The Analysis of Results of Stochastic Evacuation Models

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Abstract
All humans are unique, we have different characteristics and we make different decision. This is a challenge when it comes to modelling human behaviour. The models we design are based on mathematics where there is no room for inconsistencies such that are present in human behaviour. So how do we account for this when we try to model human behaviour in evacuation modelling? Most models provide the possibility to include mathematical distributions and algorithms that are supposed to represent this uncertainty that we refer to as behavioural uncertainty. This thesis aims at providing a method based on functional analysis and statistics that can be used to study the effects of behavioural uncertainty on evacuation simulation results and in particular to study convergence in results for important output parameters. Previous work has been done for the most important evacuation model output, namely the evacuation time. The work in this thesis contributes by including other output parameters which are of importance both for the evacuation time and other aspects of evacuation safety. The method is accompanied by a tool that helps the user in this kind of quantitative assessment. A demonstration of the method and the tool has been provided through the use of a case study. The results showed that the analysis is efficient in analysing convergence in results for a variety of output parameters, even for output parameters with varying number of data points. This enables a more comprehensive and detailed analysis than what has previously been shown, ensuring that the behaviours that govern evacuation time also have converged in results.

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Summary

The aim of this thesis has been to develop a method on how different outputs from evacuation simulations can be analysed to determine whether or not convergence in results has been met, i.e. if the average results has converged.

This is done to analyse behavioural uncertainty, i.e. the intrinsic uncertainty in human behaviour. This is one of the uncertainties present in evacuation simulation and that needs to be considered. Since behavioural uncertainty is present in human behaviour, this uncertainty is not limited to the simulations and our models but are also present in real evacuation scenarios. Therefore, it is important to include this uncertainty when simulating evacuation. Most evacuation models of today represent this uncertainty in the form of distributions for different occupant characteristics such as walking speeds and pre-evacuation times. Some models also include algorithms to represent decision-making such as route choice (based on utility theory or other theories).

There are multiple methods to determine the number of runs needed in order to say that the variability in human behaviour has been sufficiently represented. The method developed in this thesis uses a quantitative assessment of the results to determine this number. The method is based on the method first proposed by Ronchi et.al (2014) which utilizes the concept of functional analysis. Functional analysis is a method used to quantitatively assess differences in curves, in this case the result of different output parameters used in evaluating evacuation performance. The main difference between the method in this thesis and the above mentioned is that it includes more output parameters in the analysis. The method is developed mainly for density, flowrate, queuing time, location of occupants and exit choice.

The method has then been implemented in a tool which can be used to analyse behavioural uncertainty. The aim is that this tool should assist users in the analysis which is demanding to do manually.

To demonstrate the capacity of the method and tool, a case study was conducted consisting of a total evacuation of a generic building as well as a minor additional test.

The results from the case study showed that the method and tool can be used for this type of analysis. It also showed that this kind of analysis is applicable for other output parameters as well as evacuation time, and therefore providing a more comprehensive analysis addressing the problem that different behaviours may produce the same evacuation time.

A known problem of the method is how to determine the number of data points used in the analysis. In order to apply functional analysis, the number of data points between runs needs to be the same. This can be done either by utilizing the maximum, minimum or average number of data points or by normalizing the number of data points with the use of linear interpolation. The last method was proven through the case study to be the most applicable one.

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Acronyms

ASET	Available Safe Egress Time
BU	Behavioural Uncertainty
CI	Confidence Interval
CLT	Central Limit Theorem
EPC	Euclidean Projection Coefficient
ERD	Euclidean Relative Difference
IMO	International Maritime Organization
KS	Kolmogorov-Smirnov
OET	Occupant Evacuation Time
OETC	Occupant Evacuation Time Curve
RSET	Required Safe Egress Time
SC	Secant Cosine
SD	Standard Deviation
TET	Total Evacuation Time
TETC	Total Evacuation Time Curve
WLL	Weak Law of Large numbers

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1 Introduction

The following section describes the purpose, objectives, background, method and limitations of this thesis.

1.1 Background

Evacuation models often make use of stochastic variables/distributions to represent human behaviour as pre-evacuation time, walking speed, exit choice etc. For each simulation, the model then draws a value out of these distributions and ascribes this to the agents. This is generally done for all agents in the model. Even if many evacuation models make use of stochastic variables as input, many of them only produce one result per simulation, i.e. the output is deterministic (Alvear, Abreu, Cuesta, & Alonso, 2014). The consequence of this is that the result from one run of the model to another will vary. This uncertainty is often referred to as 'behavioural uncertainty' (Ronchi, Reneke, & Peacock, 2014). Behavioural uncertainty is not something that is restricted to the modelling of human behaviour, but it is also present in the actual human behaviour. As Averill (2011) describes it: "evacuate the same building with the same people starting in the same places on consecutive days and the answers could vary significantly".

This indicates that this kind of uncertainty needs to be considered in fire safety engineering and evacuation modelling in particular. There are two fundamental ways in which uncertainty can be treated: by eliminating it or quantifying it. And since this uncertainty is present in the reality which we try to model, it is more reasonable to try to quantify it. Work has been done to quantitatively assess this behavioural uncertainty for evacuation times in evacuation modelling (Ronchi, Reneke, & Peacock, 2014; Grandison, Deere, Lawrence, & Galea, 2017). However, there are many more output parameters to consider when investigating the design of a building regarding evacuation possibilities. For example, density, queuing times, flows etc. Queuing time may be represented as a time for each agent in which it is regarded as queuing, with the use of criteria for "queuing" (time spent moving at a speed lower than a set threshold etc.). Density is more difficult to measure in means of time and therefore not as straightforward to analyse by the method proposed by Ronchi et al. (2014). Density is traditionally measured as the number of persons per area, however, this entails problems such as how to define the area to consider and large fluctuations in results as agents walk in and out of the reference area (Steffen & Seyfried, 2010). The measurement of flows shows the same problem of fluctuations as the measurement of density (Steffen & Seyfried, 2010). This indicates that in order to be able to analyse the behavioural uncertainty in these output parameters, the way we measure them must be carefully considered.

1.2 Purpose and objectives

The purpose of this thesis has been to address the problem of behavioural uncertainty and its implementations and effects on evacuation modelling and consequently on fire safety. The purpose has also been to include different output parameters into the analysis of behavioural uncertainty than what has previously been done in order to make it more comprehensive.

The objective was to develop a method on how different results from evacuation simulations can be analysed between several simulations. This method has then been implemented in a tool in which output from simulations is used as input, and a description of the effects of behavioural uncertainty is received. To demonstrate the capacity of the tool, a case study has been conducted.

1.3 Method

The foundation for this thesis has been the method for quantitatively analysing behavioural uncertainty in evacuation modelling proposed by Ronchi et. al. (2014). This method was reviewed and compared to other methods to see if there are other methods available that could be more applicable. Next, the output parameters intended to study was described in a mathematical way so that they can be implemented in the method.

A short discussion has been made about different measurement methods, i.e. how density etc. is measured, but the developed method is supposed to work regardless of measurement method and evacuation software as long as the output parameter is correctly defined.

A tool was then developed with the method implemented with the use of Excel VBA (Visual Basics for Applications). The tool is accompanied by a short user guide.

To display the capabilities of the tool it has been tested on a simple case study. The case study consisted of a total evacuation of a generic building. The simulation was conducted using the evacuation simulation software Pathfinder version 2018.3.0730, developed by Thunderhead Engineering. Limited effort has been put into trying to select representable inputs since the main objective is to demonstrate the tool functionalities rather than to produce reasonable RSET for a specific scenario.

1.4 Limitations

There have been no efforts in trying to develop a new way of measuring densities, flowrates, queuing time and other output parameters. The thesis was limited to only looking at existing procedures and determining how to best implement them in the tool.

Similar for methods of analysing behavioural uncertainty, there has been no efforts in defining completely new ways of conducting this analysis, but rather on refining/applying existing ones. The thesis was also limited to only review existing methods and choose the one most suitable to implement in the tool.

The case study has been used to demonstrate the ability of the tool regarding its ability to analyse the behavioural uncertainties. The results in form of absolute values for densities, flowrates, etc. are not of interest and the inputs may not be appropriate if an evacuation safety analysis were to be conducted of the same building.

2 Theory

This section presents some background theory of the concepts that will be used and discussed further on in this thesis.

2.1 Evacuation and simulation thereof

Evacuation refers to the process of moving people from a dangerous place to somewhere safe. In the case of fire safety and in the context of buildings, this often refers to the process where people are moving themselves to safety, even though assisted evacuation may be present and also the use of mechanical means such as elevators or escalators. The fact that we mostly rely on people to put themselves in safety means that individual human behaviour needs to be considered. Some of the aspects included in the term human behaviour and that have a large impact on evacuation is people's awareness, motivations, beliefs, decisions, attitudes, behaviours, and coping strategies (Kuligowski E. D., 2016). A simplified representation of human response in a fire situation is presented in Figure 1 below.

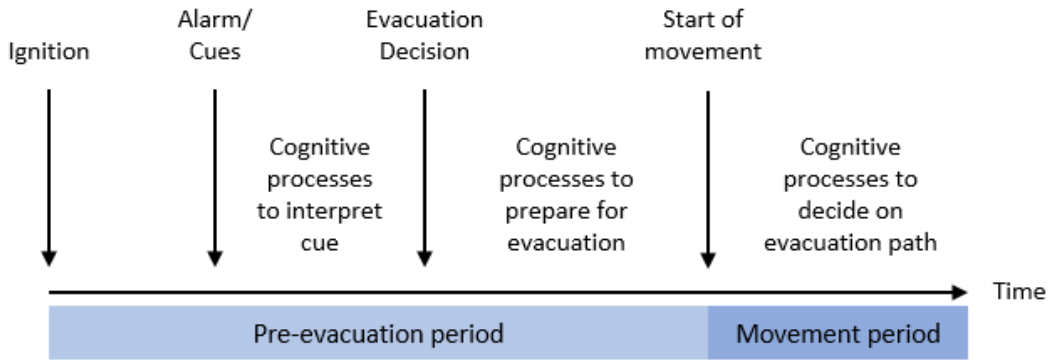


Figure 1. Simple representation of human response to fire and other threats.

As can be seen in the figure above, human response consists of many different actions and decision which together constitutes what we call pre-evacuation time. When implemented in evacuation models, this is simplified even further. If an alarm is present, one may use the time until the alarm sounds as the first part of pre-evacuation time. The rest is most often simplified by a set time or a distribution of times for the whole population. The length of this time is set by the user and may be based on the type of alarm, occupants, type of building etc. This means that little or no consideration is taken in the simulation to the underlying processes which govern this pre-evacuation time (Gwynne & Hunt, 2018). Instead, it is simply a representation of current theory, data, and the judgement and knowledge that a user or developer of the model brings to the table (Gwynne, Hulse, & Kinsey, 2015; Kuligowski, Gwynne, Kinsey, & Hulse, 2017).

Most evacuation models have the possibility to include the pre-evacuation period, but the main focus is often the simulation of movement rather than the decision-making process. Movement can be simulated with a variety of different methodologies (Xiaoping, Tingkuan, & Mengting, 2009), some more sophisticated than others. The more sophisticated models make use of some sort of individual choice, for example route choice based on densities etc. (Kuligowski, Peacock, & Hoskins, 2010). Models also modify characteristics such as

walking speed etc. based on other parameters such as densities (Kuligowski, Peacock, & Hoskins, 2010).

Engineers are familiar with the process of simplifying the reality when it comes to physical or mathematical events in real-life. They may however not be so familiar with simplifying psychological or sociological processes such as the pre-evacuation time (Purser & Bensilum, 2001), partly as a result of lack of understanding (Gwynne, Kuligowski, & Nilsson, 2012). This means that the models available today cannot represent the behaviour of people based on underlying factors simply because we do not have the knowledge of what these are and how we could implement them in a model, even though some efforts have been done to get a better understanding (Kinsey, Gwynne, Kuligowski, & Kinateder, 2018). If this was possible, maybe we could define underlying circumstances as inputs in the models at such precision that we could regard evacuation as deterministic. But we are not there yet and perhaps will never be, therefore we need to be aware that the results are uncertain.

2.2 Behavioural uncertainty

A model is an effort to represent reality. Therefore, a difference between the modelled and reality will always be present (Tavares & Ronchi, 2015). Behavioural uncertainty relates to one type of uncertainty present in evacuation modelling and refers to the intrinsic variability in human behaviour (Tavares & Ronchi, 2015). When we design models, we often want to limit the uncertainties as much as possible. This could be referred to the fact that the Newtonian sciences has traditionally been the most acknowledged science (Heylighen, Cilliers, & Gershenson, 2007). Newtonian science is based on the ideas of determinism and reductionism, simply explained as the idea that the whole can be understood by the analysis of its individual parts (Heylighen, Cilliers, & Gershenson, 2007). However, human behaviour is complex and can therefore not be treated as a simple problem and uncertainty needs to be considered as it is not a problem only of the models that we design to represent behaviour but is a characteristic of human behaviour itself.

Variability in human behaviour may come from a variability in physical attributes. Some people move faster, some move slower for example. Variability also comes from psychological attributes such as risk awareness etc. The variability associated with psychological attributes are the variability most difficult to assess since these attributes are more difficult to measure. This makes the task of predicting human behaviour difficult. When simulating an evacuation of a building for design purposes, we are typically uncertain on the exact people that will be occupying the building afterwards, which makes it even harder to predict human behaviour.

The process of human response is highly influenced by what decision we make. In an ideal world, humans would consider all information possible and then weigh the cost and benefits of all possible courses of action and then take a decision based upon that. This theory of choice is called utility theory (Klein, 2008). However, we as humans often lack the information needed to be completely rational and we seldom try to seek out all this information in order to take a decision (Klein, 2008). Instead, we take decisions based on what we perceive (Kuligowski E. D., 2016) and look for the first workable option in

contrast to optimising (Simon, 1957). What we perceive is affected by psychological attributes such as risk awareness (Lindell & Perry, 2004). One example of this perception and its implementation in evacuation is the use of different types of alarms. The time it takes for occupants to hear the alarm is easy to calculate but understanding of the message may depend on many different factors. Here, understanding does not mean a correct interpretation of the message but rather a perception on what it means (Mileti & Sorensen, 1990). Different types of alarms (bell, spoken etc.) may be perceived differently even though the meaning is the same (Mileti & Sorensen, 1990). But as stated above, we act upon what we perceive more than we try to seek all information to make optimal decisions (Simon, 1957). This is one of the explanations to why human behaviour is stochastic.

2.3 Other sources of uncertainty

Tavares & Ronchi (2015) divided uncertainty associated with evacuation modelling into four categories, with behavioural uncertainty being one of them. The others were measurement uncertainty, model input uncertainty and intrinsic uncertainty. The relation between the different types of uncertainty and the simulation process can be seen in Figure 2 below.

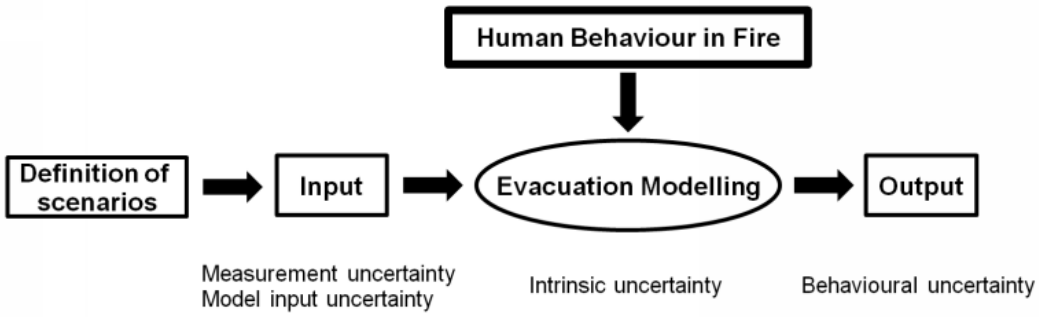


Figure 2. The modelling process and associated uncertainties (Tavares & Ronchi, 2015).

It is reasonable to treat at least model input uncertainty in the same way as behavioural uncertainty, i.e. by assigning distributions that are supposed to compensate for this uncertainty. An example of this is that we may be uncertain about the initial conditions, such as how many occupants are in the building, which type of occupants there are, their position and activity etc. Similar to behavioural uncertainty, this is something that has a natural variation and should therefore be treated as such in the modelling process.

2.4 How do existing evacuation models treat this uncertainty?

As discussed, evacuation modelling is associated with uncertainties and the models therefore needs to represent this in some way. One way that they do this is by assigning not one single value but rather distributions for various variables such as pre-evacuation time and walking speeds (Kuligowski, Peacock, & Hoskins, 2010; Lord, Meacham, Brian, Moore, Fahy, & Proulx, 2005; Ronchi & Kinsey, 2011). Random variables may also be present in the model itself to simulate randomness in exit choice, space conflict resolution, occupant positioning etc. (Ronchi, Kuligowski, Reneke, & Nilsson, 2013). Models then generally make use of pseudo-random sampling from these distributions and proceeds with calculating a result (Ronchi E. , 2016). The term pseudo-random means that the generated

values from the sampling satisfy statistical testing for randomness but that they are produced with the use of mathematical procedures. This can be achieved with various sampling methods, for example latin hypercube sampling. Research has shown that different sampling methods may require more or less runs until they reach convergence (Lovreglio, Spearpoint, & Girault, 2019). This information is important to consider when analysing behavioural uncertainty.

Most of these distributions are however associated with characteristics of the occupants and not on the decision-making process (Alavizadeh, Moshiri, & Lucas, 2008; Gwynne S. M., Kuligowski, Kinsey, & Hulse, 2017). The decision-making process is represented by what we would call rational choice, i.e. the occupant makes some kind of calculation and ranks their choices before making a decision (Alavizadeh, Moshiri, & Lucas, 2008). No consideration is taken as to what information is available to the occupant (Pires, 2005). In this way, evacuation models are not able to represent human behaviour fully. Work has been done to better represent human behaviour during the pre-evacuation phase (Lovreglio, Ronchi, & Nilsson, 2016; Lovreglio, Ronchi, & Nilsson, 2015; Gwynne S. M., Kuligowski, Kinsey, & Hulse, 2017) but it has yet to be implemented in the commercially available evacuation simulations software.

These characteristics of the models mean that different runs of the same scenario may produce different results. In this way the uncertainties are represented in the results. The problem is however how to analyse this uncertainty.

3 Review of existing methods to analyse behavioural uncertainty

Research efforts have been made in analysing behavioural uncertainty in evacuation modelling (Ronchi, Reneke, & Peacock, 2014; Grandison, Deere, Lawrence, & Galea, 2017; Lovreglio, Ronchi, & Borri, 2014). It is also widely perceived in the community that methods need to be developed in order to embrace the stochastic nature of human behaviour (Averill, 2011; Lord, Meacham, Brian, Moore, Fahy, & Proulx, 2005). The methods need also to be able to quantify the difference in a set of evacuation simulations or data sets (Galea, Deere, Brown, & Filippidis, 2013).

Behavioural uncertainty results in different results being obtained between different runs of the same scenario (Tavares & Ronchi, 2015). This means that there needs to be a way of telling when we have enough results or runs so that we can say that behavioural uncertainty is sufficiently represented.

There are a number of different methods that can be used to analyse behavioural uncertainty (Kinsey M. J., 2016), some more advanced than others. In this section, some of the methods will be discussed briefly. Emphasis is put on the discussion about dynamic assessment of variance in an output variable/series which is the category the method proposed in this thesis will fall into.

The categorisation of methods discussed here were originally presented by Kinsey (2016).

3.1 Brute force

This method is the simplest to implement and straightforward to follow. The idea is simply to simulate enough runs so that you have represented all possible permutations of the input variables. The negative side of this method is that it will require a large number of runs. Some of these runs may also be unnecessary to run since they will probably yield almost identical results.

3.2 Fixed number

The number of simulations required may also be set arbitrary. This is the case in the IMO (International Maritime Organization) (2016) guidelines which require a set of up to 500 simulations. The disadvantages with this method are that there is no way of knowing if the simulations capture all behaviours. This is a consequence of the methods inability to consider the results of the simulations when defining the fixed number.

3.3 Qualitative visual assessment

This method relies on the individual model user's ability to recognize differences in results by visually analysing the 2-D or 3-D graphics of the results. This could potentially be a good method if the analyser has good knowledge about what to look for. However, it is hard to do this assessment consistently between a large number of simulations and if the geometry is complex. The method is also very user-dependant and would not be easy to compare between different users.

3.4 Dynamic Assessment of variance in an output variable/series

The last method presented is where the results of the simulation is analysed mathematically with the use of some convergence method to determine the number of runs required. Ronchi et. al. (2014) proposed a method for this type of analysis based on functional analysis. The same method had previously been implemented in the analysis between fire simulation and experimental data (Peacock, Reneke, Davis, & Jones, 1999), and also as a comparison method between evacuation model results and experimental data (Galea, Deere, Brown, & Filippidis, 2013).

The method proposed by Ronchi et. al. (2014) consists of five different convergence measures: Total Evacuation Time (TET), Standard Deviation (SD) of TET, Euclidean Relative Difference (ERD), Euclidean Projection Coefficient (EPC) and the Secant Cosine (SC). The latter three are associated with functional analysis. Simplified, the method is described as a procedure of measuring when the occupant-evacuation time curves have converged to the average occupant-evacuation time curve, based on an arbitrary defined convergence criterion.

Another method for determining convergence of TET is proposed by Grandison et. al. (2017) which makes use of confidence intervals. The method is proposed to limit the number of required simulations when certifying evacuation performance of passenger ships according to international guidelines, which otherwise demands a sample of 500 simulations (IMO, 2016). While Ronchi et. al. (2014) makes use the average TET as one of the convergence criteria, Grandison et. al. (2017) makes use of the 95^{th} percentile TET which is described as more appropriate when the analysis is part of a risk analysis. The major limitation of this method is that it only considers TET, and not the occupant-evacuation time curve. As describes in section 2.1, TET is governed by the behaviour of the occupants. It is therefore important to consider the underlying behaviour which results in the TET. One way to do this is by studying the occupant-evacuation time curve. Another is to study other output parameters which influence the TET. The latter is the main focus of this thesis.

It is agreed that the 95^{th} percentile is useful if the results are a part of a risk analysis, but the aim of this thesis and the method developed is to study behavioural uncertainty and not to a greater extent on how to treat the results. The method Proposed by Grandison et. al. is also not applicable since it requires a Pass/Fail Criterion Time (PFCT) to compare with (Grandison, Deere, Lawrence, & Galea, 2017), which is not always defined.

This type of dynamic assessment may also be done with different levels of detail. The method proposed by Grandison et. al. (2017) does as stated only include the TET, which implies that the level of detail is limited to the whole simulation, e.g. averaging over the total spatial area, time and all occupants. Ronchi et. al. (2014) takes it a step further and introduces the OETC's in the analysis, meaning that the level of detail shifts from all occupants to individual occupants.

To further increment the level of detail, spatial aspects may also be included in the analysis, which is part of the aim of this thesis. By analysing densities at certain locations and flowrates through specific doors for example, more of the underlying behaviour which

govern TET and OET is included in the analysis. Important to note however is that the scope will always be limited, i.e. the analysed output parameters will not be able to represent all aspects of human behaviour. For example, even though the flowrate may be similar between different runs, it may be caused by different occupants.

4 Description of the generalized mathematical method applied

The mathematical method applied in the tool is described below. The method is based on functional analysis as presented by Ronchi et. al. (2014) and Peacock et. al. (1999).

Firstly, a short generic description of the form of the output parameters is presented. This is done since the convergence measures are dependent on a fix form. The specific description for each output parameter can be seen in Appendix 1.

Apart from the proposed by Ronchi et. al. (2014), a complementary inferential statistics test is implemented in the tool to make the analysis more rigid. The method for this is described in section 4.4.

4.1 Mathematical description of output parameters

In order to analyse the output parameters with the method described below, we need to define them as a data-set or vectors consisting of several data points.

