accidental model misuse. The authors suggest that defaults should represent credibly conservative estimates available in the literature (i.e., evacuation studies, egress codes and standards, or common practice), with suitable prioritisation of the sources based upon empirical and analytical support. The paper presents viable *bounding estimates* for certain types of current model defaults. In the context of this paper, a bounding default setting is a value derived from relevant empirical data that prolongs the overall evacuation time produced for a particular design. This approach is suggested as a first step in aiding the appropriate use of egress models. This is both in an attempt to facilitate good practice, but also to reduce scepticism toward egress models as a tool for use in performance-based analyses. By providing bounding defaults that prolong the overall evacuation time produced (in an overly pessimistic manner), the user is encouraged to consider alternate values for the settings that are most appropriate for their particular application; i.e., the bounding defaults are therefore provided to ensure that the user has to carefully consider the values used and that their failure to do so will be noticeable due to the extremely conservative results that will be produced.

While the authors recognize that the egress models themselves are by definition simplifications of reality (as are all models), the focus of this paper is on the following:

- the limitations in the current performance-based design process (in terms of guiding egress model use),
- the inconsistency of user expertise,
- and the misunderstanding of model techniques,

all of which might conspire to increase scepticism in modelling and inhibit its (proper) application.

The following section focuses on the limitations in the current performance-based design process, including a critical snapshot of current egress models and the difficulties encountered by those who judge performance-based analyses (often the authority having jurisdiction (AHJ)). This is then followed by a brief description of the default settings currently employed and then some suggestions as to how these may be modified to bounding default settings – encouraging users to modify settings prior to use and improving transparency in the modelling process.

## THE PROCESS OF PERFORMANCE-BASED DESIGN

In recent years, the performance-based design approach has been increasingly employed, due both to the additional flexibility provided to the designer/engineer and for its ability to quantify the safety/performance levels associated with a design given the scenarios examined – for performance levels to be demonstrated rather than assumed [5]. For life safety analysis, this approach typically requires the separate quantification of both ASET (*available safe egress time* - the time before conditions become untenable as represented by the available safe egress time) and RSET (*required safe egress time* - the time for the population to get to a place of safety, as represented by the required safe egress time). Less frequently, the two processes are coupled within the same computational environment [6]. These are then compared to establish whether there is sufficient time for a population to reach a safe place before the conditions become untenable [5]. This comparison is achieved by generating an RSET estimate that is then modified through the use of a safety factor (a coefficient based on engineering judgement to compensate for omissions and unknowns in the calculation of RSET). The RSET value is compared against the ASET value to establish whether the difference between the two calculated times represents a sufficient margin of safety (a coefficient based on engineering judgement to compensate for omissions and unknowns in the calculations). This paper focuses specifically on the generation of the RSET value, for which an engineer would use some type of egress model (computer-based or otherwise).

Any egress model is merely a simplified representation of reality that involves a combination of the model's representation of current theory, data, and the user's knowledge and judgment. Initially, egress models were relatively simple, focusing either only on physical evacuee movement (originally in the form of engineering calculations) or on the decision-making process (often derived from the work of theorists or field work) [7, 8]. These approaches reflected two positions of opinion/expertise in the field. One position felt that the decision-making process was of primary importance, while the other position felt that the physical movement of the population was of primary importance in determining the outcome of an incident. Given the history of fire safety, most assumed that the physical movement of the population was the most critical (and often the only viable) calculation to make [3].

As the field has matured over recent decades, a more balanced approach has become prevalent (although it is by no means universal). It is now broadly recognised that neither physical evacuee movement nor the decision-making process can adequately capture the evacuation process in isolation. The net result of this has been that models now typically have both physical and behavioural elements albeit to different levels of detail. Over time, egress models have increased their levels of scope, sophistication, and refinement, and now employ a range of different techniques [7, 8]. More specifically, egress models have moved from being basic hand-calculations that adopt a hydraulic approach in representing people movement, to simulation tools where the agent decision-making and movement processes can be represented in a coupled manner. Additionally, in recent decades, society has seen the design and construction of larger and complex buildings and structures. In turn, model developers have created or updated their egress models to simulate and visualize larger and more complex buildings; i.e., model scope and refinement have developed and continue to be developed.

Unfortunately, given the relative immaturity of the field and its multi-disciplinary nature, the complexity employed within current models often supersedes the underlying theory, the data available, and the expertise and experience of the user [9].[*] To make matters worse, the provision and use of model defaults often makes it possible for a non-specialist, with little or no understanding of egress issues, to use the model and produce results. For instance, performing egress calculations may only constitute a fraction of an organization's workload. In this situation, someone without specialist understanding of egress may be required to apply a model to assess performance as part of their much wider job requirements. The provision of pre-defined model defaults may result in both the model

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[*] This paper focuses on egress models. It is certainly acknowledged that fire models are also susceptible to similar issues.

developer and the user supplying answers that may conflict with a more informed understanding of human behaviour in fires and the specifics of the scenario being examined.

The performance-based design process is complex. Typically, the model is developed by one party (the model developers), used by a second party (an engineer), who has been hired by a third party (the client, building owner, etc.), and produces results that are assessed by a fourth party (building official, AHJ, peer reviewer, etc.). This process can occasionally be further complicated by the scenarios of interest being stipulated by other parties (e.g., risk managers within the client's organization). The levels of expertise regarding the theoretical and empirical basis of egress models can vary greatly between these four parties. Typically, those that sit in judgement of the results produced (e.g., AHJs) come from different backgrounds and have varying levels of experience with the performance-based design process. In addition, AHJs must be aware of the assumptions employed, the model capabilities and the specific results being presented before the results can be adequately assessed. Given the proliferation of models, inconsistency in terminology, and the variety of approaches, assumptions and empirical data employed, it is extremely difficult for AHJs (and, indeed, for anyone) to establish whether the assumptions employed are credible, the scenarios examined are relevant, and the results produced are representative and sufficiently conservative. In effect, it is often difficult for an AHJ to establish whether the user has thoughtfully selected the model settings in order to produce credible scenario assumptions, or simply used the model as provided, with little or no regard as to whether the scenario is germane. Previously, it may have been possible to identify which models and users were appropriate by name, given the relatively small size of the field. However, the expansion of the field (those involved and the tools that are used) now makes this more problematic.