Consider a simulation consisting of *q* number of data points. The vector that describes the generic output parameter *x* would then be denoted as:

$$\vec{x} = (x_1, x_2, \dots, x_{q-1}, x_q)$$

Where x_1 corresponds to the first data point of *x*, x_2 to the second data point of *x* and so on. If we were to simulate *n* runs of the same scenario, *n* vectors $\vec{x}_{ij}$ would be obtained, where *n* is the total number of runs, *q* is the number of data points, *i* denotes a specific data point and *j* denotes a specific run.

$$\vec{x}_{ij} = (x_{1j},\ x_{2j}, \dots, x_{(q-1)j}, x_{qj})$$

So for example, a simulation with 2 runs (=*n*) and 3 data points (=*q*) would result in the following vectors:

$$\vec{x}_{i1} = (x_{11}, x_{21}, x_{31})$$

$$\vec{x}_{i2} = (x_{12}, x_{22}, x_{32})$$

The next step is to present a variable which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of data points is still denoted *q*, and a specific run is denoted *j*, then the *j*th average curve, $\vec{X}_j$, is described by the following vector:

$$\vec{X}_j = (X_1, X_2, \dots, X_{q-1}, X_q)$$

Where:

$$X_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} x_{1j},\ X_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} x_{2j},\ \dots,\ X_q = \frac{1}{j}\sum_{j=1}^{1<j<n} x_{qj}$$

For example, if *j*=1, then $\vec{X}_j$ would correspond to the values of the first run, i.e. $\vec{x}_{i1}$. If *j*=4, then $\vec{X}_j$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\vec{x}_{i1}$, $\vec{x}_{i2}$, $\vec{x}_{i3}$ and $\vec{x}_{i4}$.

4.2 Functional analysis

This part of the method corresponds to the last three convergence measures as describes by Ronchi et. al. (2014). The three convergence measures are: Euclidean Relative Difference (ERD), Euclidean Projection Coefficient (EPC) and the Secant Cosine (SC). The measures are only briefly introduced here. For full description see Ronchi et. al. (2014) and Peacock et. al. (1999). The equations are taken from the first of the two.

4.2.1 Euclidean Relative Difference

ERD corresponds to the relative distance between two vectors. For the purpose of explaining the method, the two generic vectors $\vec{x}$ and $\vec{y}$ will be introduced. ERD is calculated using equation 1.

Equation 1.

$$ERD = \frac{\|\vec{x} - \vec{y}\|}{\|\vec{y}\|} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(y_i)^2}}$$

A set of ERD can then be calculated, each one corresponding to two consecutive pairs of vectors, e.g. $\vec{X}_j$ and $\vec{X}_{j-1}$. These could then be formed into a vector denoted:

Equation 2.

$$\overrightarrow{ERD} = \left(ERD_1, \dots, ERD_p\right)$$

Where:
p = j-1

Since $\vec{X}_j$ corresponds to the arithmetic mean of the data-sets, ERD will converge to the expected value of 0 (the case of two curves identical in magnitude) when the number of runs is enough, due to the weak law of large numbers. This results in the convergence measure described below:

Equation 3.

$$ERD_{convj} = \left|ERD_j - ERD_{j-i}\right|$$

4.2.2 Euclidean Projection Coefficient

This concept exists to represent the angle between the two vectors. The projections coefficient is a scalar which enables the projection of $\vec{y}$ on $\vec{x}$. See Figure 3 below for a visualisation.

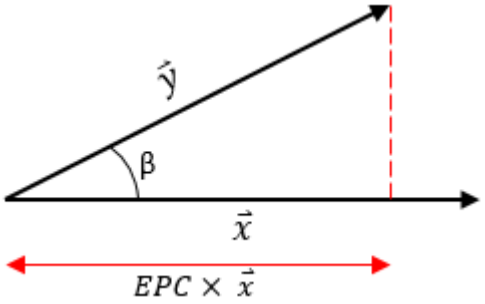


Figure 3. Visualisation of the projection coefficient.

EPC is calculated using equation 4.

Equation 4.

$$EPC = \frac{\langle \vec{x}, \vec{y} \rangle}{\|\vec{y}\|^2} = \frac{\sum_{i=1}^{n}(x_i y_i)}{\sum_{i=1}^{n} y_i^2}$$

A set of EPC can then be calculated, each one corresponding to two consecutive pairs of vectors $\vec{X}_j$. These could then be formed into a vector denoted:

Equation 5.

$$\overrightarrow{EPC} = \left(EPC_1, \ldots, EPC_p\right)$$

Where:
p = j-1

Since $\vec{X}_j$ corresponds to the arithmetic mean of the data-sets, EPC will converge to the expected value of 1 (the best possible agreement between two consecutive arithmetic mean vectors) when the number of runs is enough. This results in the convergence measure described below:

Equation 6.

$$EPC_{convj} = \left|EPC_j - EPC_{j-i}\right|$$

4.2.3 Secant cosine

The last concept associated with functional analysis to be introduced is the secant cosine (SC). This represent a measure of the differences in shape between the two curves. The investigation consists of analysing the first derivative of both curves. Again, see Ronchi et. al. (2014) and Peacock et. al. (1999) for full description. SC is calculated using Equation 7.

Equation 7.

$$SC = \frac{\langle \vec{x}, \vec{y} \rangle}{\|\vec{x}\|\|\vec{y}\|} = \frac{\sum_{i=s+1}^{n} \frac{(\Delta x_{i-s})(\Delta y_{i-s})}{s^2(\Delta t_{i-1})}}{\sqrt{\sum_{i=s+1}^{n} \frac{(\Delta x_{i-s})^2}{s^2(\Delta t_{i-1})} \sum_{i=s+1}^{n} \frac{(\Delta y_{i-s})^2}{s^2(\Delta t_{i-1})}}}$$

Where:
t is the measure of the spacing of the data; *s* represents the number of data points in the interval; *n* is the number of data points in the data-set.

The variable *s* is user defined and should be carefully considered. The value of *s* describes how much noise or scatter that is considered when making the comparison. A smaller value of *s* means that more noise is included and vice versa. When defining *s*, the inherent noise of the data to be analysed needs to be considered as well as the natural variation in the data. Galea et. al. (2013) recommended that *s/n* should be somewhere in between 0,03 and 0,05. This recommendation will be implemented as a suggestion in the tool.

A set of SC can then be calculated, each one corresponding to two consecutive pairs of vectors $\vec{X}_j$. These could then be formed into a vector denoted:

Equation 8.

$$\overrightarrow{SC} = (SC_1, \dots, SC_p)$$

Where:
p = j-1

Since $\vec{X}_j$ corresponds to the arithmetic mean of the data-sets, SC will converge to the expected value of 1 (the two curves have identical shapes) when the number of runs is enough. This results in the convergence measure described below:

Equation 9.

$$SC_{convj} = |SC_j - SC_{j-i}|$$

4.3 Output parameter value and Standard deviation

In the original method proposed by Ronchi et. al. (2014), convergence tests of TET and SD of TET were conducted. For the purpose of this thesis, these output parameters were generalised in order to later be adapted to the different output parameters to study. TET represents the time at which the last occupant completed their evacuation. If each occupant is a data point, then this represents the highest value of all data points in the data-set. In the original method, the data points were ordered based on their value from smallest to largest, i.e. the data point with the largest value (evacuation time) were also the last data point in the data-set.

When doing the same analysis for other output parameters, it seems reasonable to make the analysis based on the largest or "worst" value. This could for example be the highest density, highest flowrate or the longest queuing time. What the value should represent is presented in section 5. The method that follows is applicable to all output parameters presented in this thesis.

For each simulation, there will be one data point, x_i, of particular interest. This data point is renamed to Φ for the purpose of this description. The value Φ for all simulations (*n*) can then be formed into a data-set or vector:

Equation 10.

$$\vec{\Phi} = (\Phi_1, \dots, \Phi_n)$$

The arithmetic mean of the value Φ for j runs can then be expressed using equation 11.

Equation 11.

$$\Phi_{avj} = \frac{1}{j}\sum_{i=1}^{j} \Phi_i$$

The law of large numbers tells us that when j is large enough, Φ will converge to the expected value, or mean of Φ. The convergence measure can then be formulated as follows:

Equation 12.

$$\Phi_{convj} = \frac{\left|\Phi_{avj} - \Phi_{avj-1}\right|}{\Phi_{avj}}$$

The analysis of the standard deviation of Φ is the same as for Φ. The convergence measure is therefore formulated as follows:

Equation 13.

$$SD_{convj} = \frac{\left|SD_{avj} - SD_{avj-1}\right|}{SD_{avj}}$$

Where: $SD_{avj} = \sqrt{\frac{1}{j}\sum_{i=1}^{j}\left(\Phi_j - \bar{\Phi}\right)^2}$

4.4 Kolmogorov-Smirnov test

For the purpose of this thesis, a Kolmogorov-Smirnov test (KS-test) is implemented as a complement to the convergence criteria proposed by Ronchi et. al. (2014). The KS-test has previously been implemented in the field of evacuation modelling, see Lovreglio, Ronchi & Borri (2014).

The KS-test is a non-parametric statistics test used to determine if two samples may come from the same underlying distribution. This may be done either between an empirical sample and a probability distribution or between two empirical samples. In this case, the test will be applied on the aggregated values of two consecutive runs, i.e. between the curves $\vec{X}_j$ and $\vec{X}_{j-1}$.

To conduct the test, the values need to be presented in the form of a cumulative distribution function, named $F_{j,q}(X)$, where q is the number of data points and j is the number of the run. To use TET as an example, the y axis on the graph of the function would represent how many percentages of the occupants that have evacuated at that time (the x-axis value).

The KS-statistic is then calculated with the function listed below:

Equation 14.

$$D_{q,w} = sup\left|F_{j-1,q}(X) - F_{j,q}(X)\right|$$

The statistic represents the largest difference between the two functions. A graphical description of the statistic is presented in Figure 4 below.

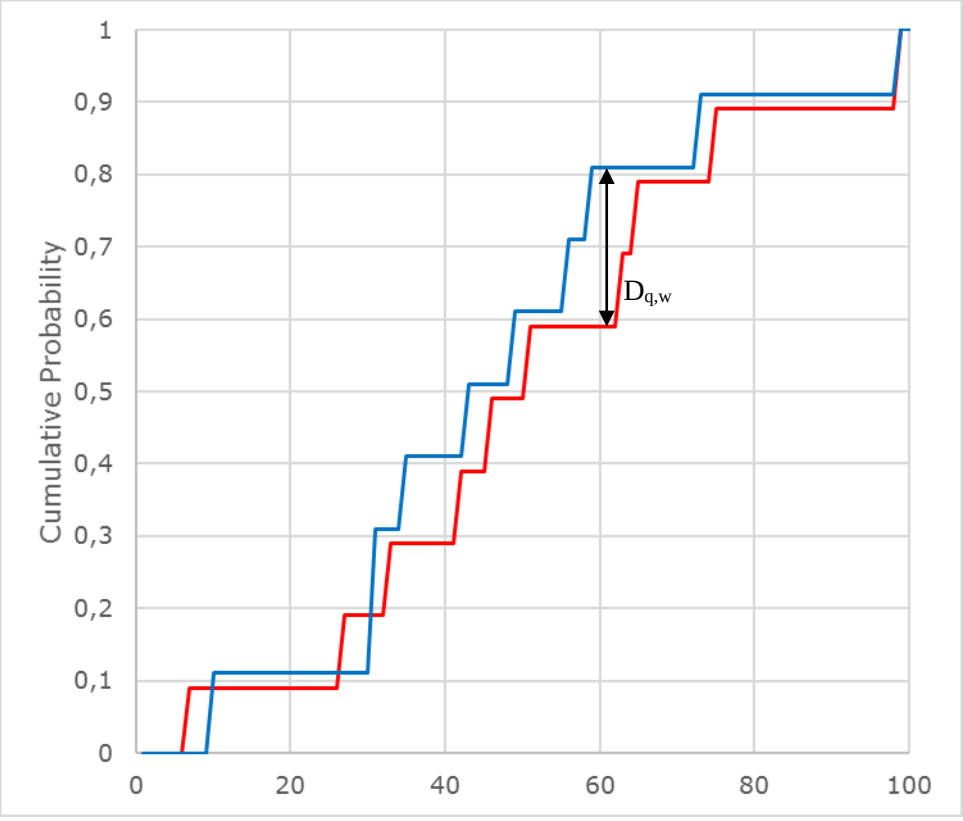


Figure 4. Visualisation of the KS-statistic, $D_{q,w}$.

Another common test is the student's t-test. The difference between the KS-test and the student's t-test is that the student's t-test compares the mean and standard deviation of the two samples, meaning that two curves with vastly different shapes may not be indicated as different in such a test. The KS-test is therefore deemed to be more applicable in this case since we are interested in the shape of the OETC's and other curves.

To determine if the two samples may come from the same distribution a null hypothesis needs to be formulated. The null hypothesis, named H_0, describes the hypothesis that the two samples are drawn from the same distributions. H_0 is rejected at level α if:

Equation 15.

$$D_{q,w} > c(\alpha) * \sqrt{\frac{q+w}{q*w}}$$

Where:

$$c(\alpha) = \sqrt{-\frac{1}{2}\ln(\alpha)}$$

For the purpose of this thesis, the test is passed when the null hypothesis has not been discarded for a certain number of simulations, *k*. This number is set arbitrarily.

4.5 Problems associated with varying number of data points

Depending on how the division of the data-set into data points is done, the number of data points might differ between simulation runs. In the original method proposed by Ronchi et. al. (2014) the separation was made based on the number of occupants, which meant that the number of data points were the same between different runs when the number of occupants were. For some of the output parameters discussed in this thesis, it is more reasonable to make the division based on some constant time difference, δt.

A possible problem when making the separation based on the time difference δt is that the number of time steps, q, will vary when the TET does, i.e. the number of time steps is smaller when the TET is shorter and vice versa. A solution for this could be to let the simulation run with the most time steps set the number of time steps for all simulation runs, and then fill out the time steps for the rest of the simulation runs with the value zero. A simple explanation can be seen in Table 1 below.

Table 1. Explanation of solution to problem with varying number of time steps.

Time step	**Output parameter value (simulation 1)**	**Output parameter value (simulation 2)**
1	2	3
2	4	3
3	3	4
4	2	1
5	1	0
6	1	0

However, this technique might yield unrealistic differences when comparing the curves since the output parameter value does not necessarily approach zero when the simulation comes to an end. Doing the opposite, i.e. letting the simulation run with the smallest amount of time steps decide the number of time steps to include might yield more realistic results, but it will also mean that we disregard possible important data. A method in between, i.e. utilizing the average number of data points simply means a combination of the two above methods.

The fourth option is to manipulate the data-sets so that they all contain the same number of data points. This would mean that the division into data points would not be done as per time step (e.g. 1 second) but instead based upon how much of the simulation has been completed (e.g. 0,1 %). This would mean that two data point may not represent the value at the exact same time in the simulation but rather how much of the evacuation process that is completed. As long as the TET does not vary significantly between runs, this could be a good technique to use in order to make the different curves comparable. In the tool, this option is implemented by modifying the number of time steps to be the same as the simulation run with the largest number of time steps with the use of linear interpolation.

4.6 Limitation of scatter in output parameter values

For some output parameters the amount of scatter in results is expected to be high depending on measurement technique. To compensate for this, a moving average approach is utilized were the method and tool enables the user to define a moving average interval. This means that if the moving average interval is defined to be ±10 seconds, then the value at the central data point is an average of the 10 previous, the central and the 10 sequent data points. This also means that some data points near the ends of the data sets will be left out since there is no data to do the moving average calculations.

4.7 Evaluation method

When the convergence measures have been calculated, the results need to be evaluated to see if convergence has been met. Convergence has been met when the arbitrarily set acceptance criteria (denoted TR and D_{crit}) has been met for an arbitrarily set consecutive number of runs (denoted *b* and *k*). As stated earlier in this section, all the different convergence units are expected to convergence to the value zero when the number of runs increase. The acceptance criteria should therefore be close to that number. The following method is based on the method proposed by Ronchi et. al. (2014) but modified to suit the purpose of this thesis:

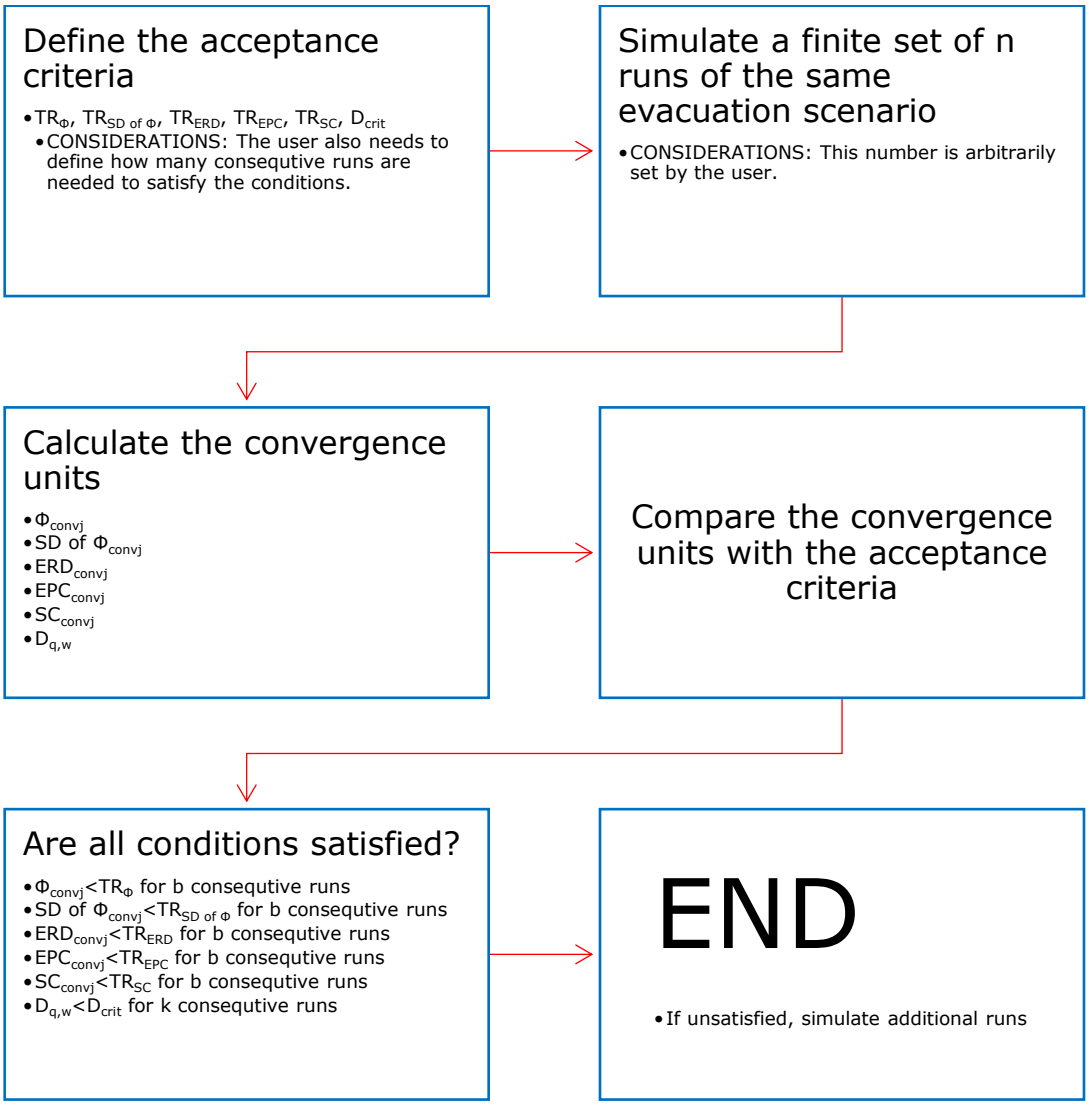


Figure 5. Schematic representation of the evaluation process.

4.8 Limitations of the method

The main limitation of the method is the arbitrarily set acceptance criteria which relies on the user's good judgement. These needs to be carefully assessed in order for the method to be valid. Another limitation is the neglecting of data associated with the suggested solutions to the problem associated with varying number of data points as well as the neglecting of data associated with the moving average approach.

5 Description of simulation output parameters

This section consists of descriptions of the output parameters intended to study. This is done in order to get a better understanding of them. A short discussion on measurement methods is also done to highlight some of the issues to consider when trying to measure them in an evacuation simulation. The tool is however designed to be generic, i.e. not dependant on one specific measurement method. The form of the output parameters is important though and each output parameter is accompanied with a mathematical description, found in Appendix 1, of how the output parameters should be presented to the tool. The value which is to be considered the value of interest and should represent the value Φ as discussed in section 4.3 will also be presented for each output parameter.

5.1 Density

[…] *the mass per unit volume of a substance measured* (Kirkpatrick, 1992).

In the case of evacuation modelling, the occupants are often represented by the amount of floor area they occupy and not the volume, i.e. they are seen as 2-dimensional objects. Mass is measured in number of occupants. The density is then measured in occupants per floor area [occ/m^2] or as occupied floor area per floor area [occ m^2/m^2]. One struggle is how to define the area in which to study density. Density and flow alike are concepts of fluid dynamics defined for situations with a seemingly infinitely number of particles (Steffen & Seyfried, 2010). In the context of evacuation, the number of particles is limited which makes the concepts problematic to use.

If the area of measurement is very small, large fluctuations are to be expected as people move in and out of the area. This may be compensated by averaging over either time or a bigger area but then with the cost of lower resolution (Steffen & Seyfried, 2010). Another way of compensating this is by using Voronoi diagrams which divides the total area into separate areas for each particle or occupant and then assigns each point in space to the particle closest (Steffen & Seyfried, 2010). This means that the lines that can be seen in Figure 6 below represents points where the distance between two or more particles or individuals are equally long.

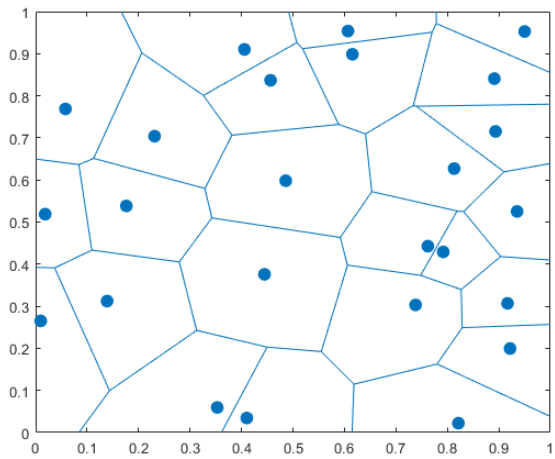
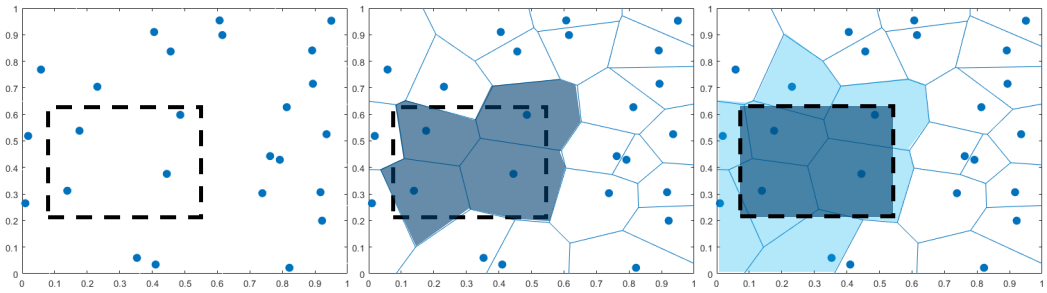


Figure 6. Particles or occupants with Voronoi cells drawn around them.

Density can then be calculated as the area of the Voronoi cells which particle is in the reference area ($D_{V'}$) or as an average of the densities of the individual Voronoi cells intersecting the reference area (D_V). Figure 7 below illustrates the different ways of calculating densities compared to the classical way (D_S).



(a) classical density D_S *(b) Voronoi density $D_{V'}$* *(c) Voronoi density*

Figure 7. Comparison between (a) classical density D_S, (b) Voronoi density $D_{V'}$ and (c) Voronoi density D_V.

With this method, it is possible to calculate densities with high resolution and low scatter without the need to average over time or space (Steffen & Seyfried, 2010). Some of the problems associated with the definition of the reference area still exists though.

As always, it is of outmost importance to think about why it is that we are interested in measuring the density of the crowd in order to find an adequate way to do it. In large scale evacuation where population density is high, congestion is a problem which needs to be dealt with since it will prolong the total evacuation time (Gwynne & Rosenbaum, 2016). Congestions refers to an area with high density (Fruin, 1971). So, what we really need to do is to identify areas with high densities and not so much density at an exact place. If the evacuation model allows it, this can be analysed graphically by watching the results from the simulation and seeing where occupants are. The problem arises when this needs to be compared and quantified between several simulations.

One possible way to do this would be to divide the calculation mesh in several small regions where the density could be calculated using Voronoi cells to minimize the scatter without having to average over a significant amount of time or space. These values could then be compared between simulations to study convergence.

It is clearly seen that the definition of reference area is of outmost importance in order to calculate density in a proper way. It is possible to define an almost infinitely large reference area in which no occupants are located (Steffen & Seyfried, 2010), see Figure 8 below.

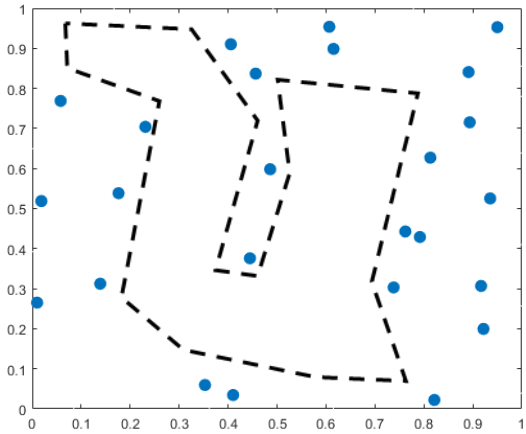


Figure 8. Depiction of a poorly defined reference area with the density 0 occupants/m².

An important aspect to consider when defining the reference area is what area is used by occupants. Pauls (1987) found that the area closest to walls wasn't used by occupants (*boundary layer*), resulting in the term *effective width*, which refers to the width of a walkway or stairway which is used by occupants. When defining the reference area, it is therefore important to subtract the boundary layer so that we get an accurate measurement of density.

Hoskins (2015) made the same kind of observation for stairs. He could see that when the direction of travel changed 180° on a landing in a stairway, the whole landing was typically not used by occupants. If we were to measure density and using the whole landing as reference area, we would then get a lower density since all occupants would be crammed in one place.

The mathematical description of density in the format described in section 4.1 can be found in Appendix 1. The value Φ will in the case of density represent the highest density measured in each run as this data point is deemed as the most interesting one.

5.2 Flowrate

[…] *to move, run or spread, as a fluid* […] (Kirkpatrick, 1992)

In this case we are interested in flow through doors. This would mean the amount of movement through the door, and since occupants are not really a fluid as discussed in section 5.1, we calculate this as number of people per some time period that passes the door, represented as a line. Similar to density, this method to measure flow is originally defined for situations with a seemingly infinite number of particles, which results in large scatter when applied to evacuation problems (Steffen & Seyfried, 2010).

The use of Voronoi cells could also be applied here and the flow would then not be calculated as one occupant passing the line at one exact moment but rather as how much of that occupant's Voronoi cell has passed the line of the door (Steffen & Seyfried, 2010). This produces a result with less scatter without the need to average over time, even though this method also benefits from averaging (Steffen & Seyfried, 2010). So depending on the desired resolution, flow may be measured in the classical way of counting heads passing a line, or with the use of Voronoi cells, both with the possibility of averaging over time.

But why are we interested in measuring flow? As stated in section 2.1, evacuation refers to the process of moving people away from danger to a safe place. Flow through exits is then a measurement of at what rate this is done. When constructing a building, cost is often of importance to the contractor, and additional doors will add to that cost. It is therefore desired that the evacuation exits present is fully utilized in order to minimize the total amount of door width needed. By analysing flow through doors, one may optimize the placement and width of doors without lowering the level of safety.

The mathematical description of flowrate in the format described in section 4.1 can be found in Appendix 1. The value Φ will in the case of flowrate represent the highest flowrate measured in each run as this data point is deemed as the most interesting one.

5.3 Queuing time

Queue: […] *a file of persons, vehicles etc. waiting their turn.* (Kirkpatrick, 1992)

Fruin gives another definition: *"Queuing may be broadly defined as any form of pedestrian waiting that requires standing in a relatively stationary position for some period of time"* (1971, p. 62).

Queuing means to wait for something, often in a specific order of some sort, both physical and not. In an evacuation scenario, the flow of people will encounter obstacles that will hinder the flow. One example is a wide corridor that leads to a narrow door. This will lead to congestion since the people arriving at the door will do so in a faster pace than they can pass through the door, given that the initial flow is large enough. In this case a tidy queue will not form but the mass of people will behave more as a fluid, everyone tries to go through the door in the fastest way possible. This phenomenon is called *dislocable queue*, see Figure 9, and has been observed in experiments (Zhang, Song, & Xu, 2008). Fruin (1971) defines this as a "bulk" queue. It means that the occupants adjust their individual speed continually letting those in front or close to the target to go first, i.e. showing the characteristics but not the form of an ordered queue.

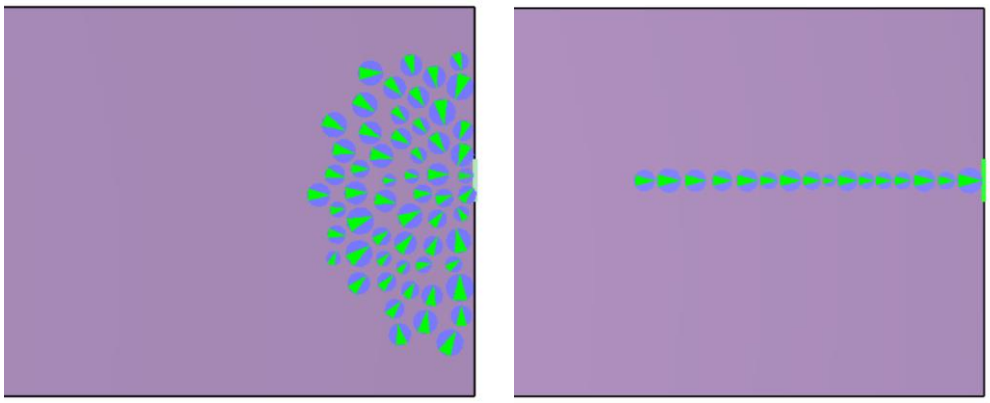


Figure 9. Dislocable queue (left) versus regular queue (right) in the model Pathfinder.

This congestion will lead to a slowing down of the flow and each individual will have to adjust their speed in order to avoid bumping in to each other. Queuing time is quite straight forward to measure, we will measure the time of which we are queuing. The problem is however how we defines a queue. It is also important to consider what it is exactly that we

are interested in. In evacuation scenarios, queuing time is important to consider since it slows down the process of evacuation. What should be considered is then the amount of extra time the queuing process adds to the total evacuation time.

Normally when there is a queue, the occupancy load is high, which leads to crowding also on other parts of the path which makes the occupants take longer time to exit. So, a simple comparison between how much longer time it takes for the occupant to exit when there are other occupants versus when there is none is not enough. As stated above, a queue usually involves waiting for something, which would mean that the velocity of an occupant in a queue would be significantly lower than their maximum capacity. But the queue isn't stationary, it is assumed that the occupants move a bit to optimize their chances to exit faster. This can be seen in Fruin's definition where he recognizes that a queue involves *relatively* stationary positioning but not completely (Fruin, 1971). As occupants reach the exit, the queue is also moving forward at a certain pace depending on the number of occupants, configuration of queue and exit capacity.

One way to measure the amount of extra time required to exit as a result of queuing would then be to measure the time at which an occupant travels at a speed lower than a certain threshold. This threshold is sometimes called *jam time* (Thunderhead Engineering, 2018). As the velocity of the queue is dependent on the situation, the threshold should also be set accordingly. Components which will have an influence on the velocity of the queue and should be included when defining the *jam velocity* are for example: the geographical expansion of the queue and the flow capacity of the flow constraint.

The mathematical description of queuing time in the format described in section 4.1 can be found in Appendix 1. The value Φ will in the case of queuing time represent the longest queuing time measured in each run as this data point is deemed as the most interesting one.

5.4 Used exit

If we were to only consider the TET and occupant-evacuation time curve in the analysis, we might get the same result even though the underlying behaviour might be different. One example of this is that two occupant evacuation times may be identical, but they may refer to completely different occupants or exits (Ronchi, Reneke, & Peacock, 2014). To analyse this information per occupant would be quite demanding since occupant positioning within the computational domain is randomized between each run, making it difficult to establish what is to be considered to be the "same" occupant. We can however analyse door specific information. This could be done either by counting the total number of occupants that use a specific exit in a simulation, or by analysing exit specific occupant-evacuation time curves. The latter enables a more in-depth analysis but is also more computational demanding. It is also reasonable to assume that the convergence criteria will be fulfilled later for the exit specific occupant-evacuation time curves than for the global occupant-evacuation time curves due to fewer data available. This will result in a larger number of runs needed. For the purpose of this thesis, used exit will be measured as exit specific occupant-evacuation time curves. The case study will determine if this method is successful or not.

The mathematical description of used exit in the format described in section 4.1 can be found in Appendix 1. The value Φ will in the case of used exit represent the total number of occupants which used an exit in each run as this data point is deemed as the most interesting one.

5.5 Spatial location of occupants

The last output parameter that will be studied and implemented in the tool presented by this thesis is a measure of where the occupants are located throughout the simulation. To give the exact position of each occupant and then compare it between different simulations would not be possible since it would require a too comprehensive analysis. The problem with what is to be considered as the same occupant as discussed for the output parameter Used Exit also constitutes a problem. It could also be argued that we are not interested in that high level of resolution when doing an evacuation simulation as part of an evacuation analysis. The interest lies instead in knowing where the 'mass' of people is located. One way of measuring this is by counting the number of occupants at a specific location at a certain time. The location could be a room, a stairway, a floor etc. depending on what the model user defines as interesting. Regardless of what area or location that the user defines, the form of the output parameter is still the number of people in that area at a certain time.

Note that this output parameter is very similar to density, with the exception that the reference area is in general larger and that for this output parameter we do not divide the number of occupants with the reference area.

The mathematical description of spatial location in the format described in section 4.1 can be found in Appendix 1. The value Φ will in the case of spatial location represent the highest occupancy measured in each run as this data point is deemed as the most interesting one.

6 Description of tool

This section describes how the output parameters described above are implemented in the tool and how the tool works. The tool is developed using VBA in Excel and is made to be off-the-shelf compatible with Pathfinder version 2018.3.0730. What this means is that the tool is compatible with the output format that Pathfinder uses. The tool is however compatible with other evacuation software as well, but it may require some modification of the format of the output data. See Appendix 2 for a user's guide to the tool.

6.1 Input data

As described above, the tool is designed to be off-the-shelf compatible with Pathfinder version 2018.3.0730. The format of the input data is therefore required to be the same that Pathfinder uses, including the names of the output files. For full description, see Appendix 2. In order to utilize the tool with other evacuation simulation software, another piece of code may be required to modify the data before presenting it to the tool. This code should modify the form of the data so that it looks as described in Appendix 2.

In order to conduct the calculations described in section 4, the tool retrieves the data from the output files and orders it in the vectors described in section 4.1, e.g. $\vec{x}_{ij}$ and $\vec{X}_j$.

The output parameters described in section 5 are the ones that the tool can analyse.

Due to the last data point not being a complete time step in Pathfinder output, the last data point is neglected when the data points represent time steps. This is regarded to have a limited impact on the results since the difference between two time steps is generally small and the difference would be even smaller when the time step is shorter.

The tool also includes an option to utilize moving average for the output parameters which have time steps as data points. This is done to make it possible to generate a better analysis for output parameters which have large scatter in the output. For flowrate for example, when it is measured as in Pathfinder, e.g. number of occupants which have passed during a time step, the measurement does not include the position of the occupants which passed before and after. This means that if three occupants passed a door for three consecutive time steps, the flowrate during the second time step is the same as if only one person would have passed at the second time step and none in the others. One way to deal with this problem is to utilize moving average as implemented in the tool. Another way would be to utilize Voronoi diagrams as discussed in section 5.2, this method enables the measurement to take into account the occupants which have just passed the door or is soon going to.

When moving average is enabled, the data points which lie in the tails of the data sets are neglected since there isn't data for the moving average calculation. E.g. if moving average is defined as ± 30 s, the first and last 30 data points is neglected. Another option would be to modify the moving average interval at the ends of the data sets, but this would make the calculations less transparent for the user.

6.2 Calculations

The tool utilizes the method described in section 4 to calculate the different convergence measures. The tool lets the user define the convergence criteria explicitly for each output parameter and uses them to determine whether convergence has been met or not. As discussed, the results will also vary depending on the number of data points chosen to study.

6.3 Description of outputs

Output will be presented in three stages: to display the input data, to display the calculations, and to display the overall results.

In order to display the input data in a comprehensible way, the tool draws a graph containing the values from all runs analysed. When the number of runs is high, it will not be possible to see each individual run in the graph, but that is not the purpose. The purpose is to give an overview of the runs and the variability in the results. The tool is also programmed to provide the user with basic descriptive statistics for the different output parameters such as maximum, average and minimum value and the standard deviation as well as a 95% confidence interval of the sample mean.

The tool also presents to the user a graph containing all the aggregated runs, the last aggregated run is highlighted in red. The last curve represents the best estimate of the average curve. This graph is visualized for transparency reasons since this is the data used in the calculations.

The results of the calculations from the five convergence measures and the KS-test will be presented for all runs, i.e. the tool will not only present when convergence has been met but also the calculation process. The results will be presented individually for all output parameters.

To get a quick overview over the results, results will be displayed that tells the user if convergence has been met or not. This is presented in a table as one answer per output parameter and convergence measure.

7 Case study

This section contains a case study used to demonstrate the capacity of the tool. The purpose of this thesis is not to analyse behavioural uncertainty in a specific case but rather to develop a method applicable to most cases. Therefore, this section is only to be seen as a demonstration of the tool and method and nothing else.

7.1 Pathfinder version 2018.3.0730

The case study will be simulated using the evacuation software Pathfinder version 2018.3.0730 developed by Thunderhead engineering. Pathfinder is an agent-based continuous model. Route choice utilises an algorithm of the model in which a locally quickest path planning approach is used (Thunderhead Engineering, 2018). This means that routes are ranked hierarchically using local and global information about people location, queuing times at exits and distance to exits.

The sampling method used in Pathfinder to assign characteristics to occupants based on distributions varies with the type of distribution under consideration. For the case study, the standard normal and log-normal distributions will be used. To generate random numbers from the standard normal distribution, Pathfinder uses the Polar method. From a log-normal distribution, Pathfinder uses the Adapted Box-Mueller method truncated by range.

7.1.1 Output parameter measurement

As discussed in section 6, the method and tool work regardless of measurement method. However, a discussion about the measurement techniques used in Pathfinder version 2018.3.0730 is useful to determine whether the measurement techniques have an impact on the analysis. Evacuation time is measured in seconds and is presented as one value per occupant. Queuing time is measured in jam time, i.e. the time which an occupant spends moving at a speed lower than some threshold value (Thunderhead Engineering, 2018). For the case study, the default value of 0,25 m/s will be used.

Density may be measured in two different ways: density in a specific room, or with the use of measurement regions. The method of measurement regions is the one used in the case study. The measurement regions in Pathfinder version 2018.3.0730 utilises Voronoi diagrams (Thunderhead Engineering, 2018) as presented in section 5.1. This method is helpful in limiting the scatter in results, something which may benefit the calculations on convergence. The case study will determine if this is the case.

Flowrate is measured per door and is presented in the form of number of occupants which have passed the door during a specific time step. The measurement does not utilise Voronoi diagrams which means that the amount of scatter will be very high, especially if the door is narrow. The case study will determine if the analysis is possible anyway with the use of moving average.

Used exit is measured in number of occupants which have used a specific exit. The measurement is done during the whole simulation, i.e., data is presented as a function of time, not as a single value summarising the whole simulation.

Spatial location is measured in occupancy, i.e. how many occupants which occupy a room at a specific time step. Hence, the measurement is quite similar to density, except that spatial location is presented in the form of number of occupants, in contrast to number of occupants per area.

7.2 Description of case study

This section includes a description of the case study and the input data used.

7.2.1 Building

The building used in the case study is a school building which has yet to be built. The exact location of the building is kept secret due to request from the provider of the drawings. The use of the building is however known, and the building is to be used as a university building, which means that the occupants will mainly be students and staff participating in various educational activities. In the case study, an occupancy of 1855 occupants distributed between the floors has been used.

The building consists of a total of seven stories, where two are below ground level. Detailed visualisation of how the model looks in Pathfinder can be found in Appendix 3.

The building has two main exits, located on opposite sides of the building. These can be reached from the other floors via three staircases. Apart from these, the building is equipped with three other exits all located on the ground floor.

In the analysis of density, flowrates, spatial location and used exit, areas of interest need to be chosen by the user. For the purpose of demonstrating the tool, the two main exits have been chosen to be of particular interest for both flowrate and used exit. Another exit has also been chosen to be of particular interest, this one is located at one of the staircases. See Appendix 3 for visualisation of where these points of interest are located.

For density measurement, the last set of stairs in the central staircase is selected. In a fire safety analysis, this could be of particular interest in order to see how much of the stairs capacity is utilized. For spatial location, the area closest to the atrium on the three first floors are chosen to be of particular interest, this is because this area is utilized as one of the main evacuation routes.

A summary over points of interest can be found in Table 2

Table 2. Points of interest chosen for the case study.

Point of interest	Description
MainExit1	One of the two main exits. Width = 2,0 m.
MainExit2	One of the two main exits. Width = 2,0 m.
SecondaryExit1	Emergency exit adjacent to one of the staircases. Width = 2,0 m
SecondaryExit1	Emergency exit adjacent to one of the staircases. Width = 2,0 m
LastStair	Density measurement region at the last set of stairs in the central staircase.
belowstairs	Density measurement region at the bottom of the central staircase.
Atrium_lvl0	The main escape route on the ground floor.
Atrium_lvl1	The main escape route on level 1.

7.2.2 Occupant characteristics

Occupant characteristics are defined from experimental data from experiments with similar setting as the case study. The data is gathered from the SFPE handbook (Gwynne & Boyce, 2016). The walking speed of the occupants is set as a truncated normal distribution with the mean value of 1,5 m/s, standard deviation of 0,5 m/s, minimum value of 0,5 m/s and maximum value of 2,0 m/s. The distribution is visualized in Figure 10 below.

Figure 10. The distribution of walking speeds used in the case study.

Pre-evacuation time is also retrieved from the data in the SFPE handbook (Gwynne & Boyce, 2016). The data is represented as a log-normal distribution with μ=4,5 and σ=1. This results in the median value of 90 seconds. The distribution is cropped with a minimum value of 5 seconds and a maximum value of 300 seconds. The distribution is visualized in Figure 11 below.

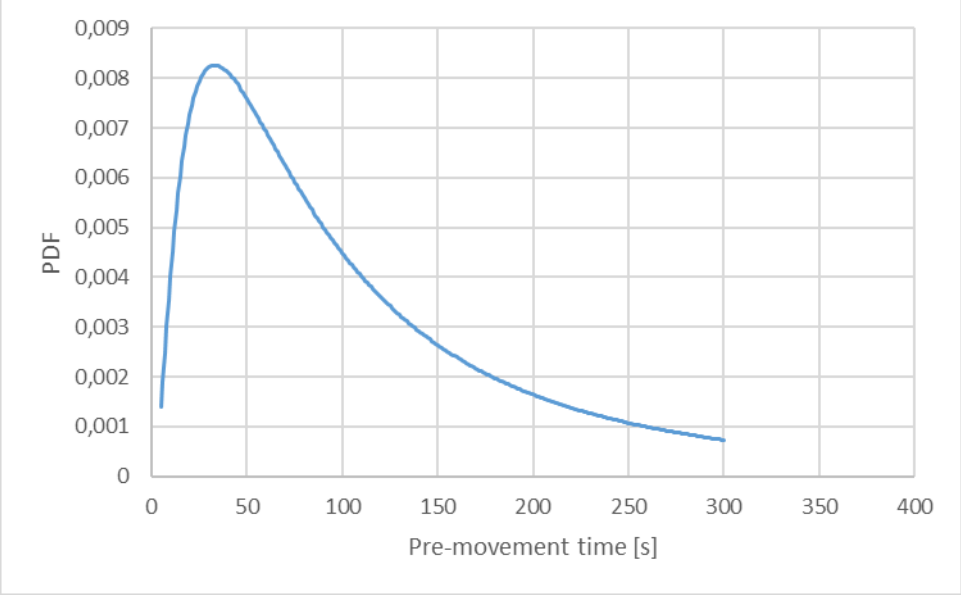


Figure 11. The distribution of pre-evacuation times used in the case study.

7.2.3 Randomizable variables

For each individual run, occupant characteristics has been randomly sampled and ascribed for all agents according to the occupant characteristics distributions presented in section 7.2.2.

Similarly, for each run, occupant positioning within the domain has been randomized.

Due to the algorithms present in Pathfinder version 2018.3.0730, route choice will also vary between runs as a result of occupant characteristics and positioning.

7.2.4 Convergence criteria

In order to do the analysis, the user needs to define some convergence criteria (see section 4.7). These could be individual for all output parameters analysed. The convergence criteria used in the case study is presented in Table 3 below.

Table 3. Convergence criteria used in the case study.

Output parameter\criteria	**TR_{Φ}**	**$TR_{SD\ of\ \Phi}$**	**TR_{ERD}**	**TR_{EPC}**	**TR_{SC}**	**b**	**α**	**k**
Evacuation time	0,1%	1,0%	0,1%	1,0%	0,1%	10	5%	5
Queuing time	1,0%	1,0%	1,0%	1,5%	0,5%	10	5%	5
Density	1,0%	1,0%	1,0%	1,5%	0,5%	10	5%	5
Flowrate	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5
Spatial location	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5
Used exit	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5

Note that these criteria are not a general recommendation that should be applied in other settings, they are purely for demonstration purpose.

7.3 Results

The following section presents the results from the case study. For more detailed results, see Appendix 4.

When the data is retrieved, the tool presents a graph to the user containing the runs retrieved. Two examples of such graphs are presented in Figure 12 and Figure 13 below. A total of 80 runs has been analysed in the case study.

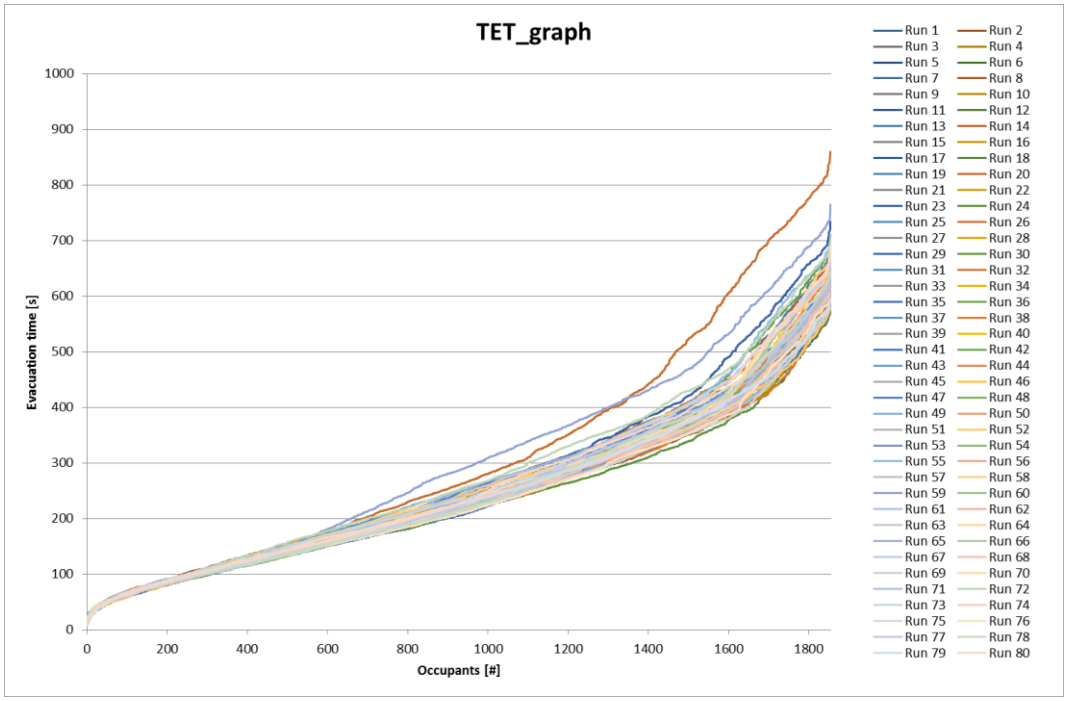


Figure 12. Graph over OETC's.