A number of approaches are available to combat these issues and encourage consistent application of egress models during the performance-based design process. These include the following:

(1) The development of fire safety engineering curricula to ensure that anyone who might professionally employ egress tools has had the appropriate training on the subject matter and the models available,
(2) The licensing of model users that have either attended accredited courses or who have reached a pre-determined level of expertise in egress behaviour and modelling,
(3) The licensing of egress models that have been demonstrated and documented to produce credible and acceptable results for a variety of application types,
(4) The licensing of AHJs to specifically ensure that they are sufficiently expert to judge (1), (2) and (3), and
(5) The development of an overarching performance-based design structure (including a library of data-sets deemed appropriate for use) that constrains the process such that the results are consistently produced and presented.

However, all of these solutions have proven difficult to implement, either practically, politically, or financially. They require the agreement of interested parties on what constitutes good practice, what is an acceptable result, and/or what techniques and data-sets can be employed with egress models. They also require time and effort to develop and implement and a willingness for constraints on practice to be imposed. While any or all of these approaches may improve the performance-based design approach, they are contentious and may potentially lead to commercial, organisational and academic concerns. For instance, would additional educational requirements, user credentials and model licensing lead to a reduced application of egress tools, irrespective of their value? This question might concern model developers. The modification of egress model defaults is intended to assist with the implementation and effectiveness of such initiatives. In their absence, it may help guide model use, without constraining it to the degree that these initiatives might allow.

## MODEL DEFAULTS

A default setting is an initial condition or algorithm setting provided by a developer as part of the model software. Defaults enable the model to be used without configuration and/or the provision of new data. In reality, the vast majority of software programs, including engineering models, require defaults to prevent the model from initially being too difficult to use and to provide some guidance on parameter selections be they quantitative (data) or qualitative (selecting settings, switches, etc.).

Default values or parameters can prove most useful in the simulation of certain (basic) scenarios that are commonplace and/or similar to those from which the default data was collected [3]. However, in cases where more complex scenarios are to be simulated or where the intended scenario differs significantly from the scenario represented by the default settings/parameters, the use of default values or parameters can provide the user with ready-made input that are not relevant to the intended (modelled) scenario, potentially skewing the results of the analysis.

Model developers employ a number of default settings within models. Default settings either take the form of a pre-set value for a particular parameter or a certain type of algorithm that simulated occupants will follow. Egress models simulating evacuation scenarios typically have an array of parameters that the user can configure, with accompanying defaults. However, a discussion on all default values is beyond the scope this paper. This paper focuses on defaults provided for the five performance behavioural elements listed below [3]:

- pre-evacuation time – the time for evacuees to initiate response and commence movement to a place of safety,
- travel speed – the maximum uncongested walking speed at which individual evacuees move towards a place of safety,
- route usage/choice – the routes selected by the evacuees from those available,
- route availability – the routes available to the evacuees,
- flow conditions / constraints – the relationship between speed/flow, population density and population size.

These elements could be defined in a number of different ways. However, in one form or another, these elements would need to be addressed for an egress tool to be employed in a current performance-based design application.

## CURRENT MODEL DEFAULTS

Table 1 presents the default settings embedded within ten currently employed models [1]. These include buildingEXODUS [10], EVACNET4 [11], EXIT89 [12], FDS+Evac [13], GridFlow [14], Legion Evac [15], Pathfinder [16], PedGo [17], Simulex [18] and STEPS [19]. These models have been selected on the basis that they are representative of the different modelling approaches and the assumptions currently employed, and that a description of their default settings is available within the public domain. As can be seen in Table 1, the models adopt a range of different default positions – some more conservative than others; i.e., adopting values that are likely to prolong the overall evacuation time. It should be recognized that the exact influence of these positions upon the results produced will be dependent upon the modelling approaches adopted within each of the models examined. The proceeding discussion should therefore be considered as indicative rather than definitive as to the impact of these positions, as these approaches are not referred to.

Several of these models allow some aspect of the model to be employed with little or no user configuration of the model behavioural settings. Where this is the case, the default value/setting is stated in Table 1. Several of the models examined require some initial user intervention, but then go on to provide default settings once this intervention has been made. The user then selects from a pre-defined list of alternatives and once an alternative is selected, a value (or distribution) is adopted. These models require user selection, but then provide default settings for these selections – in essence, the user defines the scenario and the model applies defaults based on this scenario. Where this is the case, the *User selection* for the behavioural component (i.e., the outcome of this selection) is stated. Finally, some of the models provide no default setting for particular behavioural components, requiring the user to configure them prior to use of the model [3]. Where this is the case, the fact that *No default* is provided is recorded in Table 1.

The default settings assumed are shown in Table 1 and relate to pre-evacuation times, travel speeds, route use and the flow rates applied within the models. The original sources should be examined for more information on the other defaults employed. These defaults relate to the creation of populations, as opposed to individual agents with unique movement or behavioural attributes. The defaults apply when users are providing population attributes that are used to generate a number of individuals. In many cases, different default settings are assumed when the models generate individual agents. This choice has been made purely to reduce the number of examples that need to be provided and also reflect the fact that users are likely to generate populations rather than individuals.

It should be noted that default settings may be either quantitative, where the user provides a numerical value, or qualitative, where the user selects a setting where the underlying quantitative implications are not explicit. This can have the effect of masking the particular impact of a default setting from the user unless he/she is willing to specifically examine available documentation to understand this impact. Model developers also adopt different solutions in order to address the uncertainty associated with the model input; i.e., using distributions of possible settings, constant values or defining maximum permissible thresholds.