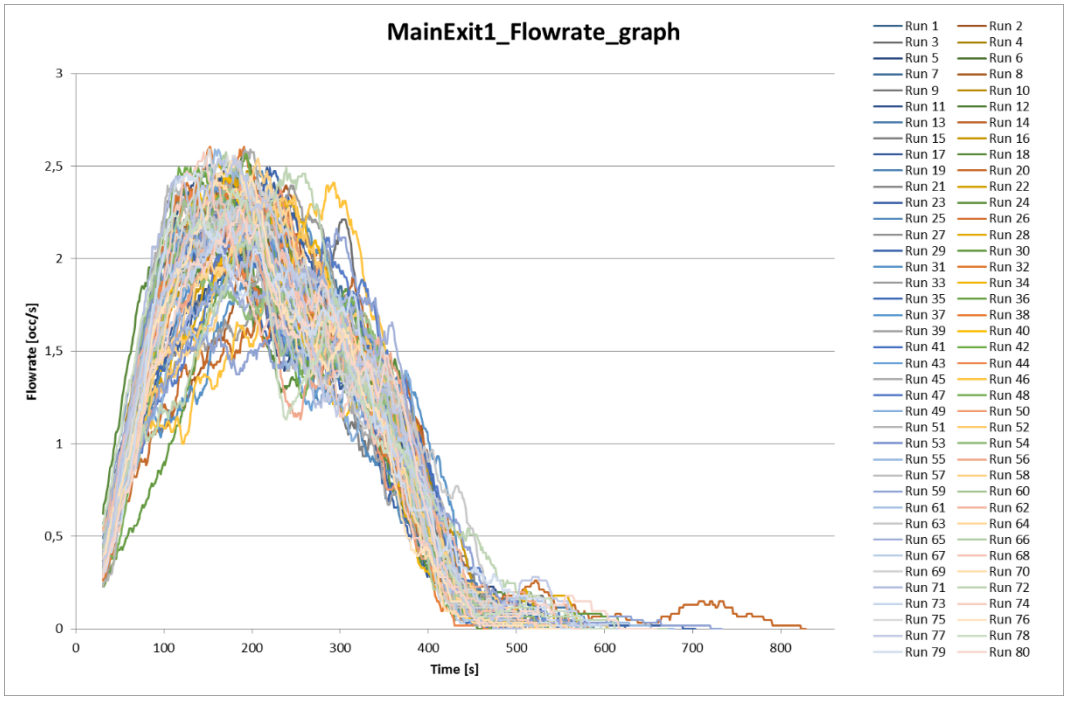


Figure 13. Graph over flowrates through MainExit1.

The descriptive statistics of the runs are presented in Table 4 below.

Table 4. Descriptive statistics from the case study.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m^2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m^2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,21	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	363,92	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	150,83	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	56,49	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	347,18	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	381,70	381,70	373,17

At this stage, the user is asked to specify what method he or she wants to use to deal with the varying number of data points, i.e. minimum, maximum, average or normalizing as discussed in section 4.5. For the purpose of demonstrating the tool, all options will be displayed as separate results in sections 7.3.1 - 7.3.4. The analysis of evacuation time and queuing time is however not affected by this so the results from the analysis of those two output parameters are the same for all options.

When the calculation that aggregates the runs is completed, a graph is displayed showing all aggregated runs, where the last run is highlighted in red. This curve represents the best estimate of the average curve for the output parameter. These graphs can be found in Appendix 4.

7.3.1 Minimum number of data points

This method utilizes the minimum number of data points, i.e. the shortest simulation defines the number of data points to be used in the analysis.

Graphs containing the aggregated runs can be found in Appendix 4.

The next step presents the results. The compiled results from the calculations can be found in Table 5 below.

Table 5. Compiled results when utilizing the minimum number of data points.

	Has convergence been met (Y/N)? At what run?															
	LastStair		**belowstairs**		**MainExit1_FR**		**SecondaryExit1_FR**		**TET**		**Queuing Time**		**Atrium_lvl0**		**MainExit2_UE**		**SecondaryExit2_UE**	
φ	Y	45	Y	58	Y	28	Y	28	Y	44	Y	30	Y	38	Y	44	Y	34
SD	Y	30	Y	30	Y	17	Y	19	Y	19	Y	30	Y	18	Y	18	Y	18
ERD	Y	19	Y	42	Y	31	Y	25	Y	43	Y	33	Y	31	Y	33	Y	35
EPC	Y	46	Y	47	Y	19	Y	18	Y	13	Y	34	Y	30	Y	34	Y	34
SC	Y	28	Y	19	Y	15	Y	15	Y	12	Y	12	Y	14	Y	14	Y	13
KS-test	Y	13	Y	13	Y	10	Y	9	Y	6	Y	6	Y	7	Y	6	Y	7
All	**Y**	**46**	**Y**	**58**	**Y**	**31**	**Y**	**28**	**Y**	**44**	**Y**	**34**	**Y**	**38**	**Y**	**34**	**Y**	**35**

The last row summarises all convergence units for the output parameters studied. The highest value in this row determines when convergence has been met for all output parameters and convergence units. The results show that convergence has been met at the 58th run for all output parameters and convergence units studied.

7.3.2 Maximum number of data points

This method utilizes the maximum number of data points, i.e. the longest simulation run defines the number of data points to be used in the analysis. All other simulation runs are filled out with data points with the output parameter value 0, except for used exit where the additional data points are filled out with the maximum value of the output parameter.

Graphs containing the aggregated runs can be found in Appendix 4.

The next step presents the results. The compiled results from the calculations can be found in Table 6 below.

Table 6. Compiled results when utilizing the maximum number of data points.

	Has convergence been met (Y/N)? At what run?																	
	LastStair		**belowstairs**		**MainExit1_FR**		**SecondaryExit1_FR**		**TET**		**Queuing Time**		**Atrium_lvl0**		**MainExit2_UE**		**SecondaryExit2_UE**	
φ	Y	45	Y	58	Y	28	Y	28	Y	44	Y	30	Y	38	Y	42	Y	28
SD	Y	30	Y	30	Y	17	Y	19	Y	19	Y	30	Y	18	Y	21	Y	18
ERD	Y	19	Y	42	Y	31	Y	25	Y	43	Y	33	Y	31	Y	41	Y	33
EPC	Y	46	Y	47	Y	19	Y	18	Y	13	Y	34	Y	30	Y	27	Y	34
SC	Y	28	Y	19	Y	14	Y	15	Y	12	Y	12	Y	14	Y	15	Y	13
KS-test	Y	18	Y	18	Y	8	Y	6	Y	6	Y	6	Y	7	Y	6	N	-
All	**Y**	**46**	**Y**	**58**	**Y**	**31**	**Y**	**28**	**Y**	**44**	**Y**	**34**	**Y**	**38**	**Y**	**42**	**N**	**-**

The last row summarises all convergence units for the output parameters studied. The highest value in this row determines when convergence has been met for all output parameters and convergence units. The results show that convergence was not met for all output parameters in 80 runs.

7.3.3 Average number of data points

This method utilizes the average number of data points, i.e. the number of data points to use in the analysis is defined according to the average length of all simulation runs. This means that for shorter simulation runs, the minimum number of data points method is applied and for longer simulation runs, the maximum number of data points method is applied.

Graphs containing the aggregated runs can be found in Appendix 4.

The next step presents the results. The compiled results from the calculations can be found in Table 7 below.

Table 7. Compiled results when utilizing the average number of data points.

	Has convergence been met (Y/N)? At what run?																	
	LastStair		**belowstairs**		**MainExit1_FR**		**SecondaryExit1_FR**		**TET**		**Queuing Time**		**Atrium_lvl0**		**MainExit2_UE**		**SecondaryExit2_UE**	
φ	Y	45	Y	58	Y	28	Y	28	Y	44	Y	30	Y	38	Y	35	Y	33
SD	Y	30	Y	30	Y	17	Y	19	Y	19	Y	30	Y	18	Y	21	Y	18
ERD	Y	19	Y	42	Y	31	Y	25	Y	43	Y	33	Y	31	Y	41	Y	35
EPC	Y	46	Y	47	Y	19	Y	18	Y	13	Y	34	Y	30	Y	27	Y	34
SC	Y	28	Y	19	Y	14	Y	15	Y	12	Y	12	Y	14	Y	15	Y	13
KS-test	Y	26	Y	18	Y	10	Y	15	Y	6	Y	6	Y	7	Y	6	Y	18
All	**Y**	**46**	**Y**	**58**	**Y**	**31**	**Y**	**28**	**Y**	**44**	**Y**	**34**	**Y**	**38**	**Y**	**42**	**Y**	**35**

The last row summarises all convergence units for the output parameters studied. The highest value in this row determines when convergence has been met for all output parameters and convergence units. The results show that convergence has been met at the 58th run for all output parameters and convergence units studied.

7.3.4 Normalizing data points

This method modifies the number of data points for all simulation runs so that they all contain the same number of data points. The longest simulation run sets the number of data points, then all other simulation runs data points are modified with the use of linear interpolation. This means that two data points no longer represent the same time step.

Graphs containing the aggregated runs can be found in Appendix 4.

The next step presents the results. The compiled results from the calculations can be found in Table 8 below.

Table 8. Compiled results when normalizing the number of data points.

	Has convergence been met (Y/N)? At what run?															
	LastStair		**belowstairs**		**MainExit1_FR**		**SecondaryExit1_FR**		**TET**		**Queuing Time**		**Atrium_lvl0**		**MainExit2_UE**		**SecondaryExit2_UE**	
φ	Y	45	Y	58	Y	28	Y	28	Y	44	Y	30	Y	38	Y	42	Y	28
SD	Y	30	Y	30	Y	17	Y	19	Y	19	Y	30	Y	18	Y	21	Y	18
ERD	Y	19	Y	42	Y	34	Y	17	Y	43	Y	33	Y	35	Y	31	Y	23
EPC	Y	46	Y	47	Y	19	Y	18	Y	13	Y	34	Y	29	Y	31	Y	20
SC	Y	28	Y	19	Y	15	Y	15	Y	12	Y	12	Y	15	Y	15	Y	13
KS-test	Y	15	Y	14	Y	13	Y	15	Y	6	Y	6	Y	8	Y	9	Y	14
All	**Y**	**46**	**Y**	**58**	**Y**	**34**	**Y**	**28**	**Y**	**44**	**Y**	**34**	**Y**	**38**	**Y**	**42**	**Y**	**28**

The last row summarises all convergence units for the output parameters studied. The highest value in this row determines when convergence has been met for all output parameters and convergence units. The results show that convergence has been met at the 58th run for all output parameters and convergence units studied.

8 Additional tests

In addition to the above presented case study, the tool and method has also been tested on a smaller case, namely a simple example consisting of the geometry in the IMO test 10 (IMO, 2016). The number of occupants is set to 50 and their position and characteristics are randomized between each run. The walking speed is the same as in the above presented case study, see Figure 10. The pre-evacuation time distribution is however changed to a normal distribution with mean (μ) = 15 s, standard deviation (σ) = 10 s, maximum = 30 s and minimum = 0 s.

The table below displays the convergence criteria used for the IMO test 10 study.

Table 9. Convergence criteria used in the IMO test 10 study.

Output parameter\criteria	TR_{Φ}	$TR_{SD\ of\ \Phi}$	TR_{ERD}	TR_{EPC}	TR_{SC}	b	α	k
Evacuation time	0,5%	1,0%	0,5%	1,0%	0,1%	10	5%	5
Queuing time	1,0%	1,0%	1,0%	1,5%	0,5%	10	5%	5
Density	1,0%	1,0%	1,0%	1,5%	0,5%	10	5%	5
Flowrate	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5
Spatial location	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5
Used exit	0.5%	1,0%	0,5%	1,0%	0,5%	10	5%	5

Note that these criteria are not a general recommendation that should be applied in other settings, they are purely for demonstration purpose.

An initial number of 80 runs were simulated were occupant positioning and characteristics were randomized.

The moving average approach were utilized for the output parameters flowrate, density and spatial location. The moving average value was set to ±5 s. Note that a higher value would have been needed but due to the short simulation times (approximately 50 s) this was not possible since most of the data would have been cropped out.

The table below contains a short description of the points of interest chosen.

Table 10. Points of interest chosen for the IMO test 10 study.

Point of interest	Description
MainExit	One of the two exits. Width = 1,2 m.
SecondaryExit	One of the two exit. Width = 0,9 m.
M_exit	Density measurement region in front of the main exit.
S_exit	Density measurement region in front of the secondary exit.
Corridor	The area/room connecting the cabins. This is the main and only escape route.

The descriptive statistics from the IMO test 10 study can be found in Table 11 below.

Table 11. Descriptive statistics from the IMO test 10 study.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
M_exit_Max density [occ/m²]	1,55	0,45	0,23	0,91	0,96	0,86
S_exit_Max density [occ/m²]	2,15	0,78	0,26	1,36	1,42	1,31
MainExit_Max flowrate [occ/s]	1,45	0,73	0,18	1,10	1,14	1,06
SecondaryExit_Max flowrate [occ/s]	1,18	0,73	0,10	0,94	0,97	0,92
TET [s]	58,00	38,78	3,36	46,68	47,41	45,95
Max queuing time [s]	16,40	2,03	3,34	6,57	7,30	5,85
Corridor_Max occupancy [occ]	24,27	12,36	2,58	17,28	17,84	16,72
MainExit_Max usage [occ]	29,00	18,00	2,32	24,30	24,81	23,79
SecondaryExit_Max usage [occ]	31,00	20,00	2,33	24,91	25,42	24,40

The option to utilize the normalizing data points method was chosen for this study. The results from the study can be seen in Table 12 below.

Table 12. Compiled results from the IMO test 10 study.

	Has convergence been met (Y/N)? At what run?															
	LastStair		**belowstairs**		**MainExit1_FR**		**SecondaryExit1_FR**		**TET**		**Queuing Time**		**Atrium_lvl0**		**MainExit2_UE**		**SecondaryExit2_UE**	
φ	Y	35	Y	49	Y	46	Y	50	Y	42	Y	64	Y	47	Y	30	Y	34
SD	Y	23	Y	23	Y	21	Y	18	Y	18	Y	32	Y	23	Y	18	Y	20
ERD	Y	36	Y	41	Y	36	Y	44	Y	21	Y	35	Y	35	Y	35	Y	36
EPC	Y	46	Y	40	Y	32	Y	33	Y	27	Y	75	Y	34	Y	35	Y	36
SC	Y	16	Y	17	Y	16	Y	15	Y	14	Y	16	Y	14	Y	16	Y	16
KS-test	Y	6	Y	11	Y	8	Y	13	Y	6	Y	6	Y	10	Y	6	Y	6
All	**Y**	**46**	**Y**	**49**	**Y**	**46**	**Y**	**50**	**Y**	**42**	**Y**	**75**	**Y**	**47**	**Y**	**35**	**Y**	**36**

The last row summarises all convergence units for the output parameters studied. The highest value in this row determines when convergence has been met for all output parameters and convergence units. The results show that convergence has been met at the 75th run for all output parameters and convergence units studied.

9 Discussion

Since more output data are investigated, the method proposed here extends the method proposed by Ronchi et. al. (2014) which leads to a better confidence in the results for assessing variance between repeat simulation runs. That is because it is less likely that all output parameters convergence in results if the behaviour is not the same (Ronchi, Reneke, & Peacock, 2014, p. 1569). It is important to note however that the level of detail could be increased further by analysing individual occupants positioning etc. Many of the output parameters presented here are averaged over space or time, which is of cost of resolution. To increase the level of detail further, work has to be done to establish how this is best to be done. Some problems that would arise is for example what is to be regarded as the same occupant when occupant positioning is randomized as part of the uncertainty analysis. The scatter in results would also pose a big problem. The compromise done in this thesis is therefore essential to minimize the scatter in results and at the same time keeping a high level of detail in the analysis and subsequently a high resolution.

The output parameters chosen in this study provides a greater level of detail than to only analyse TET, which will likely mean that the amount of variance will be significantly higher which in turn will increase the need for a greater number of repeat runs. This can also be seen in the results from the case study.

The output parameters included in this thesis are exemplary and should not be seen as a thorough description of the evacuation process. The method proposed in this thesis could be applied to even more output parameters if necessary since all output parameters included in this thesis were analysed efficiently and that they represent the variety of output parameters possible to measure in an evacuation scenario.

Due to the fact that the method is successful, it may also be used in validating simulation software against real world experiments. The output parameters implemented in the method and the tool could without much effort be measured during an evacuation trial. This would lead to a more rigid validation procedure when more output parameters are included and consequently the possibility that less trials would be needed when more output parameters can be analysed.

The option to utilize moving average for output parameters with much scatter enables results more valuable for the user since it includes estimations of the values of the data points adjacent to the one analysed. For example for flowrate, it includes estimation of when the next occupant are passing through and when the previous occupant passed through as discussed in section 6.1. However, the method introduces a problem as it increases the volatility in the results and further when the convergence measures are met for that output parameter. A better method could be to implement Voronoi diagrams in the measurement of the output parameter such as implemented for density measurements in Pathfinder. If this method is implemented, the need for moving average would decrease as can be seen in the results from the density measurements presented in section 7.3.

The different methods used to address the problem associated with varying number of data points are evaluated through the results from the case study. The results showed that the maximum method is the one associated with the most limitations. This is as a consequence

of the methods assumption that the data sets can be filled out with the value 0 (or maximum value for the used exit output parameter). For some output parameters, this assumption makes the differences in results very large since the end tail of the data set does not necessarily approach to this value. One example is when moving average is utilized which crops the end tail of the data.

For the output parameter Used Exit, the assumption is instead that the data sets are filled out with the maximum value of the data set, i.e. the total number of occupants which used the exit. This also results in large difference between the runs at the end of the data sets which poses a problem to the analysis. The maximum data points method is therefore deemed as the method least useful in this type of analysis. The same goes for the average data points method where the maximum data points method is utilized for some of the data sets.

The minimum data points method is more useful when calculating convergence, but it also neglects the end of the data sets which might provide useful information for the analysis. So even though the analysis is possible with this method, it is deemed as less useful.

The method that proved most useful is the method that normalizes the number of data points between all runs. In this method, all the collected data is used and analysed. The problem is however that two data points in two different runs no longer represent the exact same time. This is however deemed to have little impact on the results if the relative difference in number of data points is limited.

The case study proved that this type of analysis is efficient even when the number of data points are no longer the same with the use of minimum and normalizing data points method. This would mean that this type of analysis could be conducted even though the number of occupants between different runs may vary. This is something that is generally not included in the evacuation simulation software's of today, and it is deemed to have a large influence on the results if this were to be included. As discussed in section 2.3, this is something that is typically not known when designing a building, and it will also change from time to time so it would be reasonable to include this uncertainty in the software.

A limitation of the method that was discovered thru the case study is that it is not efficient in analysing convergence when there is limited or no change in the data. This typically occurs at the start or end of the calculation for the output parameters Flowrate, Density, Used exit and Spatial Location. A possible solution could be to crop the data set so that only the parts that is subject to regular change in the output parameter values would be included. This is however not tested in this thesis.

It is important to note that the method does not only analyse the behavioural uncertainty included in the simulations but other uncertainties as well. The action to randomize the occupant's position within the domain between runs is something not generally associated with behavioural uncertainty but instead it should be seen as a model input uncertainty. The method and tool does however analyse variability in results and not only one specific uncertainty. The same can be said about walking speed as it is not only a choice to move at a certain speed but also a physical attribute.

When comparing the results from the case study and the IMO test 10 study it can be concluded that convergence was met later in the latter of the two. This is to be expected when the amount of data is smaller meaning that the characteristics and position of a single occupant will have a larger impact on the results. The results from the two studies showed however that the analysis is possible in vastly different settings, i.e. both small and large cases.

Ideally, the thesis would include a validation section to validate the method against actual human behaviour data. Due to the limited data on repeated evacuation trials/events, this is not possible at the moment.

10 Conclusion

Through the case study, it is shown that the proposed method is efficient in analysing convergence in results not only for TET but for other output parameters as well. This enables an analysis which is more comprehensive and at a greater level of detail than what previous methods has according to the performed review. This ensures that the underlying behaviours that govern TET also have converged, i.e. the problem that different behaviours may produce the same TET has been addressed. This type of quantitative analysis is essential in evacuation modelling due to the stochastic characteristics of human behaviour.

By conducting this analysis efficiently, the user makes sure that all possible outcomes of human behaviours have been simulated and that the range of results therefore represents the range of results which may take place in real life. When comparing to ASET, this means that the building or construction analysed is safe to evacuate independent on variability in human behaviour.

It is important to note that this type of analysis is dependent on the input defined by the user in form of distributions for occupant characteristics. The method does not analyse behavioural uncertainty per se but only the effect of the distributions and algorithms implemented in the model which is supposed to represent behavioural uncertainty. It is therefore of outmost importance that the user and developer define these as correctly as possible so that a correct representation is made.

The main drawback with the method proposed is that it relies on the users' good judgement in deciding acceptance criteria. To date, there is no guidance on how these criteria should be set. Preferably, a statistical method would be applied in determining these criteria or possibly with the use of empirical data.

The tool developed as a part of this thesis has shown to be useful in this type of analysis. With the use of this tool, the analysis of results of stochastic evacuation models has been made available for fire safety engineers which may have hesitated before due to the work load associated with manually conducting this type of analysis. This enables the quantitative assessment of behavioural uncertainty in a variety of fields, and in the field of fire safety design of constructions in particular.

11 Suggestions for further research

One of the main limitations of this method is the arbitrarily defined convergence criteria. A statistical method based on confidence intervals would benefit this analysis as it limits the effects of the user's judgement. Alternatively, a study determining how to set the acceptance criteria could help the user in this step, possibly with the use of empirical data on variance in human behaviour.

As stated, the method is only able to analyse behavioural uncertainty that is implemented in the simulations by the user. More studies on how this is best done is therefore essential for this kind of analysis to be valuable. As stated, the decision-making process is often grossly simplified in the models with the use of distributions which could be argued to be very imprecise. In order to make the analysis of behavioural uncertainty as accurate as possible, considerations need also to be taken in how it is represented in the model and not only how it creates variability in results.

With the proposed method, studies could be conducted to determine the most important output parameters which govern TET. This could be done with the use of sensitivity analysis on the variability in results. This could then help the user in determining which parts of the design are most problematic and then make changes there to achieve the most "bang for the buck".

Through the work in this thesis, it is determined that more output parameters could be analysed with the proposed method. This means that there is a possibility that output parameters such as exposure to smoke etc. could also be implemented. More work is needed in order to do this.

Due to the proven success of the proposed method, it could be implemented to validate evacuation simulation software. Studies to determine its applicability is needed. Efforts to collect data from repeated evacuation trials/events to validate against are also essential if this is to become a possibility.

Even though the method developed in this thesis has proven to be able to analyse the effects of behavioural uncertainty, how to present the results from the evacuation simulations has not been determined. This is also dependant on the intended use of the study. If the simulations are to be used in a risk analysis, a confidence interval could provide valuable information to the user.

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Appendix

Appendix 1 Mathematical description of output parameters

This appendix contains the mathematical descriptions of the output parameters implemented in the method and tool.

Density

Regardless of how we choose to define the reference area, density is measured in occupants per unit floor area as discussed above. The method for analysis should be applicable even though the method of measurement might differ. In a simulation, density will vary over time, resulting in a series of values. In order to be able to analyse densities with the method proposed by Ronchi et. al. (2014), we need to divide the measurement of density in a set of data points which then can be composed into a vector (Peacock, Reneke, Davis, & Jones, 1999). Since we measure density at a specific time, it would be reasonable to make the division of data points based on some time interval, δt. Another possibility would be to make the division based on some difference in density, δd. Ronchi et. al. (2014) chose to make the division based on when the occupants had evacuated, i.e. one data point referred to the time at which an occupant had evacuated. The opposite would be to divide the simulation time into different time steps, and then defining a data point as how many occupants that evacuated during that time step.

Consider a simulation consisting of q number of time steps. The vector that describes the density would then be denoted as:

$$\vec{d} = \left(d_1, d_2, \dots, d_{q-1}, d_q\right)$$

Where d_1 corresponds to the density at the first time step, d_2 to the density at the second time step and so on. If we were to simulate n runs of the same scenario, n vectors $\vec{d}_{ij}$ would be obtained, where n is the total number of runs, q is the number of time steps or data points, i denotes a specific time step and j denotes a specific run.

$$\vec{d}_{ij} = \left(d_{1j},\ d_{2j}, \dots, d_{(q-1)j}, d_{qj}\right)$$

So for example, a simulation with 2 runs (=n) and 3 time steps (=q) would result in the following vectors:

$$\vec{d}_{i1} = (d_{11}, d_{21}, d_{31})$$

$$\vec{d}_{i2} = (d_{12}, d_{22}, d_{32})$$

The next step is to present a output parameter which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of time steps is still denoted q, and a specific run is denoted j, then the jth average curve, $\vec{D}_j$, is described by the following vector:

$$\vec{D_j} = \left(D_1, D_2, \dots, D_{q-1}, D_q\right)$$

Where:

$$D_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} d_{1j},\ D_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} d_{2j},\ \dots,\ D_q = \frac{1}{j}\sum_{j=1}^{1<j<n} d_{qj}$$

For example, if *j*=1, then $\vec{D_j}$ would correspond to the values of the first run, i.e. $\vec{d}_{i1}$. If *j*=4, then $\vec{D_j}$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\vec{d}_{i1}$, $\vec{d}_{i2}$, $\vec{d}_{i3}$ and $\vec{d}_{i4}$.

Flowrate

Similar as for density, a mathematical description of flowrate is needed in order to implement it in the method. The method should also be applicable regardless of measurement technique.

In a simulation, flowrate will vary over time, resulting in a series of values. In order to be able to analyse flowrates with the method proposed by Ronchi et. al. (2014), we need to divide the measurement of flowrate in a set of data points which then can be composed into a vector (Peacock, Reneke, Davis, & Jones, 1999). Since we measure flowrate as a function of time, it would be reasonable to make the division of data points based on some time interval, δt. Another possibility would be to make the division based on some difference in flowrate, δf.

Consider a simulation consisting of *q* number of time steps. The vector that describes the flowrate would then be denoted as:

$$\vec{f} = \left(f_1, f_2, \dots, f_{q-1}, f_q\right)$$

Where f_1 corresponds to the flowrate at the first time step, f_2 to the flowrate at the second time step and so on. If we were to simulate *n* runs of the same scenario, *n* vectors $\vec{f}_{ij}$ would be obtained, where *n* is the total number of runs, *q* is the number of time steps or data points, *i* denotes a specific time step and *j* denotes a specific run.

$$\vec{f}_{ij} = \left(f_{1j},\ f_{2j}, \dots, f_{(q-1)j}, f_{qj}\right)$$

So for example, a simulation with 2 runs (=*n*) and 3 time steps (=*q*) would result in the following vectors:

$$\vec{f}_{i1} = (f_{11}, f_{21}, f_{31})$$

$$\vec{f}_{i2} = (f_{12}, f_{22}, f_{32})$$

The next step is to present a output parameter which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of time steps is still denoted *q*, and a specific run is denoted *j*, then the *j*th average curve, $\vec{F}_j$, is described by the following vector:

$$\vec{F}_j = (F_1, F_2, \dots, F_{q-1}, F_q)$$

Where:

$$F_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} f_{1j},\ F_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} f_{2j},\ \dots,\ F_q = \frac{1}{j}\sum_{j=1}^{1<j<n} f_{qj}$$

For example, if *j*=1, then $\vec{F}_j$ would correspond to the values of the first run, i.e. $\vec{f}_{i1}$. If *j*=4, then $\vec{F}_j$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\vec{f}_{i1}$, $\vec{f}_{i2}$, $\vec{f}_{i3}$ and $\vec{f}_{i4}$.

Queuing time

In order to implement queuing time in the tool, we need to describe it in a mathematical way. And as always, the method is general and is applicable to all possible ways of calculating queuing time.

In a simulation, queuing time will be different for each occupant, resulting in a series of values. The format of queuing times is very similar to the format of evacuation times analysed by Ronchi et. al. (2014), i.e. one value for each occupant with the possibility to order the occupants from low to high queuing time. This set of queuing times can then be composed into a vector (Peacock, Reneke, Davis, & Jones, 1999).

Consider a simulation consisting of *q* number of occupants. The vector that describes the queuing time would then be denoted as:

$$\vec{w} = (w_1, w_2, \dots, w_{q-1}, w_q)$$

Where w_1 corresponds to the queuing time of the first occupant, w_2 to the queuing time of the second occupant and so on. If we were to simulate *n* runs of the same scenario, *n* vectors $\vec{w}_{ij}$ would be obtained, where *n* is the total number of runs, *q* is the number of occupants or data points, *i* denotes a specific occupant and *j* denotes a specific run.

$$\vec{w}_{ij} = (w_{1j},\ w_{2j}, \dots, w_{(q-1)j}, w_{qj})$$

So for example, a simulation with 2 runs (=*n*) and 3 occupants (=*q*) would result in the following vectors:

$$\vec{w}_{i1} = (w_{11}, w_{21}, w_{31})$$

$$\vec{w}_{i2} = (w_{12}, w_{22}, w_{32})$$

The next step is to present a output parameter which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of occupants is still denoted *q*, and a specific run is denoted *j*, then the *j*th average curve, $\vec{W}_j$, is described by the following vector:

$$\vec{W}_j = (W_1, W_2, \dots, W_{q-1}, W_q)$$

Where:

$$W_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} w_{1j},\ W_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} w_{2j},\ \ldots,\ W_q = \frac{1}{j}\sum_{j=1}^{1<j<n} w_{qj}$$

For example, if *j*=1, then $\overrightarrow{W_j}$ would correspond to the values of the first run, i.e. $\overrightarrow{w}_{i1}$. If *j*=4, then $\overrightarrow{W_j}$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\overrightarrow{w}_{i1}$, $\overrightarrow{w}_{i2}$, $\overrightarrow{w}_{i3}$ and $\overrightarrow{w}_{i4}$.

Used Exit

In order to implement queuing time in the tool, we need to describe it in a mathematical way.

In a simulation, evacuation time will be different for each occupant, resulting in a series of values. The format of exit specific OETC is very similar to the format of evacuation times analysed by Ronchi et. al. (2014), i.e. one value for each occupant with the possibility to order the occupants from low to high evacuation time. This set of evacuation times can then be composed into a vector (Peacock, Reneke, Davis, & Jones, 1999).

Consider a simulation consisting of *q* number of occupants. The vector that describes the exit specific occupant evacuation time would then be denoted as:

$$\overrightarrow{exit} = \left(exit_1, exit_2, \ldots, exit_{q-1}, exit_q\right)$$

Where w_1 corresponds to the evacuation time of the first occupant, w_2 to the evacuation time of the second occupant and so on. If we were to simulate *n* runs of the same scenario, *n* vectors $\overrightarrow{w}_{ij}$ would be obtained, where *n* is the total number of runs, *q* is the number of occupants or data points, *i* denotes a specific occupant and *j* denotes a specific run.

$$\overrightarrow{exit}_{ij} = \left(exit_{1j},\ exit_{2j}, \ldots, exit_{(q-1)j}, exit_{qj}\right)$$

So for example, a simulation with 2 runs (=*n*) and 3 occupants (=*q*) would result in the following vectors:

$$\overrightarrow{exit}_{i1} = \left(exit_{11}, exit_{21}, exit_{31}\right)$$

$$\overrightarrow{exit}_{i2} = \left(exit_{12}, exit_{22}, exit_{32}\right)$$

The next step is to present a output parameter which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of occupants is still denoted *q*, and a specific run is denoted *j*, then the *j*th average curve, $\overrightarrow{EXIT_j}$, is described by the following vector:

$$\overrightarrow{EXIT_j} = \left(EXIT_1, EXIT_2, \ldots, EXIT_{q-1}, EXIT_q\right)$$

Where:

$$EXIT_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} exit_{1j},\ EXIT_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} exit_{2j},\ \ldots,\ EXIT_q = \frac{1}{j}\sum_{j=1}^{1<j<n} exit_{qj}$$

For example, if *j*=1, then $\overrightarrow{EXIT_j}$ would correspond to the values of the first run, i.e. $\overrightarrow{exit}_{i1}$. If *j*=4, then $\overrightarrow{EXIT_j}$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\overrightarrow{exit}_{i1}$, $\overrightarrow{exit}_{i2}$, $\overrightarrow{exit}_{i3}$ and $\overrightarrow{exit}_{i4}$.

Spatial location

In order to implement a measure on the spatial location of occupants in the tool, we need to describe it in a mathematical way. The description presented here can be implemented regardless of what area or location of interested is chosen.

In a simulation, the number of occupants in an area will vary over time, resulting in a series of values. In order to be able to analyse this with the method proposed by Ronchi et. al. (2014), we need to divide the measurement of occupants in the area in a set of data points which then can be composed into a vector (Peacock, Reneke, Davis, & Jones, 1999). Since we measure occupants in the area as a function of time, it would be reasonable to make the division of data points based on some time interval, δt. Another possibility would be to make the division based on some difference in number of occupants, δl.

Consider a simulation consisting of *q* number of time steps. The vector that describes the number of occupants in the area would then be denoted as:

$$\vec{l} = (l_1, l_2, \dots, l_{q-1}, l_q)$$

Where l_1 corresponds to the number of occupants in the area at the first time step, l_2 to the number of occupants in the area at the second time step and so on. If we were to simulate *n* runs of the same scenario, *n* vectors $\vec{l}_{ij}$ would be obtained, where *n* is the total number of runs, *q* is the number of time steps or data points, *i* denotes a specific time step and *j* denotes a specific run.

$$\vec{l}_{ij} = (l_{1j},\ l_{2j}, \dots, l_{(q-1)j}, l_{qj})$$

So for example, a simulation with 2 runs (=*n*) and 3 time steps (=*q*) would result in the following vectors:

$$\vec{l}_{i1} = (l_{11}, l_{21}, l_{31})$$

$$\vec{l}_{i2} = (l_{12}, l_{22}, l_{32})$$

The next step is to present a output parameter which is associated with the arithmetic mean of the values of the runs. This means that the output parameters represent the arithmetic mean of the previous runs and not only the values for the specific run. If the total number of time steps is still denoted *q*, and a specific run is denoted *j*, then the *j*th average curve, $\vec{L}_j$, is described by the following vector:

$$\vec{L}_j = (L_1, L_2, \dots, L_{q-1}, L_q)$$

Where:

$$L_1 = \frac{1}{j}\sum_{j=1}^{1<j<n} l_{1j},\ L_2 = \frac{1}{j}\sum_{j=1}^{1<j<n} l_{2j},\ \dots,\ L_q = \frac{1}{j}\sum_{j=1}^{1<j<n} l_{qj}$$

For example, if j=1, then $\vec{L}_j$ would correspond to the values of the first run, i.e. $\vec{l}_{i1}$. If j=4, then $\vec{L}_j$ would correspond to the arithmetic mean of the values of four consecutive runs, i.e. the arithmetic mean of $\vec{l}_{i1}$, $\vec{l}_{i2}$, $\vec{l}_{i3}$ and $\vec{l}_{i4}$.

Appendix 2 Tool user guide

This appendix serves as a user's guide to the tool developed by the author.

Introduction

The tool serves as a post-simulation processor of evacuation simulation data. The purpose of the tool is to analyse behavioural uncertainty and determine whether convergence has been met or not within the simulation runs analysed.

The tool can analyse the following six output parameters: Occupant evacuation time, queuing time, flowrate, density, used exit and spatial location.

The foundation and underlying calculations can be found in the work by Erik Smedberg (2019).

Input data format

The tool is designed to be applicable to different evacuation scenarios, but it also demands the data to be presented to it in a certain format. Note: The format is the format that Pathfinder version 2018.3.0730 uses, so if this software is used, no modifications to the input data is required. If other software is used, then the user might need another code to modify the data before introducing it to the tool. There is however an option available that makes the format used in FDS+Evac for evacuation time directly implementable. If other software is used, the data should then be presented in the form described below.

The required input format of the data is presented below for each of the six output parameters possible to analyse.

Total evacuation time:

The total evacuation time should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

"Name of scenario"_"Run number"_occupants.csv, e.g. example_1_occupants.csv

The data should lie in the first sheet of the file. The column names should lie in row 2 and the value of the cell that lies in the column that contains occupant evacuation times should be named "exit time(s)" The occupant numbers should lie in column B and start on row 2. The values need not to be ordered from smallest to largest. Figure below shows example.

	A	B	C	D	E	F	G
1	id	name	exit time(s	active time	jam time t	jam time r	start time(
2	0	1	123,675	12,025	0,15	0,15	0
3	1	2	83,775	30,25	0,175	0,175	0
4	2	3	44,5	12,775	0,15	0,15	0
5	3	4	127,7	10,775	0,3	0,3	0
6	4	5	84,95	25	0,225	0,225	0
7	5	6	27,45	3	0,2	0,2	0
8	6	7	130,95	13,25	0,175	0,175	0
9	7	8	111,5	13,6	0,25	0,25	0
10	8	9	65,075	12,625	0,2	0,2	0
11	9	10	56,375	34,075	0,225	0,225	0
12	10	11	79,3	30,55	0,175	0,175	0

The output parameter values should represent the evacuation time for a specific occupant, expressed in seconds.

Queuing time:

The queuing time should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

“Name of scenario”_”Run number”_occupants.csv, e.g. example_1_occupants.csv

The data should lie in the first sheet of the file. The column names should lie in row 2 and the value of the cell that lies in the column that contains queuing times should be named “jam time total(s)” The occupant numbers should lie in column B and start on row 2. The values need not to be ordered from smallest to largest. Figure below shows example.

	A	B	C	D	E	F	G
1	id	name	exit time(s	active time	jam time t	jam time r	start time(
2	0	1	123,675	12,025	0,15	0,15	0
3	1	2	83,775	30,25	0,175	0,175	0
4	2	3	44,5	12,775	0,15	0,15	0
5	3	4	127,7	10,775	0,3	0,3	0
6	4	5	84,95	25	0,225	0,225	0
7	5	6	27,45	3	0,2	0,2	0
8	6	7	130,95	13,25	0,175	0,175	0
9	7	8	111,5	13,6	0,25	0,25	0
10	8	9	65,075	12,625	0,2	0,2	0
11	9	10	56,375	34,075	0,225	0,225	0
12	10	11	79,3	30,55	0,175	0,175	0

The output parameter values should represent the queuing time for a specific occupant, expressed in seconds.

Density:

The density measurements should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

“Name of scenario”_”Run number”_measurement-regions.csv, e.g. example_1_measurement-regions.csv

The data should lie in the first sheet of the file. The column names should lie in row 1 and the value of the cell that lies in the column that contains density measurements should be named the same of that of the region that is to be analysed. The time steps should lie in column B and start on row 3. The time steps should start at the value 0 and increase 1 s per row. Figure below shows example.

	A	B	C	D	E	F	G
1	Time	Region00	Region00				
2	Time	Density	Velocity				
3	s	pers/m2	m/s				
4	0	0,02	0				
5	1	0,02	0				
6	2	0,02	0				
7	3	0,02	0				
8	4	0,02	0				
9	5	0,02	0				
10	6	0,02	0				
11	7	0,02	0				
12	8	0,02	0				

The output parameter values should represent the density in the region at a specific time step, expressed in occupants/m^2.

Flowrate:

The flowrate measurements should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

"Name of scenario"_"Run number"_doors.csv, e.g. example_1_doors.csv

The data should lie in the first sheet of the file. The column names should lie in row 1 and the value of the cell that lies in the column that contains flowrate measurements should be named the same of that of the door that is to be analysed. The time steps should lie in column A and start on row 2. The time steps should start at the value 0 and increase 1 s per row. Figure below shows example.

	A	B	C	D	E	F	G
1	time(s)	Remaining	Exited (Tot	Door00	Door00 wi	Door00 to	Door01
2	0	50	0	0	1	0	0
3	1	50	0	0	1	0	0
4	2	50	0	0	1	0	0
5	3	50	0	0	1	0	0
6	4	50	0	0	1	0	0
7	5	50	0	0	1	0	0
8	6	50	0	0	1	0	0
9	7	50	0	0	1	0	0
10	8	50	0	0	1	0	0
11	9	50	0	0	1	0	0
12	10	50	0	0	1	0	0

The output parameter value should represent the flowrate at a specific door and time step, expressed in occupants/s.

Spatial location:

The spatial location measurements should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

“Name of scenario”_”Run number”_rooms.csv, e.g. example_1_rooms.csv

The data should lie in the first sheet of the file. The column names should lie in row 1 and the value of the cell that lies in the column that contains spatial location measurements should be named the same of that of the location that is to be analysed. The time steps should lie in column A and start on row 2. The time steps should start at the value 0 and increase 1 s per row. Figure below shows example.

	A	B	C	D	E	F	G
1	time(s)	Remaining	Exited (Tot	Room00	Room01	Room02	Room03
2	0	50	0	7	7	11	3
3	1	50	0	7	7	11	3
4	2	50	0	7	7	11	3
5	3	50	0	7	7	11	3
6	4	50	0	7	7	11	3
7	5	50	0	7	7	11	3
8	6	50	0	7	7	11	3
9	7	50	0	7	7	11	3
10	8	50	0	7	7	11	3
11	9	50	0	7	7	11	3
12	10	50	0	7	7	11	3

The output parameter value should represent the number of occupants at a specific location at a specific time step, expressed in number of occupants.

Used exit:

The used exit measurements should be presented to the tool in the form of a comma separated Excel file (.csv). The name format should be:

“Name of scenario”_”Run number”_doors.csv, e.g. example_1_doors.csv

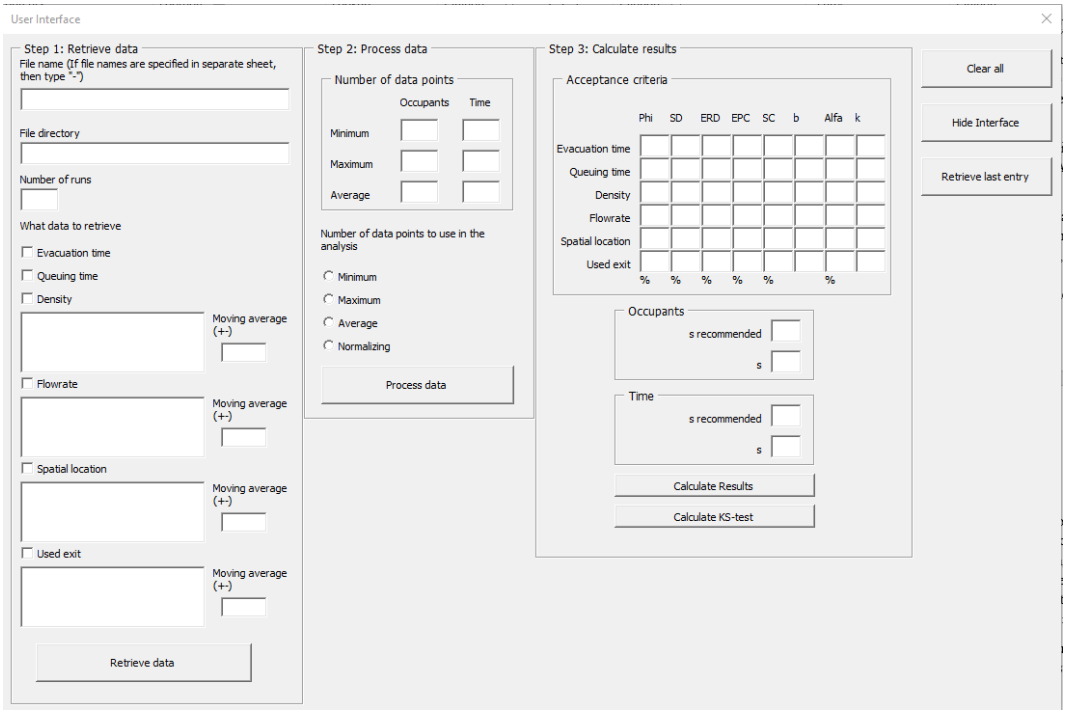
The data should lie in the first sheet of the file. The column names should lie in row 1 and the value of the cell that lies in the column that contains flowrate measurements should be named the same of that of the door that is to be analysed. The time steps should lie in column A and start on row 2. The time steps should start at the value 0 and increase 1 s per row. Figure below shows example.

	A	B	C	D	E	F	G
1	time(s)	Remaining	Exited (Tot	Door00	Door00 wi	Door00 to	Door01
2	0	50	0	0	1	0	0
3	1	50	0	0	1	0	0
4	2	50	0	0	1	0	0
5	3	50	0	0	1	0	0
6	4	50	0	0	1	0	0
7	5	50	0	0	1	0	0
8	6	50	0	0	1	0	0
9	7	50	0	0	1	0	0
10	8	50	0	0	1	0	0
11	9	50	0	0	1	0	0
12	10	50	0	0	1	0	0

The output parameter value should represent the number of occupants which have used a specific exit at a specific time, expressed in number of occupants

User interface

The user interface asks the tool user to provide all the input data required to do the analysis. The user interface is divided into three categories based on the three steps of the analysis: the retrieval of data, the processing of data and the calculation of results. A figure displaying the user interface is presented below:



In the box named “Step 1”, the user is requested with the details of the scenario to analyse. The first textbox asks for the name of the file. Note that the file names might also be defined in a separate sheet named “Run names”, then this box should be filled with “-“. This option is mainly for if other software than pathfinder is used. This option does however not include different file endings such as “_occupants” that pathfinder uses- Next, the user is requested for the file path of the folder where all the runs are located. It is important that all the files lie in the same folder. The user also needs to declare the number of runs to analyse.

A separate userform is provided where minor changes in the input data format can be defined. This sheet also includes an option to reset values to Pathfinder or FDS+Evac defaults.

The tool can analyse all six possible output parameters or only some if requested. The user is requested for the name of the different doors, rooms etc. where needed.

The option to utilize moving average is included in the tool and can be specified for output parameters that utilize time steps as data points. The moving average is calculated using linear interpolation. This option could be used when large scatter in the input data is expected.

When all the above information is filled in, the "Retrieve Data" button should be clicked, and the retrieval begins. This might take some time. A progress bar appears to indicate the user on the progression.

In step 2, the user is requested for how many of the data points is wished to include in the analysis. Three options are available: Min (the simulation with the least data points determines how many data points is to be analysed), Max (the simulation with the most data points determines how many data points is to be analysed), Avg (the average number of data points between all runs is used to determine the number of data points to include in the analysis) and Normalizing (the number of data points is normalized for all runs based on the maximum number of data points with the use of linear interpolation). Note that the Max and Avg option should not be used when moving average is utilized. The text boxes above indicate the number of data points in the data, left is for data points as time steps and right is for data points as number of occupants. When this is declared, the "Aggregate data" button can be clicked, and the tool processes the data it retrieved in the previous step.

This step also produces graphs over all aggregated runs for each output parameter. Here the last run is highlighted in red as it represents the best estimate of the average curve for the output parameter.

Step 3 handles the calculation of the result of the analysis. The user is requested to define various convergence criteria. The criteria are described below:

- Φ: The maximum tolerable change of Φ between two aggregated runs.
- SD: The maximum tolerable change of SD of Φ between two aggregated runs.
- ERD: The maximum tolerable change of ERD between two aggregated runs.
- EPC: The maximum tolerable change of EPC between two aggregated runs.
- SC: The maximum tolerable change of SC between two aggregated runs.
- b: The number of consecutives runs the above criteria have to be fulfilled in order to regard the results as converged.
- α: The level of confidence on which you can reject the null hypothesis in the KS-test.
- k: The number of consecutives runs the KS-test must pass in order to regard the results as converged.

The button "Calculate Results" calculates the results from the first five convergence criteria when clicked. The button "KS-test" calculates the KS-test when clicked.