The output provided by each of these models is sensitive to the input data provided. The manner and extent of this sensitivity varies between the models; i.e., how much the results change in response to modified input parameters. In addition, the detail to which this sensitivity is documented for each model varies greatly. The variety in the extent of documentation is influenced by the lack of a requirement on models to document such information or on guidance on the sensitivity of output results to input parameters.

Pre-evacuation time is the time for evacuees to commence movement to a place of safety. Sometimes, this concept is referred to using different terminology, including pre-movement time, pre-response time, pre-travel activity time, response time, or delay time [9]. Several egress models assume by default that the evacuation processes commences without delay (e.g., Pathfinder, STEPS and FDS+Evac assume an instantaneous response). Alternatively, other models assume that agents begin evacuation at different times over a period of time (e.g., buildingEXODUS, Legion and GridFlow distribute the majority of their default responses up to 30, 60 and 74 s respectively). Again, although these distributions are assumed, the applicability to the scenario at hand will vary greatly.

Numerous approaches are used by egress models to numerically represent travel speeds. Models typically generate a distribution of values across the simulated population, produced through the use of a pre-defined range, a defined difference from the mean or through the use of the standard deviation. Default average horizontal travel speeds range from 1.15 m/s to 1.35 m/s. An even larger variety is evident in the bounding values employed, with minimum travel speeds ranging from 0.2 m/s (EXIT89) to 1.2 m/s (buildingEXODUS), and maximum travel speeds ranging from 1.36 m/s (EXIT89) to 2.05 m/s (STEPS) [10, 12, 19]. In addition, the exact method used within the model to represent movement will also determine when these values are employed and how they affect the results produced; for instance, whether speeds are controlled by local navigation, occupant density, experienced delays, etc.

**Table 1: Default settings for the core components of ten evacuation models. References are included for the data sources supporting the default settings employed where mentioned in the original source.**

| Evacuation model | Default settings for the core components | | | |
|---|---|---|---|---|
| | **1) Pre-evacuation time** | **2) Travel speeds (unimpeded/ horizontal)** | **3) Route Availability<br>4) Route Use** | **5) Flow Conditions (Max)** |
| buildingExodus 5.0 [10] | 0-30 s | 1.2 – 1.5 m/s [20] | Available/ Nearest Exit | 1.33 pers/s/m [21] |
| EVACNET4 [11] | No default | No default | Available/Optimal Route Use | No default |
| EXIT89 [12] | No default | User-selection: emergency or non-emergency conditions distribution [22] | No default | No default (User-specified capacity) [22] |
| FDS+Evac 2.3.1 [13] | 0 s. | User-selection: Population employed | No default | 1.3 pers/s/m [21] |
| GridFlow 3.30 [14] | Log-normal distribution (95% of the population evacuated after 74 s) [14] | Mean = 1.2 m/s,<br>Standard deviation (SD) = 0.2 m/s [20] | Available/ Nearest exit | 1.3 pers/s/m [21] |
| Legion Evac 1.0.0 [15] | Log-normal distribution with the 1st percentile = 30 s, and the 99th percentile = 60 s [23] | Max = 1.7 m/s | Available/ Nearest exit | Calculated |
| Pathfinder 2012 [16] | 0 s | Constant value = 1.19 m/s | Available/ Nearest exit | Calculated |
| PedGo 2.5.0 [17] | No default | No default | Available/ Nearest exit | Maximum - 1.2pers/s/m [24] |
| Simulex 6.0 [18] | 1.0 ± 0.5 s | 1.35 ± 0.2 m/s, (60% population)<br>1.15 ± 0.2 m/s (40% population) | Available/ Nearest exit | Calculated |
| STEPS 5.0 [19] | 0 s | Normal distribution [20]<br>Mean = 1.35 m/s,<br>SD = 0.255 m/s,<br>Min = 0.65 m/s,<br>Max = 2.05 m/s | Available/ Conditional | 1.49 pers/s/m [25] |

When modelling egress, there needs to be consideration of what routes (or final exits) are available for evacuation, what final exits occupants will actually use of those available, and how they select routes to reach the final exits. The issues of default settings for route finding and final exit choice are closely tied together, and the availability of a route or final exit will invariably affect how occupants select their route. In the majority of cases (buildingEXODUS, GridFlow, Legion, Pathfinder, PedGo and Simulex), the default setting is for occupants to select their nearest exit and to use the shortest path to reach that exit (see Table 1). The population size, the initial distribution, the width of flow constrictions (such as doors) up to and including the final exit, whether occupants travel along horizontal surfaces or negotiate stairs, the distance between individuals' starting locations, and the exits etc., will influence whether this 'nearest exit/shortest path' approach is conservative. In contrast, STEPS by default implements a conditional route choice, where the routes adopted are influenced by several scenario factors, and FDS+Evac, EVACNET4 and EXIT89 require that the users must intervene [11,12,13, and 19].

Flow rates relate to the achievable/achieved number of evacuees across a particular component. Egress models focus primarily on providing default values for flows through doors, given that the most frequently observed narrowing within a structure is a doorway (i.e., where a flow constraint is most likely to occur). This is the component described here. Fixed default maximum flow conditions are set for most of the evacuation models currently available. Default maximum restricted flow conditions range from 1.2 pers/m/s to 1.49 pers/m/s (see Table 1). The other models either have no default setting (requiring user intervention) or do not restrict the flow rates employed, but instead allow them to be calculated by the model as a result of the simulated conditions (for instance, where the models are continuous).

As discussed, some default values or algorithms can, and often do, produce overly optimistic evacuation scenarios unrepresentative of actual events – or at least unrepresentative of the scenario in question. This leaves the authors considering the following questions:

- How representative and applicable is a default ‘scenario’ being applied (i.e. the scenario produced from the set of default settings employed)?
- Is this default ‘scenario’ conservative, optimal, or somewhere in between?