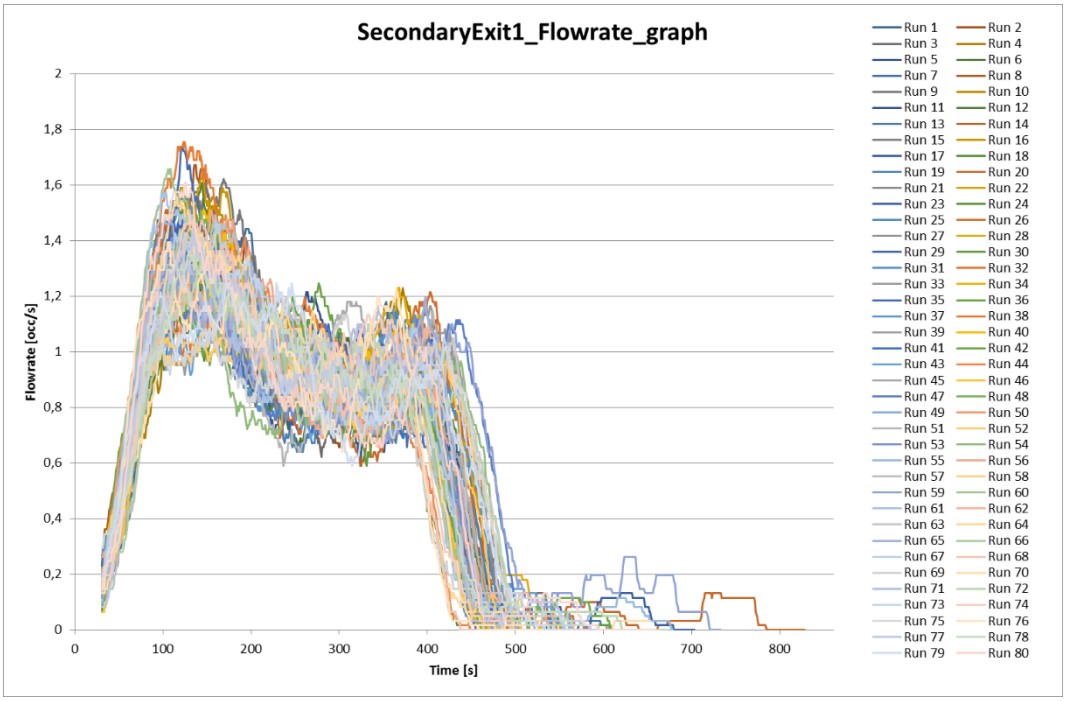
A button named “Clear” is provided which, when clicked deletes all sheets except the page containing the user interface (“HomePage”), input data format and run names.

Description of results

Results is presented in three categories: The retrieved data, the calculations to determine convergence and whether convergence has been met or not.

The retrieved data:

When the data is successfully retrieved, the tool presents to the user one graph for each output parameter (TET etc.) containing the data from all runs analysed. Graphs are presented on individual sheets named after the output parameter name and with the “_graph” ending. By checking these graphs before proceeding, the user can make sure that data was retrieved successfully.

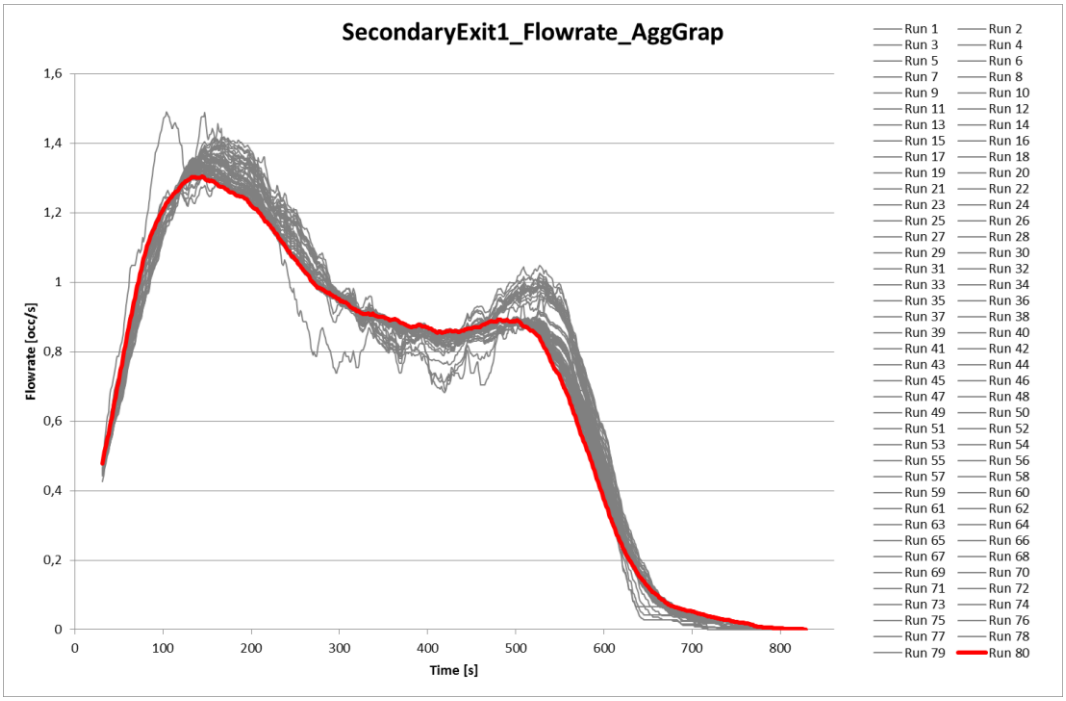


The tool also provides the user with simple descriptive statistics of the output parameters studied in the sheet named “Descriptive_Statistics”. The user is provided with the maximum, minimum, average, standard deviation, 95% CI upper bound and 95% CI lower bound for all individual run’s maximum values, e.g. minimum “max queuing time” represents the lowest value for the maximum queuing time. Figure below shows an example of such a sheet.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

The calculations:

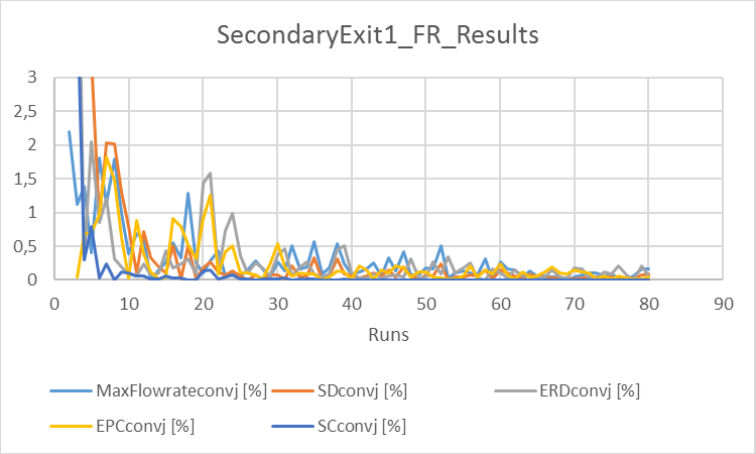
Firstly, the tool aggregates the data and displays a graph over the aggregated runs. The last runs is highlighted in red and represents the best estimate of the average curve. Figure below shows example of such a graph.



The calculations to determine if convergence has been met or not are shown to the user for transparency reasons. The calculation for the five convergence criteria Phi, SD of Phi, ERD, EPC and SC are presented in individual sheets for each output parameter. Figure below shows an example of such a sheet.

Run#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
MaxFlowratej	2,079722	1,901639	1,885246	1,759862	1,918033	1,811925	1,933753	1,735871	1,736358	2,031065	1,810465	2,110263	1,868852	1,957033	1,713826	1,934426	1,754098	1,687327	1,992215	1,916274	1,803279
MaxFlowrateavj	2,079722	1,99068	1,955536	1,906617	1,9089	1,892738	1,898597	1,878256	1,86249	1,879347	1,873085	1,89285	1,891004	1,89572	1,883594	1,886771	1,878967	1,86832	1,874841	1,876913	1,873406
MaxFlowrateconvj [%]		4,472898	1,797198	2,565713	0,119603	0,853929	0,30861	1,08296	0,846529	0,89699	0,334317	1,044182	0,097618	0,248788	0,643785	0,168383	0,415349	0,569852	0,347804	0,110375	0,187166
SDj	0,433513	1,022148	1,15106	1,19736	1,237151	1,255962	1,276065	1,281321	1,285415	1,300065	1,304264	1,31727	1,321167	1,326873	1,325698	1,329863	1,329543	1,327863	1,332394	1,335037	1,33541
SDconvj [%]		57,58807	11,19944	3,866801	3,216371	1,497706	1,575406	0,410188	0,318499	1,126871	0,321958	0,987369	0,294919	0,430064	0,088661	0,313163	0,024016	0,126516	0,340028	0,197972	0,027982
ERDj		0,152776	0,037842	0,025275	0,039223	0,022631	0,02847	0,018171	0,01797	0,015473	0,016211	0,014646	0,009622	0,012509	0,008604	0,00577	0,010273	0,011958	0,00919	0,005138	0,00465
ERDconvj [%]			11,49334	1,256701	1,394742	1,659181	0,583932	1,029933	0,02009	0,249693	0,073826	0,156566	0,502335	0,288612	0,390501	0,283316	0,450304	0,168454	0,276837	0,405158	0,048755
EPCj		0,968056	0,990008	1,008263	1,017763	1,012209	1,003672	1,001888	1,010964	0,998626	1,005764	1,001594	0,998987	0,995026	1,004887	0,995877	1,001472	0,999709	0,994564	0,998838	1,000233
EPCconvj [%]			2,195146	1,825542	0,950021	0,555449	0,853645	0,178404	0,907572	1,233841	0,713846	0,417003	0,260738	0,396036	0,986071	0,900947	0,559482	0,176366	0,514503	0,427397	0,139511
SCj		0,957176	0,990143	0,993446	0,994107	0,996979	0,997351	0,998437	0,998873	0,99833	0,998768	0,999156	0,99923	0,999334	0,999592	0,999712	0,999565	0,999671	0,999619	0,999611	0,999756
SCconvj [%]			3,296729	0,330246	0,066135	0,287245	0,037206	0,108552	0,04365	0,054347	0,043837	0,038759	0,00741	0,010397	0,025763	0,012002	0,014633	0,010525	0,005165	0,000832	0,014549

The tool also displays a graph showing the values for the five convergence measures for different runs. An example of such a graphs is displayed in the figure below.



The results from the KS-test calculations are also shown but in a separate sheet named "Kolmogorv_Smirnov_test". This sheet presents whether the KS-test was a pass or fail for each run. Figure below shows an example of such a sheet.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

Convergence:

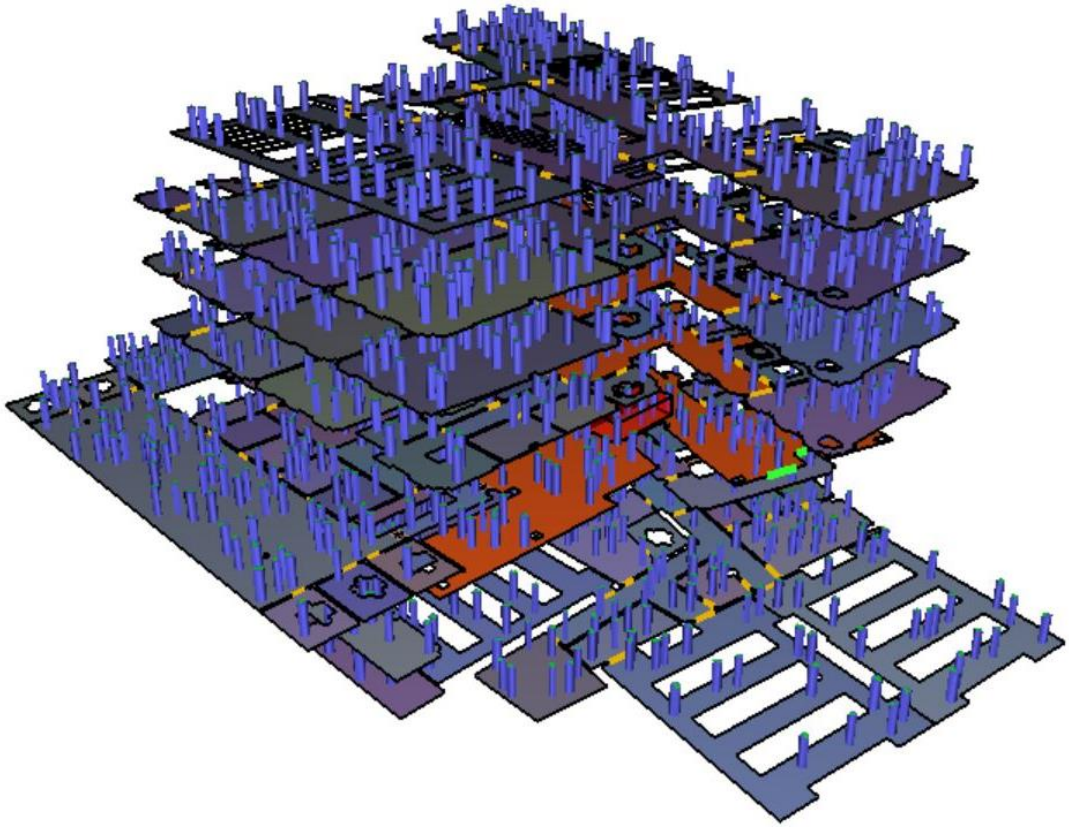
To show whether convergence has been met or not the tool provides the user with a sheet named "Results_Compiled". The sheet presents whether convergence has been met or not for each convergence criteria and output parameter. An example of such a sheet is shown in Figure below.

	Has convergence been met? At what run?																			
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET		Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44	YES	30	YES	38	YES	42	YES	35	YES	28
SD	YES	30	YES	30	YES	17	YES	19	YES	19	YES	30	YES	18	YES	21	YES	21	YES	18
ERD	YES	19	YES	42	YES	34	YES	17	YES	43	YES	33	YES	35	YES	31	YES	28	YES	23
EPC	YES	46	YES	47	YES	19	YES	18	YES	13	YES	34	YES	29	YES	31	YES	21	YES	20
SC	YES	28	YES	19	YES	15	YES	15	YES	12	YES	12	YES	15	YES	15	YES	14	YES	13
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6	YES	6	YES	8	YES	9	YES	9	YES	14
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**	**YES**	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

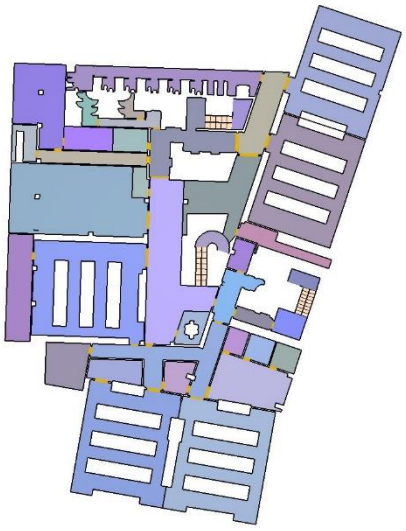
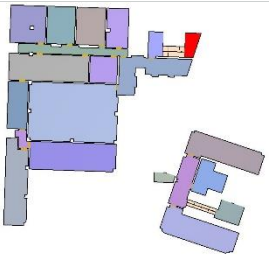
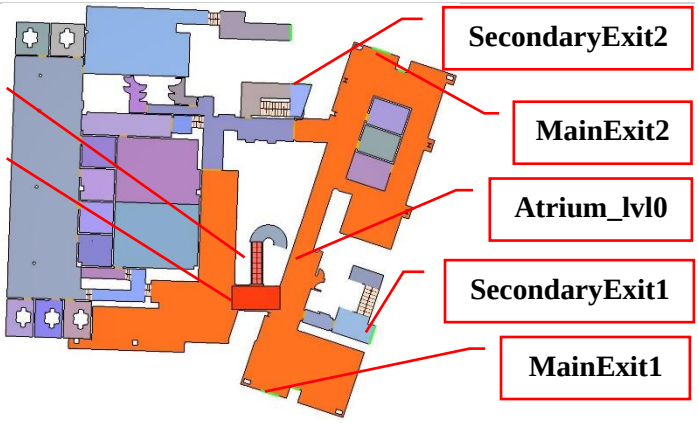
Appendix 3 Case study model

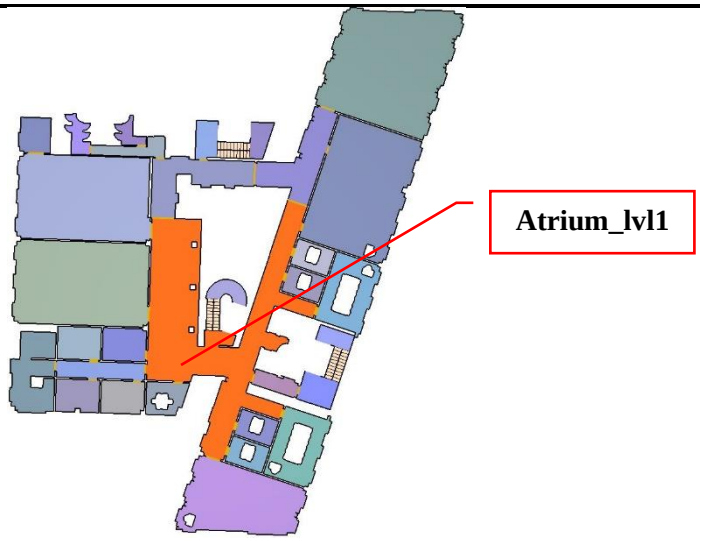
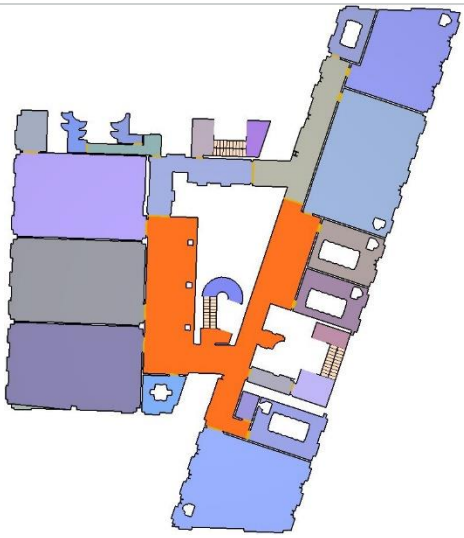
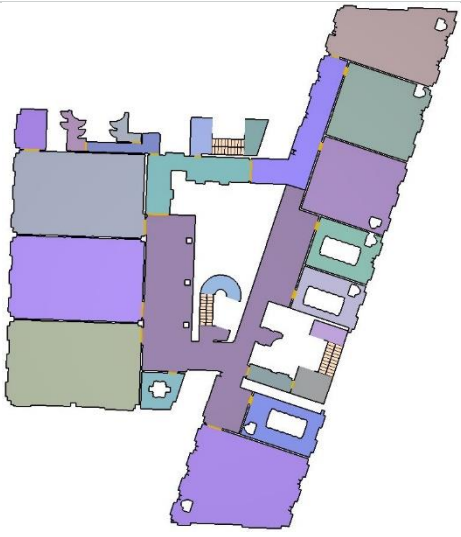
This appendix contains a description of the model of the building used in the case study. By request of the drawing provider, details that will reveal where the building are located are left out.

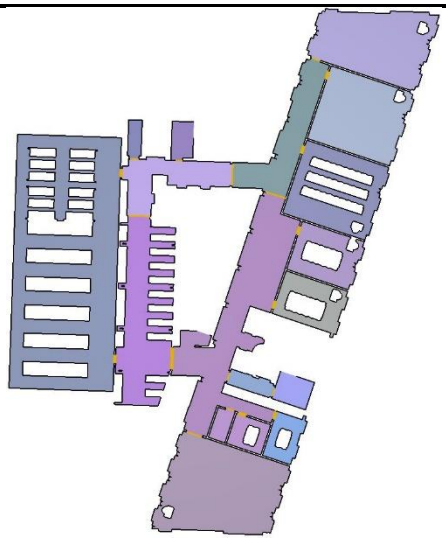
The building consists of a total of seven stories, two below ground level and five above. The building is a university building which means that the occupants will mainly consist of students and university personnel taking part in educational tasks. The different levels are reached with three internal stairs. The building is also equipped with elevators, but these will not be used in the analysis. The figure below displays an overview of the model.



The figures in the table below display the layout of the different floors. When areas of interest are present, these are highlighted and named.

Floor	
-2	
-1	
0	

1	
2	
3	

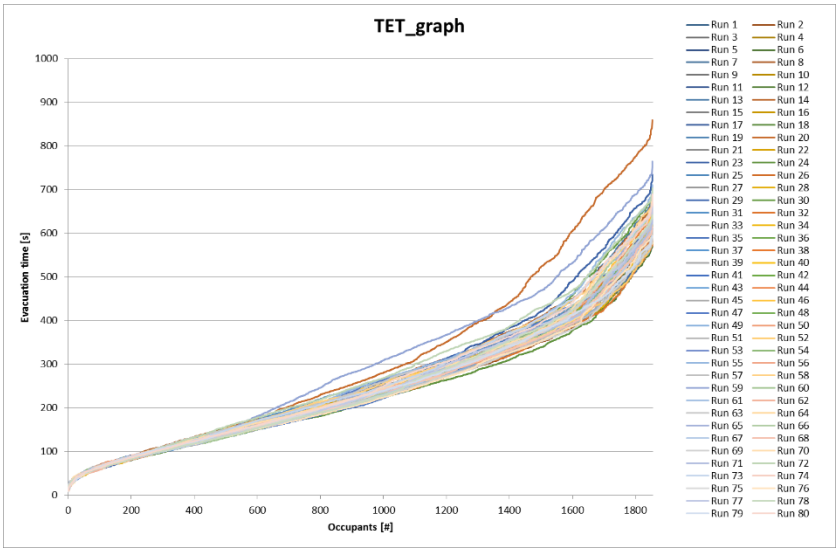
4	

Appendix 4 Detailed results from case study

This appendix contains the detailed results from the case study. This includes: graphs over the retrieved data, graphs over the aggregated data, results from the convergence calculations and the compiled results. The results are categorized after each output parameter and data points method. A total of 80 runs were simulated with 1855 occupants.

Evacuation time

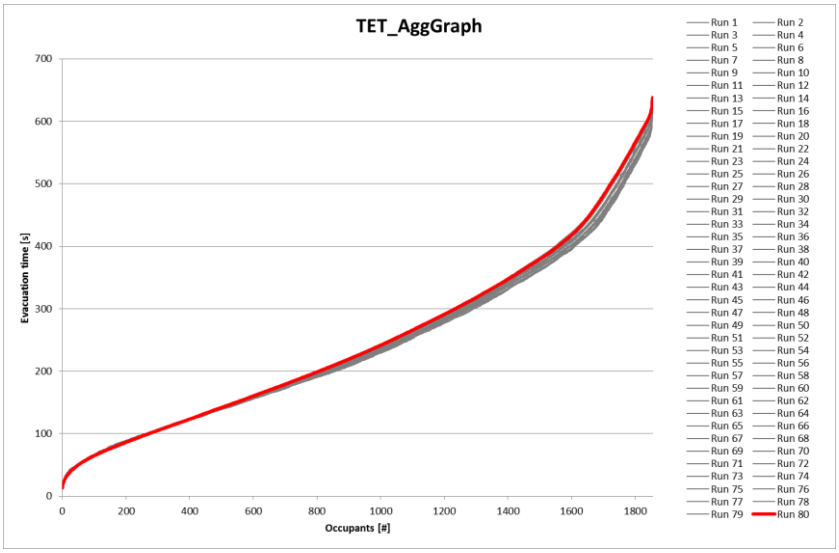
The figure below displays the graph over the retrieved runs.



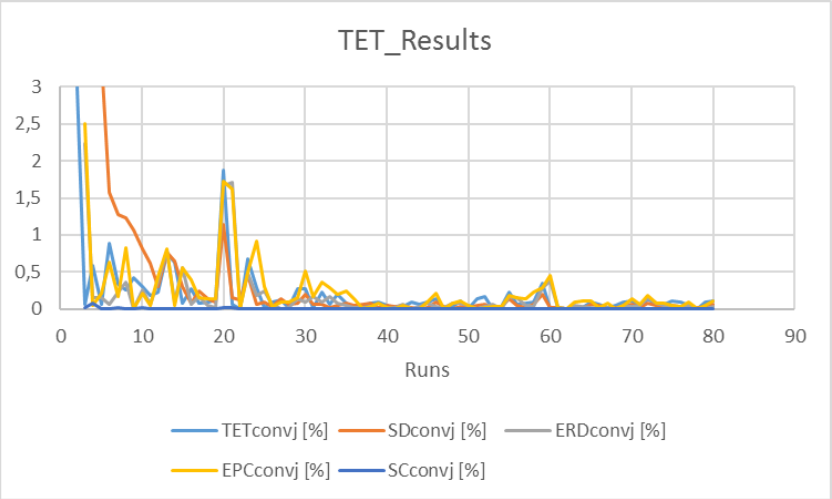
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

The figure below displays the graph over the aggregated runs.



The figure below shows the results from the calculations on convergence of the five first convergence criteria.



The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

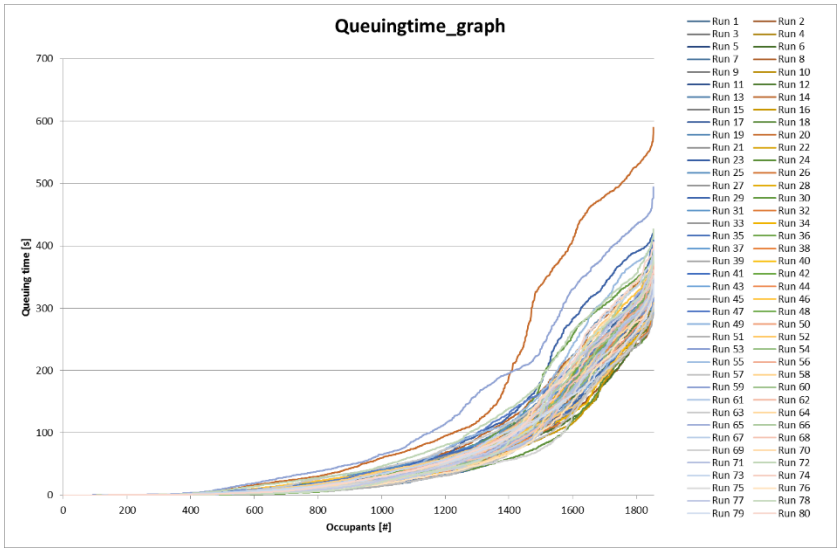
The figure below shows the compiled results.

	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

Queuing time

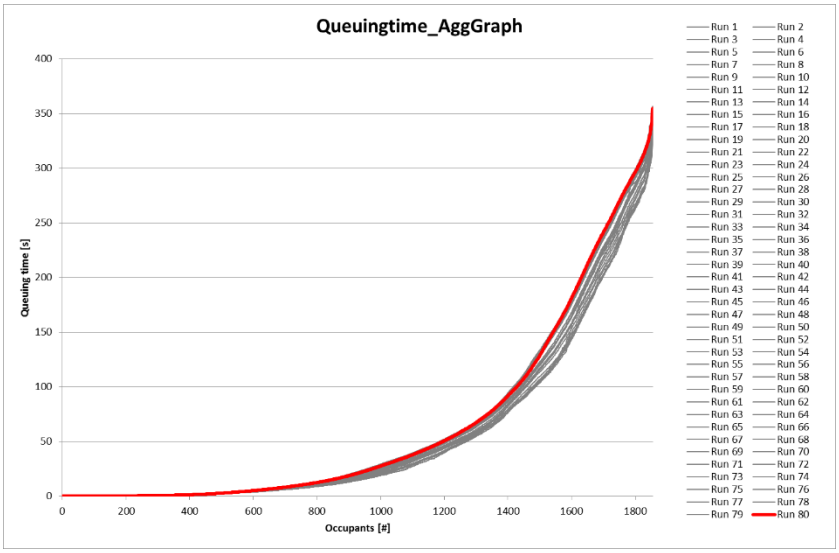
The figure below displays the graph over the retrieved runs.



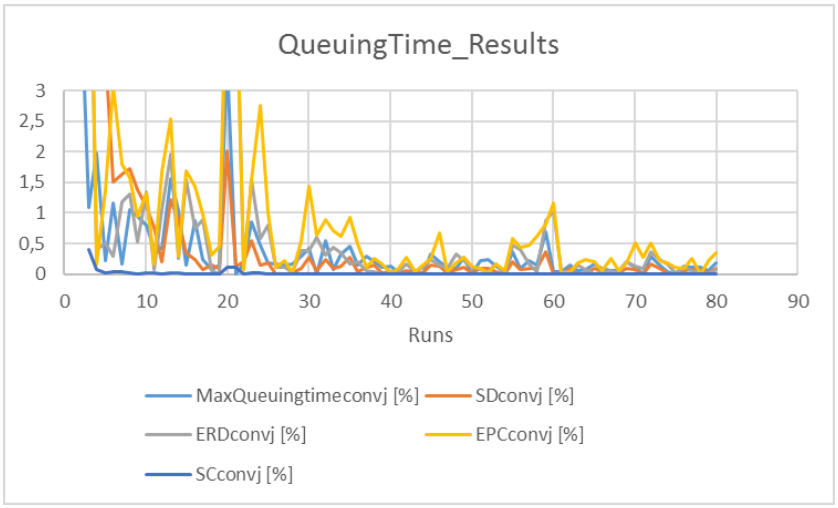
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

The figure below displays the graph over the aggregated runs.



The figure below shows the results from the calculations on convergence of the five first convergence criteria.



The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

The figure below shows the compiled results.

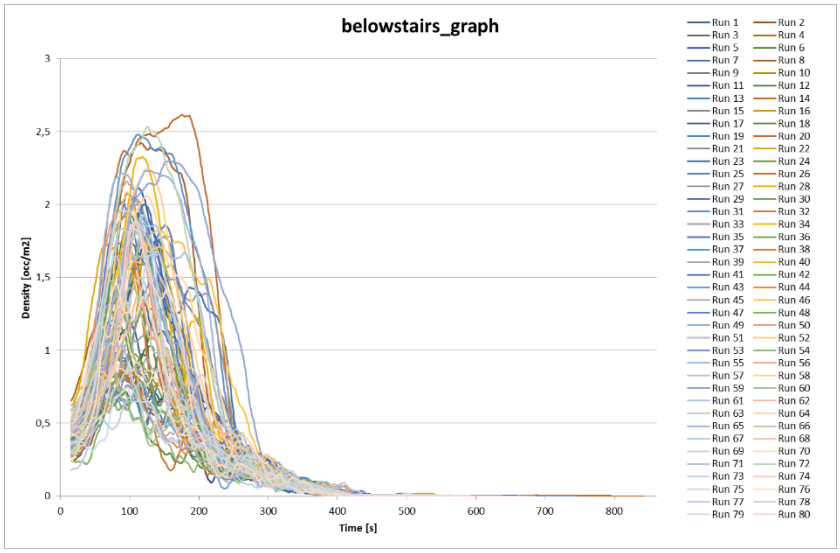
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

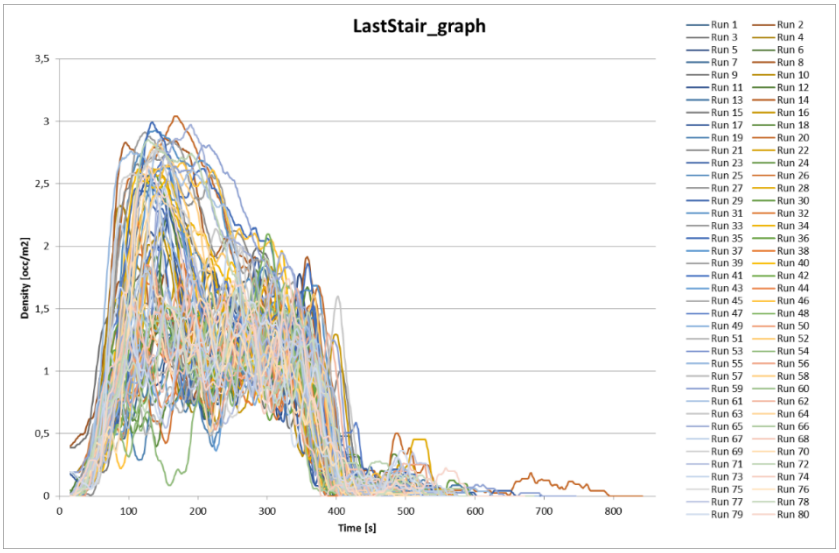
Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

Density

When density has been calculated, a moving average of ±15s has been utilized.

The two figures below display the graphs over the retrieved runs.



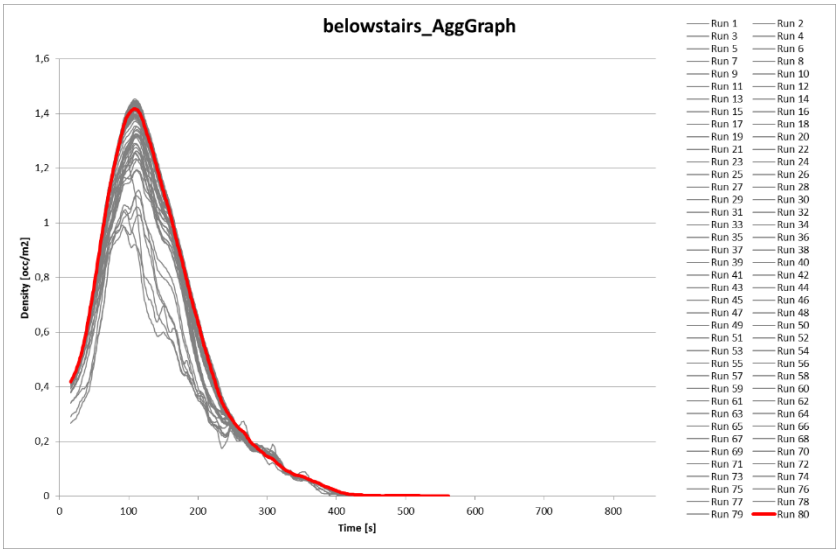


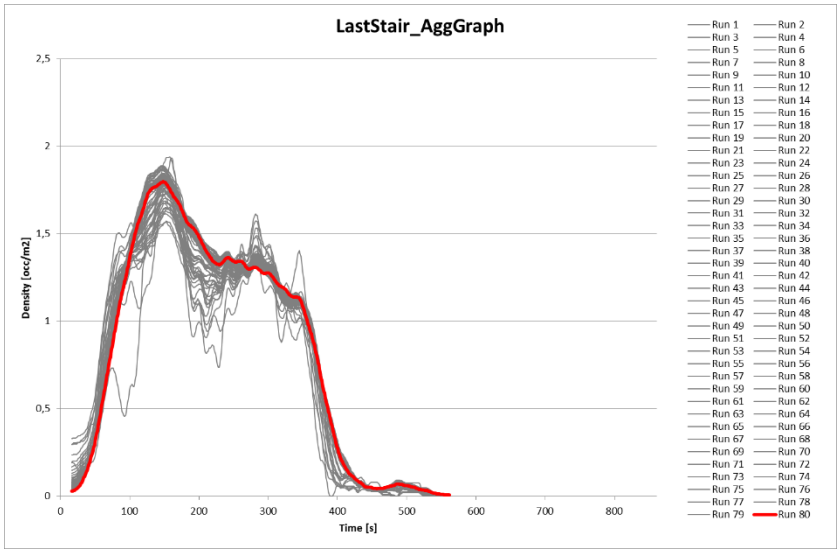
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

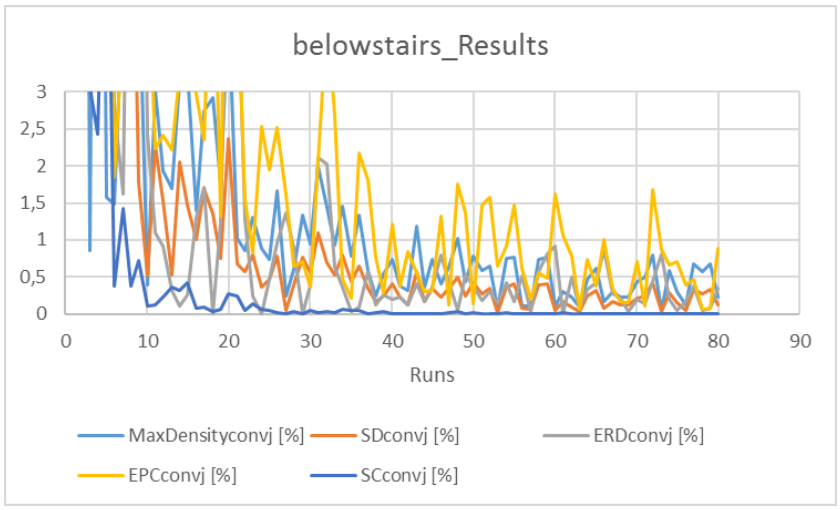
Density - Minimum number of data points

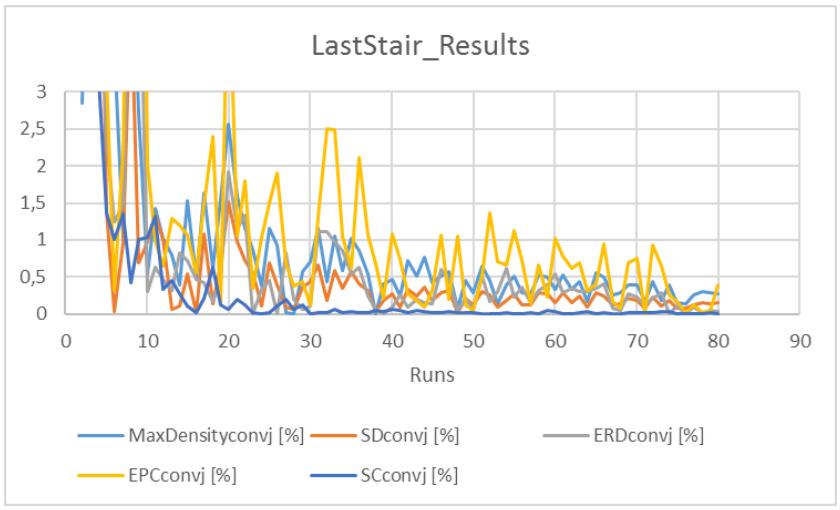
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,12931	0,058621	0,106897	0,081034	0,024259	0,025337	0,096552	0,048276	0,037931	0,096552
Run 3	0,236207	0,053448	0,087931	0,074138	0,007008	0,016712	0,048276	0,065517	0,05	0,032759
Run 4	0,077586	0,067241	0,067241	0,07931	0,007547	0,014016	0,063793	0,053448	0,037931	0,036207
Run 5	0,103448	0,098276	0,082759	0,056897	0,006469	0,01186	0,046552	0,053448	0,024138	0,031034
Run 6	0,1	0,046552	0,036207	0,051724	0,004313	0,012938	0,039655	0,044828	0,024138	0,024138
Run 7	0,055172	0,056897	0,058621	0,051724			0,058621			0,017241
Run 8	0,167241	0,094828	0,062069	0,056897						
Run 9	0,068966	0,055172	0,05	0,055172						
Run 10	0,041379	0,041379	0,034483							
Run 11	0,058621	0,041379								
Run 12	0,051724	0,025862								
Run 13	0,051724	0,02931								

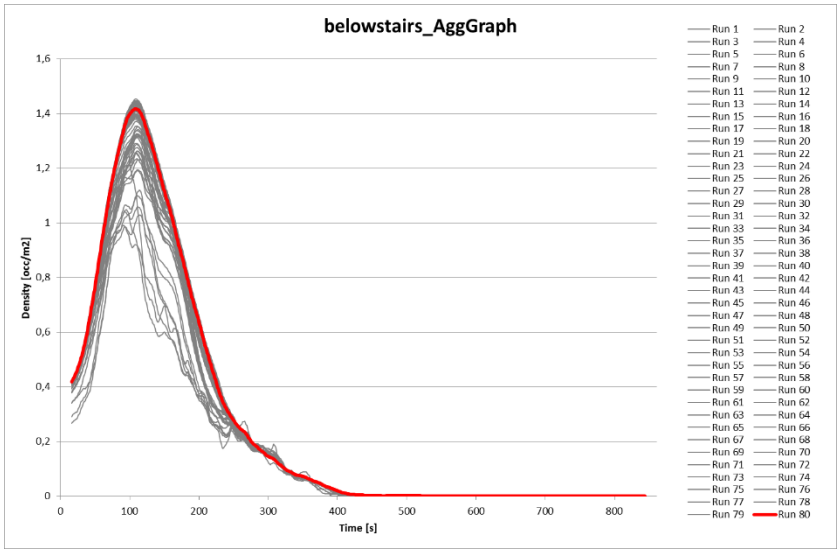
The figure below shows the compiled results.

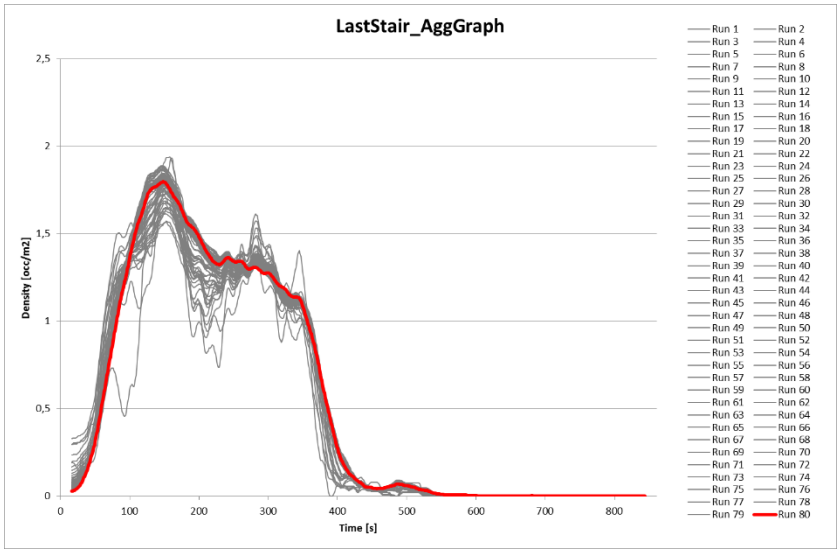
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	13	YES	13	YES	10	YES	9	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	44	YES	34
YES	30	YES	18	YES	21	YES	18	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	6	YES	7
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**44**	**YES**	**35**

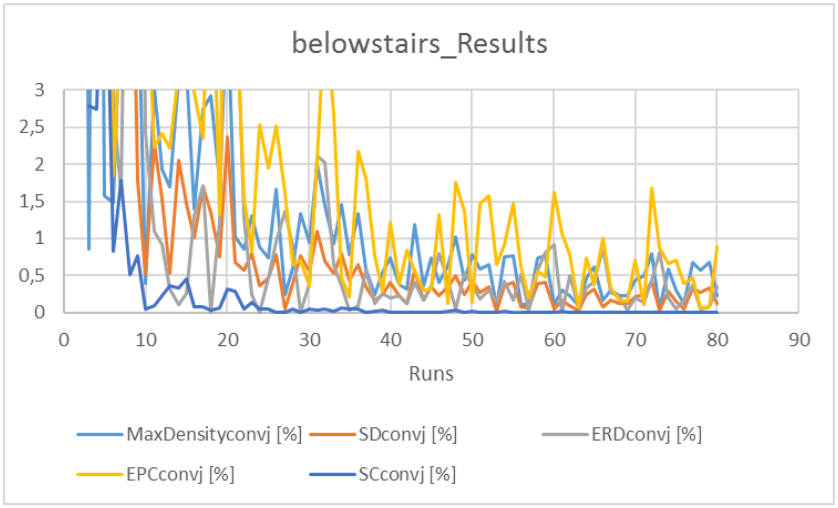
Density - Maximum number of data points

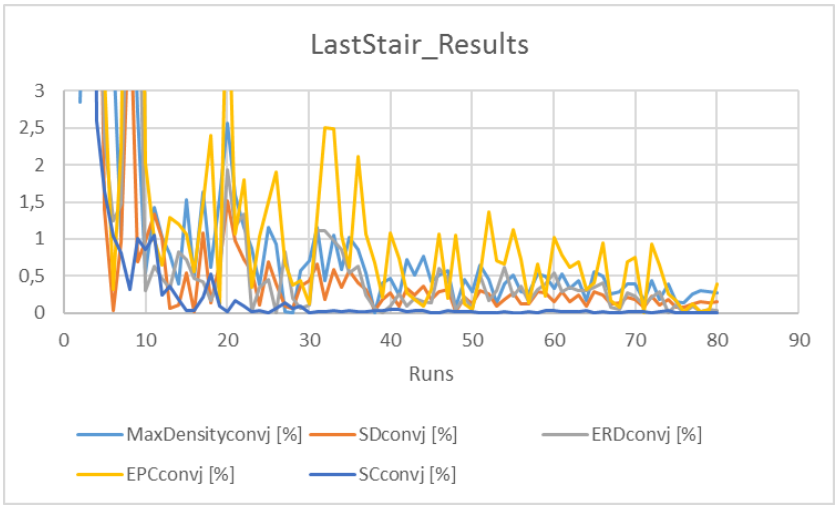
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStai	belowst	MainExit	Seconda	TET	Queuing	Atrium_I	Atrium_I	MainExit	SecondaryExit2_UE
Run 2	0,087	0,0394	0,0754	0,0545	0,0243	0,0253	0,065	0,0325	0,297	0,3398
Run 3	0,1589	0,036	0,0603	0,0499	0,007	0,0167	0,0325	0,0441	0,319	0,29
Run 4	0,0522	0,0452	0,0452	0,0534	0,0075	0,014	0,0429	0,036	0,3202	0,3271
Run 5	0,0696	0,0661	0,058	0,0383	0,0065	0,0119	0,0313	0,036	0,3063	0,3271
Run 6	0,0673	0,0313	0,0244	0,0348	0,0043	0,0129	0,0267	0,0302	0,3039	0,3202
Run 7	0,0371	0,0383	0,0394				0,0394		0,2865	0,2993
Run 8	0,1125	0,0638	0,0418						0,3063	0,3144
Run 9	0,0464	0,0371							0,3097	0,3271
Run 10	0,0278	0,0278							0,2668	0,3005
Run 11	0,0394	0,0278							0,2981	0,2935
Run 12	0,0348	0,0174							0,2668	0,2819
Run 13	0,0592	0,0603							0,2703	0,3074
Run 14	0,0348	0,0278							0,2227	0,2436
Run 15	0,0336	0,0209							0,2413	0,2529
Run 16	0,0336	0,029							0,2181	0,2367
Run 17	0,0244	0,022							0,2703	0,232
Run 18	0,0557	0,0464							0,2227	0,2715
Run 19									0,2483	0,2575
Run 20									0,1473	0,2436
Run 21									0,022	0,0638
Run 22									0,0244	0,0522
Run 23									0,0383	0,1172
Run 24									0,0835	0,1148
Run 25									0,1357	0,0638
Run 26									0,0708	0,0522
Run 27									0,0267	0,0974
Run 28									0,0255	0,1125
Run 29									0,0255	0,0673
Run 30									0,109	0,0731
Run 31									0,0267	0,0916
Run 32									0,0383	0,0789
Run 33									0,1009	0,1172
Run 34									0,1172	0,0719
Run 35									0,0499	0,0719
Run 36									0,0719	0,0545
Run 37									0,0673	0,0661
Run 38									0,0626	0,0673
Run 39									0,0719	0,0719
Run 40									0,0777	0,0522
Run 41									0,0893	0,1357
Run 42									0,1032	0,0719
Run 43									0,0719	0,0522
Run 44									0,0626	0,0835
Run 45									0,0777	0,0545
Run 46									0,1148	0,1288
Run 47									0,0708	0,094
Run 48									0,0499	0,0684
Run 49									0,087	0,0534
Run 50									0,0974	0,0626
Run 51									0,0244	0,1114
Run 52									0,0429	0,0684
Run 53									0,0383	0,0998
Run 54									0,0626	0,0684
Run 55									0,0847	0,0522
Run 56									0,0429	0,0754
Run 57									0,0673	0,0557
Run 58									0,0847	0,0731
Run 59									0,0893	0,1555
Run 60									0,022	0,0835
Run 61									0,065	0,0522
Run 62									0,1148	0,0534
Run 63									0,1334	0,1114
Run 64									0,022	0,0522
Run 65									0,0406	0,0882
Run 66									0,0267	0,0684
Run 67									0,0789	0,0789
Run 68									0,0406	0,1357
Run 69									0,0255	0,0835
Run 70									0,0847	0,0522
Run 71									0,0812	0,0638
Run 72									0,0383	0,1125
Run 73									0,0684	0,0673
Run 74									0,0835	0,0522
Run 75									0,0847	0,0835
Run 76									0,0824	0,0789
Run 77									0,1531	0,0974
Run 78									0,0719	0,0661
Run 79									0,0754	0,1172
Run 80									0,0255	0,0754

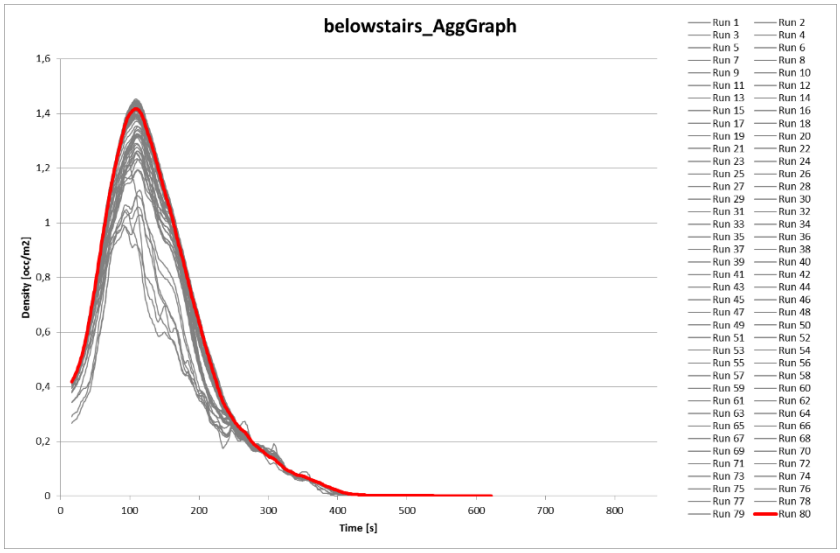
The figure below shows the compiled results.