## BOUNDING MODEL DEFAULTS

Instead of the use of optimistic default or unrepresentative values (for instance, pre-evacuation times set to zero seconds), the authors propose that default values and algorithms should represent bounding values derived from *credibly (or appropriately)* conservative estimates available in the literature (i.e., evacuation studies, egress codes and standards, or common practice). In this instance, credibly conservative estimates for each of the core egress components would be those values that produce conservative, and at times, maximum egress times for a fire/egress scenario. These bounding default values should serve as the initial foundation of each model scenario simulated by the user.

The bounding default values represent conservative estimates for each of the five parameters described. These values are *not* intended as values that would typically be used by the engineer, especially as a complete set; quite the opposite. Their purpose is to bound potential parameter values such that the engineer would typically be expected to adjust the actual parameter from the bounding value to better reflect the scenario of interest. In this case, the engineer would then need to justify the use of a more optimistic value to the third party reviewer/AHJ who would (hopefully) be aware that the parameter employed was not the bounding default value. For the bounding default approach to function as expected the AHJ would need to be familiar with these – to enable comparison with assumptions provided to them by engineers as part of results submissions. If the model user wishes to decrease the conservative nature of a particular estimate or set of estimates, which will almost certainly be the case, he/she would then be required to explicitly justify these changes.

It should be recognised that the user might still adopt the bounding defaults even though they do not represent a credible scenario when used together. This might then ensure a conservative scenario although leading to issues of over-engineering. Although potentially more desirable than under-engineered and unsafe designs, over-engineered designs may be expensive and inefficient. This is recognised as a limitation, however, it is suggested that the financial disincentives associated with the bounding defaults suggested would be prohibitive and help prevent this limitation coming into practice.

A common set of bounding default parameter values provides a number of benefits:

- It ensures that those intending to use the model with its initial configuration will then produce potentially unrealistically conservative results relative to those that might be produced using typical parameter settings. Should accidental misuse of a model occur, it will then produce pessimistic results in comparison to the current situation.

- Assuming that the initial configuration is reported early in the design phase or with the model output, it will be straightforward for third party reviewers/AHJs to identify where user assumptions were less conservative than the initial configuration or where the results do not reflect the assumptions made. This assumes that AHJs are familiar with the bounding default positions and with the practice of egress analysis.
- The model user would then have to explain these deviations from the conservative default parameter values and justify them as part of the reporting process.
- It would in no way constrain current use or applications. It would simply make the assumed initial conditions more conservative and then make subsequent deviations from the initial conditions more apparent.
- It would also allow model developers to maintain the current out-of-the-box model capabilities, allowing users to become familiar with the model capabilities and operations during the training period. It is recognized that egress modellers may often have prior expertise in the use of other types of models (e.g., fire models). As such, they are more likely to be confident in their ability to navigate around the model and then are more likely to learn how to use the model by engaging with it directly in support of other training activities.

This last point led to the authors' rejection of an approach suggesting model developers exclude model defaults outright: where a model would then arrive as a framework requiring the user to provide parameter values (that are user-definable) before the model could be used at all. It is felt that this approach, although currently employed by some existing models (see Table 1), would impact both the training and demonstration potential of many egress models and would therefore not be attractive to many model developers. It would also require a great deal more effort from the engineer in configuring the model.

In this paper, the suggested bounding values for the five performance behavioural elements are not the most conservative values available in the literature – they do not represent extreme outliers. The most conservative values were not adopted for two reasons. First, the use of extreme outlier values might preclude the immediate use of the model (out-of-the-box, see earlier discussion). For instance, the adoption of a default pre-evacuation time of several hours (observed in several real incidents [26]), may severely hamper the use of the model. The suggested approach still allows the novice user to familiarise themselves with the model. Second, the use of extreme outliers as defaults may influence the avoidance of model use altogether for egress design, training, or other types of use, which would negate the purpose of this paper. It is important, both in this paper and in the context of model use, that the bounding defaults are clearly documented in terms of their intent and their basis. Finally, the bounding defaults may generate an additional conservative scenario by which to test the robustness of a particular design's performance.

It is recognised that the absolute impact of these default settings upon the model output will differ between the various egress models. Similarly the method adopted within each model to reflect these default settings may vary significantly. However, of more importance is the outcome of the representation than the internal mechanism adopted. For instance, a conservative base travel speed ($S_1$) is introduced into Model A in place of its current default travel speed ($S_2$). This will then reduce the default travel speeds of agents in Model A, such that the assumption of Model A ($S_1$) is more conservative than Model A ($S_2$). A similar action is also assumed for Model B, such that the assumption of Model B ($S_1$) is more conservative than Model B ($S_2$). However, given the different approaches adopted, it is not possible to guarantee that Model A ($S_2$) is more conservative than Model B ($S_1$), even though it is likely if the settings are sufficiently conservative. What matters, however, is that the defaults produce relatively conservative output in comparison with other parameter sets for a particular model. The approach produces relative conservatism (within the application of each model), rather than absolute conservatism (across the application of all models).

Potential values for each of these five core egress behavioural elements are now briefly described. It is not suggested that these are definitive. The final accepted values, should this approach ever be seen as viable, would require research and discussion between interested parties (i.e., developers, users, regulators, etc.). Values would also need to be agreed upon for a broader range of parameters than the five core behavioural elements examined here (e.g., speed in smoke, speeds on different egress components, etc.). The examples presented here are therefore intended to initiate this discussion and be the first iteration of values that might then be modified. The fact that the absolute impact of the bounding defaults identified will differ between different models given the various techniques applied warrants further analysis, and will therefore require assessment from the individual model developers of the defaults' impact upon their model's performance.

The boundary defaults presented are derived from empirical data-sets and are deemed to be broadly conservative; i.e., each parameter would typically extend the overall evacuation time produced in comparison with other values seen. These default values would still allow the engineer to use the model out-of-the-box and experience the model running in the expected manner, allowing them to familiarize themselves with the model capabilities and operations. However, given their conservative nature, the bounding default values would not typically present viable values for the engineer to employ and would therefore require user manipulation. This manipulation would then need to be justified to any third party reviewer/AHJ given that would be aware of the assumed set of bounding default values.

## PRE-EVACUATION TIME

Methods that might be employed by egress models to simulate pre-evacuation timing include the following:

- all occupants begin evacuation without delay (i.e., simultaneously at 0 s otherwise referred to here as instantaneous)
- all occupants begin evacuation at some set time after the alarm sounds (i.e., simultaneous),
- occupants begin evacuation at different times over a period of time (i.e., distributed),
- and occupants begin evacuation based on the conditions within the scenario (i.e., conditional; for instance, environmentally or procedurally determined) [27].

As discussed earlier, several models provide an instantaneous pre-evacuation time default (or an approximation of this), and will only simulate pre-evacuation conditions if the user chooses to implement a pre-evacuation value or distribution. This instantaneous method ignores the effect of any time occupants may spend seeking information, preparing for evacuation, helping others, or making decisions to perform any action other than evacuation, which has been documented as a frequent occurrence in building fires [28].

Both the literature available (e.g., [26-29]) and codes/standards (e.g., [23]) can be used to identify conservative values for pre-evacuation time. Depending upon the occupancy type for the building, research often presents pre-evacuation timing as a distribution [30]. Data show that pre-evacuation time can range from seconds to greater than 30 min (1800 s) for office high-rise building fires or residential evacuation drills [26, 30]. More importantly, the data typically fits a more skewed distribution rather than a normal distribution because most individuals initiate evacuation within some shorter time frame after becoming aware of the incident, and then the remaining occupants produce a more lengthy time delay or longer tail of the distribution. For example, the mean population in the 1993 World Trade Center bombing initiated evacuation within 30 min, however, some smaller percentage of the population took up to four hours to begin evacuation [26]. Such factors that could skew the pre-evacuation time distribution include occupants' alertness, activities, movement or cognitive disabilities, familiarity with the space, etc. [26]

New Zealand guidance [29] and British Standards [23] also provide values for conservative (or maximum) pre-evacuation times. Although it should be acknowledged that regulatory guidance is not always based on empirical data, it is designed to direct engineering practice [31]. These values are often based upon the occupancy type of the building, the activities of the occupants, and the quality of the fire management. C/VM2 Verification Method: Framework for Fire Safety Design [29] suggests a simultaneous pre-evacuation time of 1800 s for buildings where occupants are considered sleeping and under the care of trained staff (e.g., hospitals and rest homes). British Standard 7974 [23], which provides a range of minimum and maximum pre-evacuation times, suggests a *minimum and maximum* value of "> 20 minutes" (1200 s) for occupants who are likely to be sleeping and unfamiliar in multi-story buildings equipped with only minimal fire management (e.g., in hotels, boarding homes, or serviced apartments).

When identifying a conservative estimate for pre-evacuation time, two main questions arise:

1) What method of simulating pre-evacuation time is more conservative: distributive, instantaneous simultaneous or conditional?
2) What is a reasonable maximum value for the pre-evacuation time from the literature and standards?

The conditional method relies on the circumstances of the simulation to predict when people react. However, only a few models incorporate this method of simulating pre-evacuation time, as there is currently not enough theory or data available to do this accurately for a large variety of buildings [7]. Therefore, this method is not considered as feasible for this conservative default approach. The instantaneous method could provide some conservative benefits on the evacuation models results; for example, if all occupants begin evacuation at the same time in a densely populated building, queues will likely develop at various locations in the building (e.g., stair entrance doors or main building exits), which is conservative in this context extending the overall evacuation time for the building. However, the simultaneous method will likely introduce additional conservative benefits on the modelling results since it prompts individuals to begin evacuation (at the same time) at some specified time after notification and still provides the potential increases in the congestion as identified previously. The distribution method accounts for the fact that individuals or groups delay for some time after notification; however, it also allows for a distributed scheme, reducing the potential for queue-imposed delays throughout the building. Therefore, a simultaneous value will be suggested for the conservative pre-evacuation time default. It is also simpler to represent within a model than some of the other options suggested.

From examining (the admittedly patchy) available research and codes/standards, a value of 1800 s (30 min) [4, 26] is suggested here as the bounding pre-evacuation time for egress models, to be applied simultaneously across the population. As noted above, this is by no means the maximum value observed in the empirical data available. However, it can be considered as a conservative value for various types of buildings, occupant types, and building alarm systems, without necessarily including the extreme tails of the distributions examined; indeed, it is extremely conservative except for a small number of real incidents where the structures were complex or involved sleeping occupants (such as the WTC, WestChase or MGM Grand incidents [26]). This is certainly the case when this value is compared with the values that would typically be employed as part of a performance-based design. It is therefore argued that the suggested value represents a sufficiently conservative default to require user modification prior to engineering use, without precluding out-of-the-box model use – a large value identified in the literature that still allows for the model to be run immediately [26, 29, 30].

*Bounding default pre-evacuation time: 1800 s*

## TRAVEL SPEEDS

The unimpeded walking speed of individuals depends on a number of factors. These include the person's age, sex, their general fitness (including any disabilities, medical conditions, etc.), encumbrance levels, whether they are travelling horizontally or using stairs and any sense of urgency. Data taken from various sources in the literature [4, 9, 26, 30, 32] would suggest that maximum unimpeded walking speeds could be approximately 1.8 m/s and average values in the order of 1.0 m/s. Of course, in reality, travel speed is often reduced through physical factors (e.g., the presence of others, nature of the terrain, etc.), psychological factors (e.g., motivation), and sociological factors (e.g., waiting for a slow moving individual in the group); only the basic unimpeded walking speed is considered here, where the individual is able to move freely in clear environmental conditions. Also, the decision to focus on walking speeds (rather than running), although justified in terms of being conservative, does introduce some ambiguities into the calculation.

Possible approaches include *homogeneous* (all occupants with the same speed), *heterogeneous-hypothetical* (occupant speeds distributed within an arbitrary range), *heterogeneous-specific* (occupant speeds distributed to represent specific situation) and *affected* (speeds manipulated to represent procedural, environmental, innate or structural factors) approaches [27]. In addition, the exact method used within the model to represent movement will also determine when these values are employed and how they affect the results produced; for instance, whether speeds are controlled by local navigation, headways, experienced delays, etc.

A frequently-used design value for unimpeded walking speed is 1.2 m/s [32] and this is specified in the newly published Verification Method [29] to meet the fire clauses of the New Zealand Building Code.[†] This design value is clearly conservative when compared to the 1.8 m/s maximum speed mentioned above; however, research published in the literature [30, 33] shows that minimum walking speeds would be around (0.1 to 0.2) m/s where a person has some form of permanent or temporary disability, whereas Boyce et al, implies that a value of 0.3 m/s might be a representative lower bound of those with a movement impairment using a movement device [34]. Given these examples, it is suggested that the unimpeded walking speed should be set to 0.3 m/s so as not to exclude the possibility that simulated occupants have some form of disability such as would be the case when modelling a hospital or care facility, while not selecting the most extreme value available.

*Bounding default travel speed: 0.3 m/s*

## ROUTE AVAILABILITY AND USAGE

Route use is directly influenced by the routes that are deemed to be available and then the manner in which the available routes are used. It is acknowledged that these defaults are of a different nature to the others addressed: more qualitative than quantitative. It is also acknowledged that the implementation of the suggested changes may be problematic for some models, given the methods that they employ to represent occupant route selection. However, the exact method selected to implement these changes is not as important as the route selected by the simulated evacuees. These changes are included as it is felt that, without their inclusion, the impact of the other more quantitative bounding defaults may be less predictable and potentially undermined.

### Availability

Other than in simple cases, buildings are likely to have many available exit routes. However, availability does not imply familiarity and use. Not all routes may be used due to lack of evacuee familiarity with the building, typical access rights (security protocols), etc., and not all of the ways out will be expected to serve as an exit (e.g., vehicle access paths). Assuming that the existence of a route implies the use of a route is an optimistic assumption.

Egress models can adopt a number of different approaches when representing exit availability. This might be *environmentally-based* (routes lost through deteriorating environmental conditions), *procedurally-based* (routes constrained by procedural measurements) or *regulation-based* (routes limited according to regulatory requirement), etc. [27]. Alternatively, from an egress modelling perspective, the initial default option might be to consider that all routes and exits are available to

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[†] Again, it should be acknowledged that regulatory guidance is not always based on empirical data, it is designed to direct engineering practice.

everyone. However, this option does not account for the possibility that a route is not viable for the reasons described above and may produce optimistic results.

A common design approach is to assess RSET with one exit assumed to be blocked by fire. As an example, the New Zealand Verification Method requires that certain design scenarios be assessed in which the primary escape route is blocked by fire [29]. This approach suggests that an egress model should at least have a default algorithm that would identify the primary exit as unavailable, where this exit will depend on the type of building, the way in which the building is normally used and other design considerations. It is probably unrealistic to expect a model to automatically assign a primary exit without further human intervention; however, it might be reasonable to assume that the primary exit is likely to be the widest final exit available and so the default final exit algorithm for an egress model might be one that discounts the widest final exit.

At this point we might ask whether discounting of the widest final exit is sufficiently conservative or should the default setting within the model be further refined? Given there is the potential that there will be more than one final exit as an alternative to the primary exit and these alternative exits could be of different widths then a reasonable conservative assumption  is to assign the use of the narrowest final by default.

**Usage**

A number of methods are available to egress models in order to simulate route use. These include the following:

- *proximity-based calculations* - occupants use nearest route,
- *design-based calculations* - occupants use routes according to capacity,
- *familiarity-based calculations* - occupant route use is biased to reflect understanding of space,
- *procedure-based* - routes are used to reflect procedural measures,
- *environmentally-based calculations* - routes used according to some tenability assessment [27].

Determining a conservative route finding algorithm for an egress model is not as straightforward as identifying the narrowest final exit, as the path to the final exit influences the clearance time and therefore whether the route should be considered conservative. Options include implementing a maximum travel distance algorithm, an algorithm that identifies the narrowest constriction along an escape route, an algorithm that assesses escape routes that might result in the slowest movement speed (e.g., results in stair descent rather than horizontal travel) or some alternative or combination. However, the scenario will dictate whether or not these approaches are conservative.

As already discussed, there will also be an interaction between the escape route that evacuees travel and the population density along that route. It might be that the longest travel distance does not provide a sufficiently conservative egress time if congestion is a more important factor. Algorithms that assess the number and/or density of agents in spaces or using particular routes could be considered, but this then requires that simulations be run in the first place to examine if population density becomes a significant factor and so do not lend themselves to default egress model settings.

Given that it is suggested that the default exit availability algorithm is one that identifies the narrowest final exit, then we can consider how agents will select a route to that exit. This combines (an admittedly inept) procedural approach with a maximised proximity approach, as outlined in the bulleted list above. An option would be to have each agent move to their final exit using their longest available travel distance. However, where agents are located in different spaces it is quite likely that their individual maximum travel distances will mean that counter-flows will be generated and produce counter-intuitive routes being generated. From a developer's point of view, it is likely that creating such algorithms will be quite difficult and time-consuming to implement in some of the models. In addition, some models may have a limited capacity to represent route availability and use, and the conditions that might then be generated; e.g., some egress models have a limited capability to simulate counter-flows so this option for an algorithm may not be viable. An alternative would be for all agents to travel to a single furthest final exit which can be determined geometrically by the model irrespective of initial location. Although this means that agents may or may not move the maximum travel distance depending where they begin, it is an algorithm that is more likely to be one that a model developer can implement and still produce a conservative outcome.

Further research is needed on assessing the effect of different exit availability, different route selection algorithms, and population size and distribution [9]. However in the absence of this research, this paper suggests that the default exit selection is the narrowest single final exit and where there is more than one final exit with the same narrowest width then the final exit that is geometrically most remote be used. If two or more final exits are of the same minimum width and the same maximum travel distance then all agents are randomly assigned to one of those final exits.

*Bounding default availability/use: Narrowest, most geometrically remote exit.*

## FLOW CONDITIONS

The assumed flow value represents the number of people that can pass by a certain point over a period of time. This can be represented as a unit (specific) flow rate per effective width or a component-based flow rate (described here [32]).

In an egress model, flow values can be imposed before the simulation begins (by either the model or the user) to represent regulatory or empirically-derived values, or predicted by the model as an outcome of the human interactions [27]. Additionally, imposed or predicted flow values can be specified in the egress models for corridors, aisles, ramps, doorways, and stairs in buildings. Therefore, this paper will identify a conservative default value for doorway flow constraints that can be imposed by the egress model before a simulation begins.

Both research and engineering analysis can be used to identify conservative default values for occupant flow. Fruin [20] specifies a minimum flow rate (i.e., calculated flow derived from observations) of 0.67 pers/s (40 pers/min) through free swinging doors in non-emergency situations. It should be acknowledged that several researchers, including Fruin, have requested that it now not be used as part of engineering analysis given the age of the data. It is used here given that is still provides a conservative estimate of expected flow and contrary data is not readily available. Additionally, Gwynne and Rosenbaum [32] present an engineering model that specifies a maximum flow of 1.30 pers/s per metre of effective width through doors, which corresponds to conditions where density is 1.90 pers/m$^2$ (representing the point in evacuation where density conditions are such that the building can obtain the optimal number of people flowing through the door or exit route space). This curve of specific flow was developed based upon an engineering analysis of data from a variety of sources, and further research has found that 1.30 pers/s/m of effective width is possibly already conservative in nature. For example, Zhang et al. [35] obtained an average door flow rate around 1.60 pers/s/m of effective width with peak values up to approximately 2.00 pers/s/m of effective width.

For the purposes of this paper, a conservative value is one in which a lower (or minimum) flow rate is suggested. A calculated flow rate of 1.19 pers/s is obtained when using Gwynne and Rosenbaum's maximum specific flow value for a 0.91 m (36 inch) wide door. When comparing 1.19 pers/s with 0.67 pers/s, Fruin's lower value for a free-swinging door provides a minimum and more conservative value. Therefore, Fruin's lower value of 0.67 pers/s (40 pers/min) is suggested here for the default flow through a door. The units for this default value are persons per second, and this value is not to be modified further for any specific door width. Instead, this conservative default value should be applied to any single leaf door, independent of size, as long as the door leaf width is sized at the regulated minimum width. In cases where double leaf doors are used, for example, the value of 0.67 pers/s

(40 pers/min) could be used for each individual door leaf (as long as each door leaf is sized at the regulated minimum width).

*Bounding default flow conditions: 0.67 pers/s for a single-leaf door opening.*

It should be noted that these suggested model defaults represent constraints rather than targets for movement or behaviour. In situations where two or more defaults interact (for example, travel speeds and flows), the outcome should be constrained by the most conservative setting of the pair (or group) of defaults, rather than the model attempting to meet all of the stipulated default settings at one time.

## DISCUSSION

The bounding values and settings suggested above are intended to provide an initial step towards producing a set of conservative default settings. It is acknowledged that the impact of these settings will differ across different models and scenarios, especially given the range of methods employed within the models. In specific scenarios, there may be more conservative options available. However, it is contended that the combined impact of these settings is broadly conservative (see Table 2), albeit potentially unrealistic. These default settings provide a baseline that the user would need to modify to represent scenarios of interest, requiring justification for these modifications to be submitted to any third party reviewers.

**Table 2: Set of suggested bounding default settings.**

| Core component | Bounding default setting |
|---|---|
| *1) Pre-evacuation time* | *1800 s* |
| *2) Travel speed* | *0.3 m/s* |
| *3) Route availability*<br>*4) Route use* | *Most remote, narrowest exit.* |
| *5) Flow condition* | *0.67 pers/s* |

The intent of these settings is to ensure that initial, out-of-the-box model use is still viable, but does not provide inappropriately optimistic results. It is not the intent of the authors, however, to limit the use of computational egress tools. Instead, the general adoption of conservative defaults settings in the manner suggested will contribute to the reduction of scepticism regarding the application of egress models in the following ways: (1) model use - reduce the likelihood of the model being accidentally used in a non-conservative manner, (2) output assessment - allow third parties to more easily assess user actions in relation to the settings employed, and (3) public relations - indicate the intent of model developers and model users to ensure the reliable and consistent use of the models.

In reality, it is highly unlikely that these defaults would be used in engineering analysis given their conservative nature. Indeed, that is the point. The implementation of these defaults would then still allow model use out-of-the-box, but would place an extra check on the actions of the user. Their accidental adoption would be notable in the unexpectedly conservative output and would then require reconfiguration of the model on the part of the user. As such, the exact impact of these default settings upon the results produced in each case is less critical than might otherwise be the case (requiring detailed justification on the basis for the assumptions made) – given that they are effectively a safety net ensuring conservative output given user error, rather than a suggested value to be employed in specific scenarios.

The values/settings provided here can be criticised on a number of fronts:

1) The values are not appropriate for typical scenarios.
2) Default settings are provided for only five performance behavioural elements, rather than all default settings in egress models.

3) The impact of these default settings on model results will be different when implemented within different models, leading to different results being produced by models using the same default settings.
4) The modification of default settings presents an unnecessary overhead to model developers and model users.
5) The default settings presented do not represent the most conservative values for each performance component.
6) The concept places significant commercial pressures upon a model.
7) There are other, potentially more appropriate methods to ensure the reliable application of egress models.

These default values are offered as one suggestion. If these criticisms encourage debate on the approach, then they are welcomed. The settings could also be criticised on an engineering basis; i.e., that the combined effect of these settings does not represent a credible scenario. However, this is deliberate. Referring to the seven criticisms, these settings are not intended to represent a credible scenario (see Point 1); indeed, it is intended, in all but hypothetical scenarios used for initial training, that the default settings would be modified by the user. It should also be noted that many current models do not employ default settings that when taken together represent scenarios that represent credible or realistic situations [7, 8]. Instead, they represent a (similarly) hypothetical situation – albeit less conservative. Regarding Point 2, it is expected that if this concept is of interest, that the parameter set would be both expanded and also the bounding values would be refined.

Regarding Point 3, it is noted that not all models represent the behavioural elements or allow user modification of these behavioural elements. It is therefore suggested that models would adopt the bounding default values where the behavioural elements are represented and user-defined. This idea is consistent with the previous discussion regarding the relative conservatism of model output by these bounding values. However, this issue would certainly need further discussion should this general approach be adopted. This approach might also help a third party reviewer understand what behavioural components were actually represented within the model in question.

Regarding Point 4, it is agreed that there might be some overhead (effort/cost) for model developers should these bounding defaults be required. However, the concept described is less onerous than others that might be considered for ensuring good practice; indeed, where appropriate the developer effort required was a factor in the bounding parameters suggested. The concept may also require more effort on the part of the model user. They would need to more closely scrutinize the parameters employed and then justify their modification. This is seen as entirely beneficial. It should also be remembered that this additional effort is much smaller than might be expected should another of the viable approaches be adopted: models having no default settings at all.

Regarding Point 5, it would have been straightforward to pick absolute conservative values for the parameter set that are available in the literature examined; i.e., the maximum or minimum values represented in the literature examined. Even more conservative hypothetical values could have been suggested than are presented here in this paper. However, this would have defeated one of the primary objectives of this concept: ensuring that the model would still be available for out-of-the-box use. Given that the results produced would be incredibly conservative, adopting more conservative defaults would be largely redundant anyway.

Regarding Point 6, it is true that a user might choose a model that has fewer safety nets in place; i.e., constrains engineering use, even if only at the initial stages. This choice might be made for a number of reasons, many of which are benign. This would primarily be a problem when a user intended to deliberately misrepresent a scenario in order to reduce the estimated egress times. In contrast, it might also be noted that some users would appreciate the additional concerns shown by model developers to ensure that the model was not mistakenly used.

Finally, Regarding Point 7, it is recognised that other more robust approaches exist for ensuring proper user practice. However, none of these are currently uniformly adopted. Indeed, there are also other default approaches available such as embedded data libraries from which the user is forced to choose given the scenario faced. However, it is felt that this approach ‘suffers’ from many of the same issues as the approach described here, without the ability to ensure a conservative initial default scenario. This was not adopted here as it was felt to be prescriptive. These might include,

- active, well-informed AHJs would ensure that the scenarios initially developed were such that they reflected credible real-world conditions (should the AHJs be active through the engineering process).
- well-informed AHJs, with detailed experience of the subject matter and the modelling tools available would notice when model configurations were inappropriate or not credible or where the model capabilities were being misrepresented, misunderstood or misapplied.
- well-informed, expert users would ensure a rigorous configuration of the models preventing the accidental adoption on inappropriate behavioural assumptions and would also be less inclined to impose inappropriate assumptions by design.
- code developers would produce a formal structure including specific guidance on the user of models, the scenarios to be examined and the data-sets to be employed.
- models could automatically ensure that any results produced were clearly associated with the initial conditions and that users are warned when default settings were used.

They may be considered to be more expensive, more onerous, more invasive (to the model developers and the model users) and typically require a more comprehensive regulatory structure to be put in place by an organisation that has taken ownership of the issue at hand.

## CONCLUSION

This paper has suggested the use of bounding default settings. These have been derived from values and algorithms available in the evacuation studies, egress codes and standards, or common practice. The provision of these settings allows the immediate use of the model for training purposes, while forcing the user to modify the default settings in order to obtain a credible simulation for the purposes of design. It is hoped that these settings would help combat issues of model misuse within engineering applications.

It is likely there will be debate as to whether bounding default values should be used at all and, if they are used, what those values should be. As mentioned, the suggested approach is intended to be a basis for further discussion, but also to be provisional in nature – to encourage the more reliable application of egress tools in the absence of regulatory guidance. Ideally, the adoption of a set of bounding default settings by model developers would produce a *de facto* regulation (expectation) regarding the initial scenario assumed within an egress model. If this should be codified, then the default settings become a redundant check on mistakenly configuring the model in an overly-optimistic manner.

The authors suggest that a user should be required to robustly justify the model values employed and that the suggested approach reinforces this. One concern might be that requiring the user to go through the model inputs and make adjustments from the conservative default values is potentially time-consuming. However, it is better (in all instances) for the user to have carefully and deliberately considered model inputs, rather than blindly rely on default values which may be inappropriate for the scenario being examined. Any deviation from these default settings requires justification by the user to be assessed by the third party reviewer/AHJ.

It is therefore contended that the adoption of bounding defaults may represent one method (albeit potentially provisional) to increase the probability of rationally, safely, and appropriately designed buildings as part of a performance-based approach. The authors hope that this action alone would provide some short-term benefit to the practice of egress analysis; however, in the longer time it might also be adopted as a small part of the more comprehensive changes identified in this paper.

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