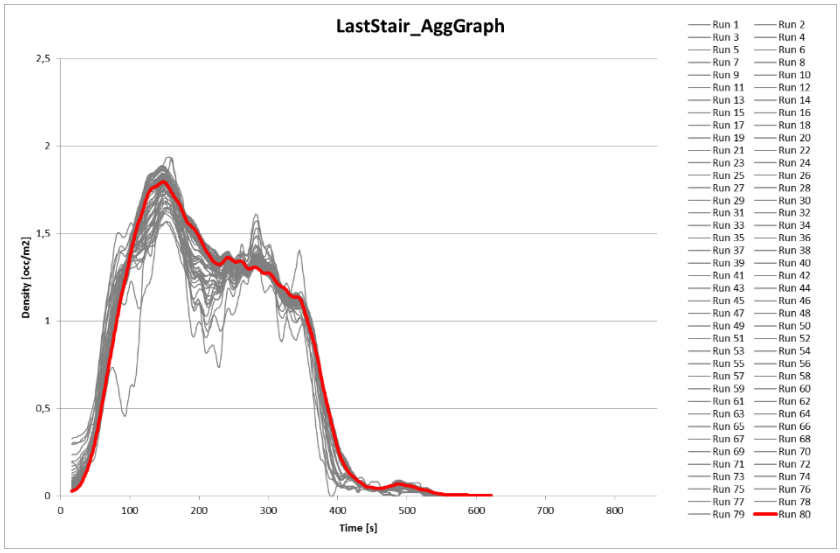
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	18	YES	18	YES	8	YES	6	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	33
YES	34	YES	30	YES	27	YES	31	YES	34
YES	12	YES	14	YES	15	YES	12	YES	13
YES	6	YES	7	YES	6	NO	-	NO	-
YES	**34**	**YES**	**38**	**YES**	**42**	**NO**		**NO**	

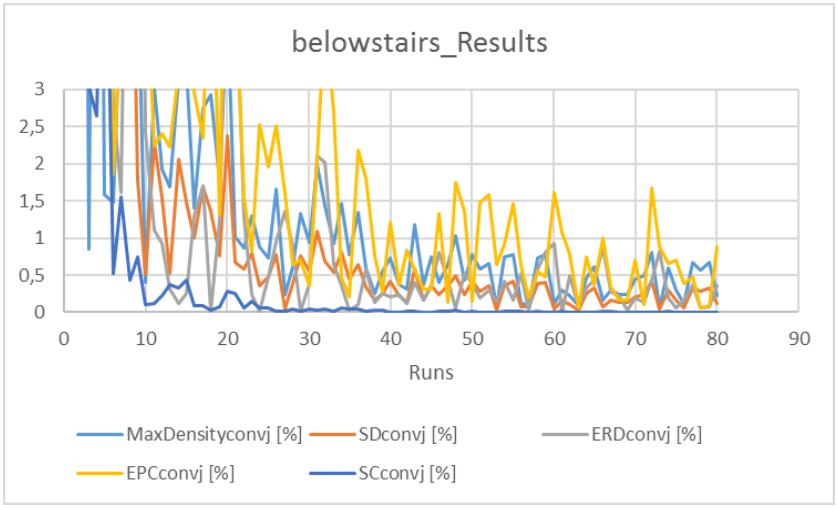
Density - Average number of data points

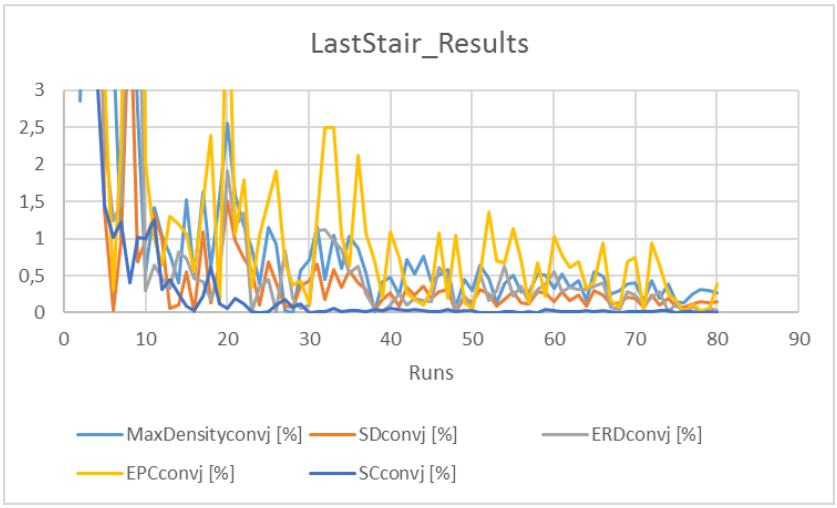
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,117188	0,053125	0,101563	0,073438	0,024259	0,025337	0,0875	0,04375	0,054687	0,1125
Run 3	0,214063	0,048438	0,08125	0,067188	0,007008	0,016712	0,04375	0,059375	0,084375	0,045312
Run 4	0,070313	0,060938	0,060938	0,071875	0,007547	0,014016	0,057813	0,048438	0,085938	0,095313
Run 5	0,09375	0,089063	0,078125	0,051562	0,006469	0,01186	0,042188	0,048438	0,067188	0,095313
Run 6	0,090625	0,042188	0,032813	0,046875	0,004313	0,012938	0,035938	0,040625	0,064062	0,085938
Run 7	0,05	0,051563	0,053125	0,046875			0,053125		0,040625	0,057813
Run 8	0,151563	0,085938	0,05625	0,051563					0,067188	0,078125
Run 9	0,0625	0,05	0,045313	0,08125					0,071875	0,095313
Run 10	0,0375	0,0375	0,03125	0,06875					0,015625	0,059375
Run 11	0,053125	0,0375		0,05625					0,05625	0,05
Run 12	0,046875	0,023438		0,045313					0,014063	0,034375
Run 13	0,079688	0,08125		0,064063					0,035938	0,078125
Run 14	0,046875	0,0375		0,045313					0,023438	0,04375
Run 15	0,045313	0,028125		0,045313						0,023438
Run 16	0,045313	0,039062								0,014063
Run 17	0,032813	0,029688								0,014063
Run 18	0,075	0,0625								0,045313
Run 19	0,064063									
Run 20	0,107813									
Run 21	0,101563									
Run 22	0,026563									
Run 23	0,035938									
Run 24	0,03125									
Run 25	0,026563									
Run 26	0,034375									

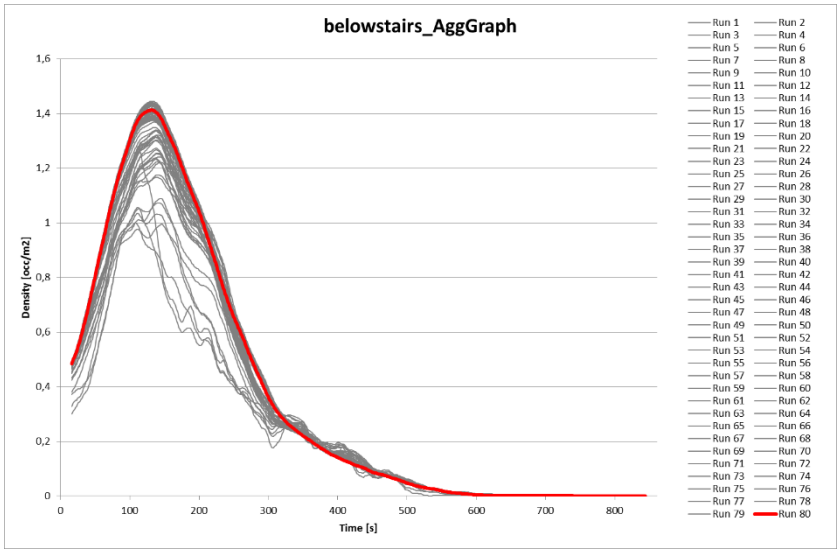
The figure below shows the compiled results.

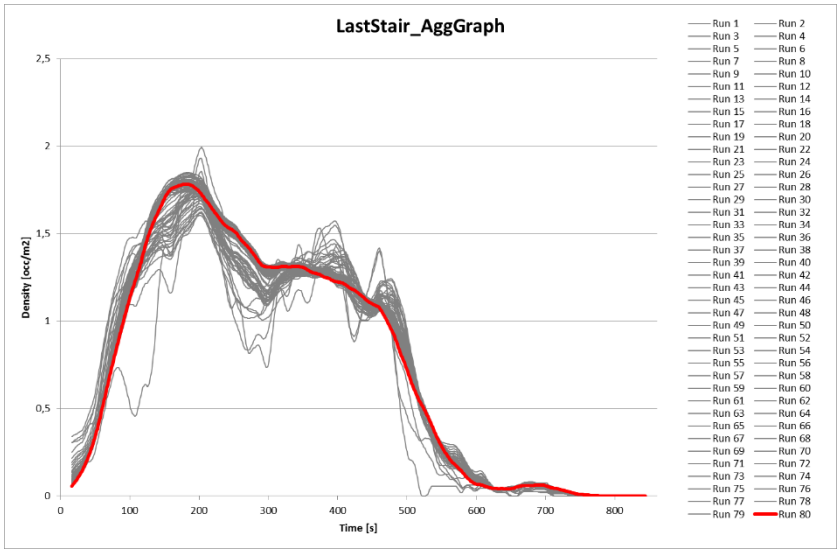
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	26	YES	18	YES	10	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	33
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	14	YES	18
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**35**

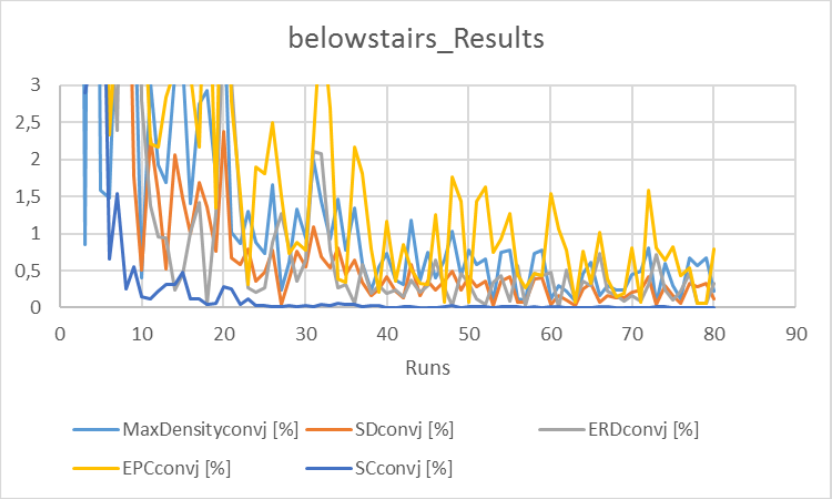
Density - Normalizing data points

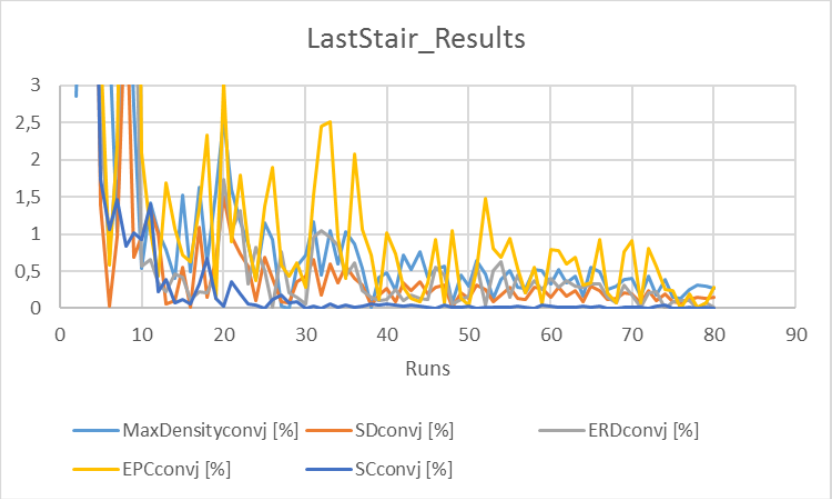
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

The figure below shows the compiled results.

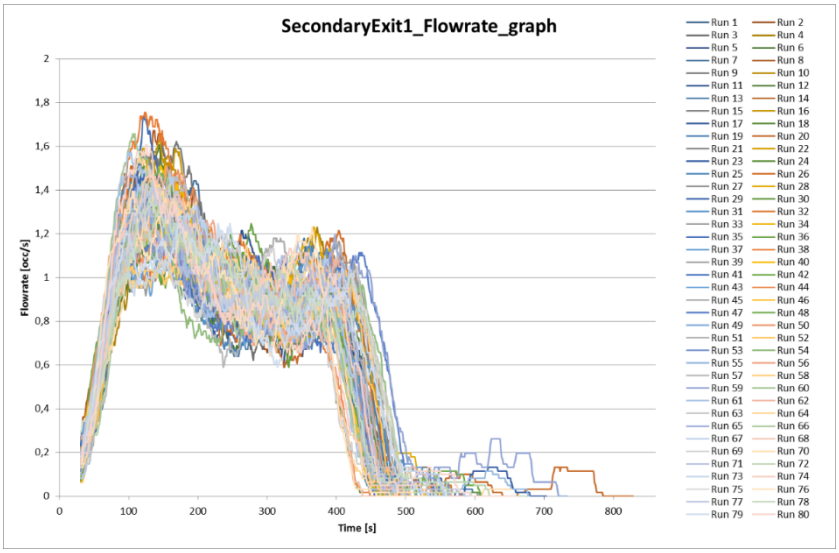
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

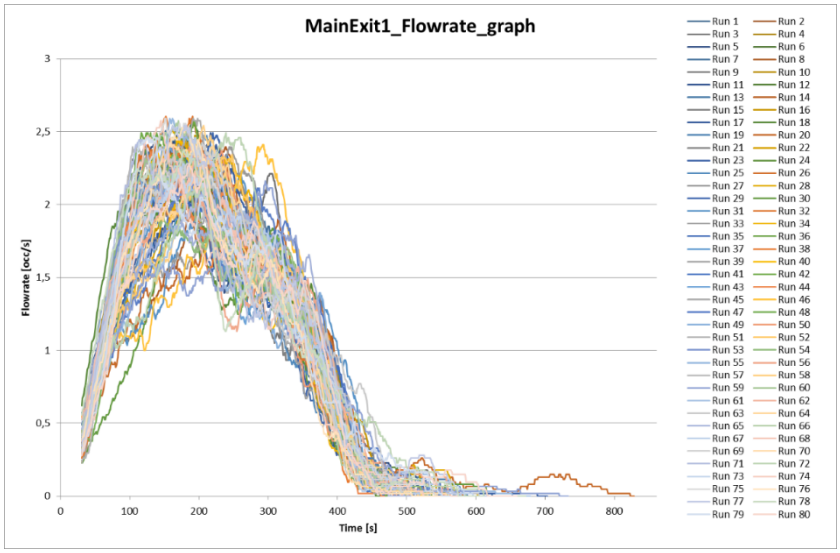
Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

Flowrate

When flowrate has been calculated, a moving average of ±30s has been utilized.

The two figures below display the graphs over the retrieved runs.



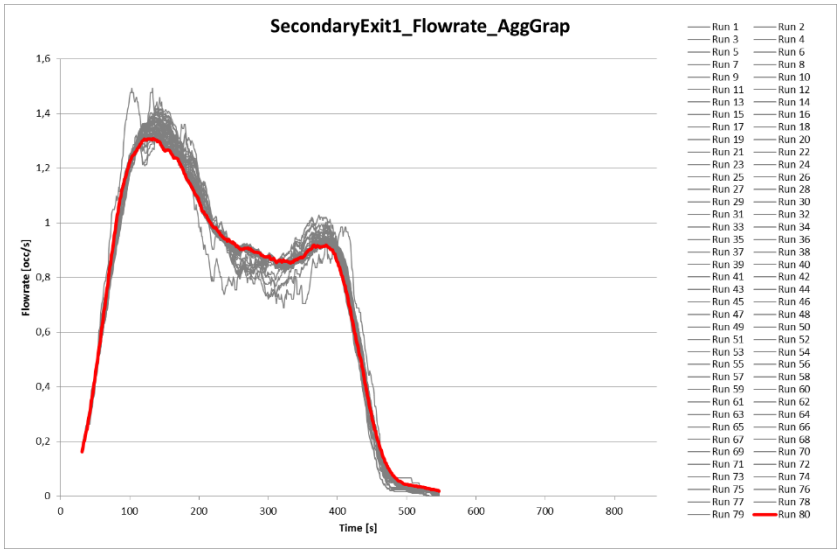


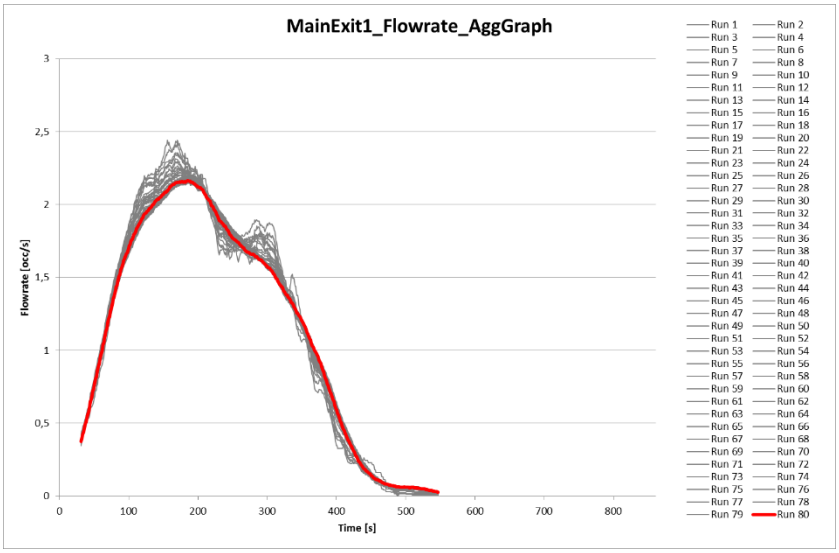
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

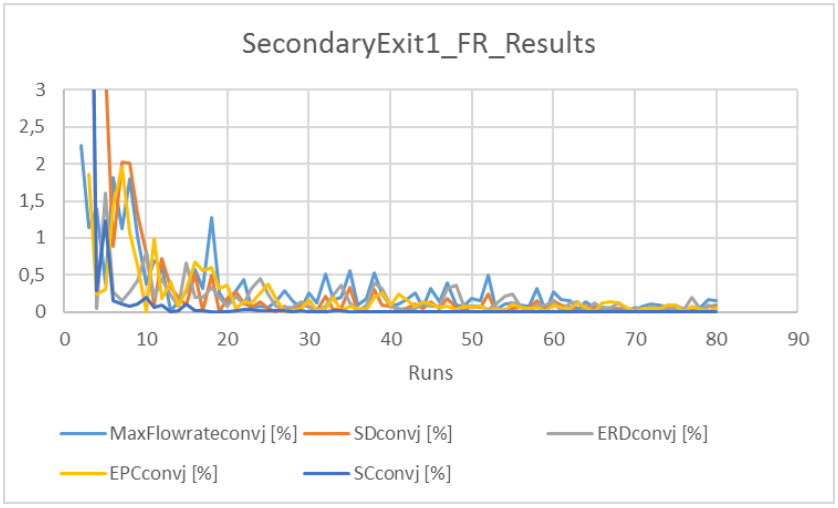
Flowrate - Minimum number of data points

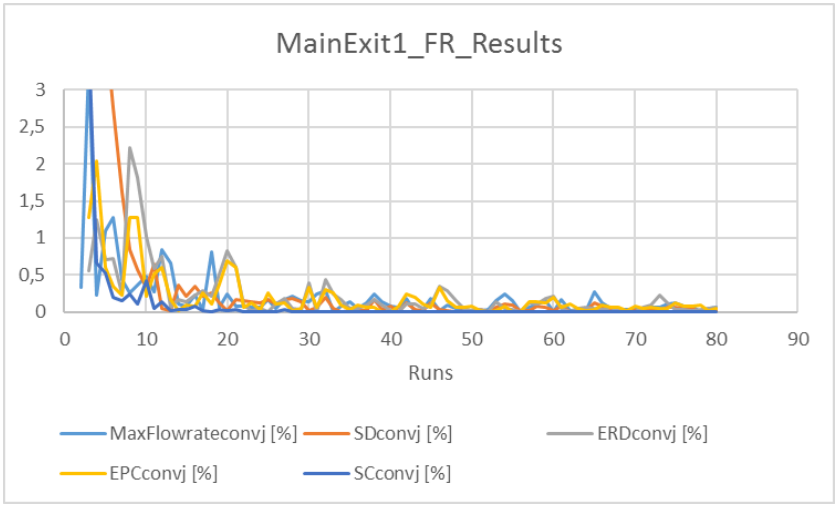
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,12931	0,058621	0,106897	0,081034	0,024259	0,025337	0,096552	0,048276	0,037931	0,096552
Run 3	0,236207	0,053448	0,087931	0,074138	0,007008	0,016712	0,048276	0,065517	0,05	0,032759
Run 4	0,077586	0,067241	0,067241	0,07931	0,007547	0,014016	0,063793	0,053448	0,037931	0,036207
Run 5	0,103448	0,098276	0,082759	0,056897	0,006469	0,01186	0,046552	0,053448	0,024138	0,031034
Run 6	0,1	0,046552	0,036207	0,051724	0,004313	0,012938	0,039655	0,044828	0,024138	0,024138
Run 7	0,055172	0,056897	0,058621	0,051724			0,058621			0,017241
Run 8	0,167241	0,094828	0,062069	0,056897						
Run 9	0,068966	0,055172	0,05	0,055172						
Run 10	0,041379	0,041379	0,034483							
Run 11	0,058621	0,041379								
Run 12	0,051724	0,025862								
Run 13	0,051724	0,02931								

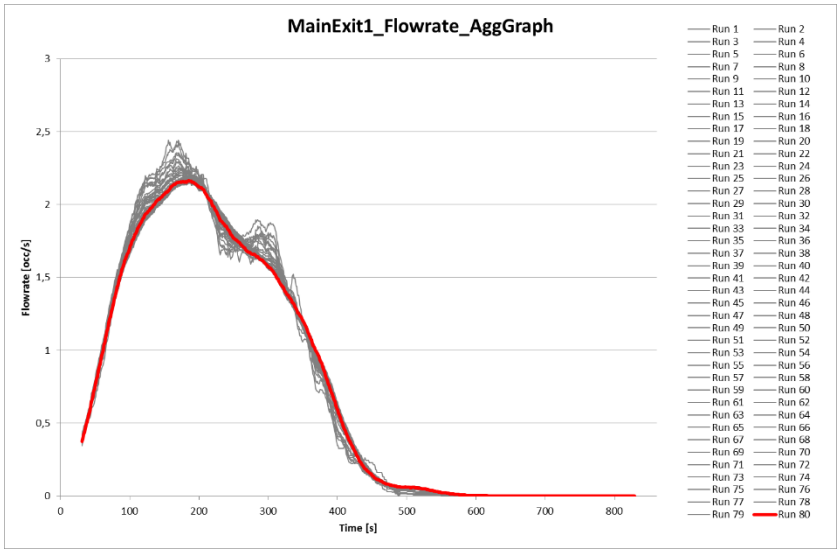
The figure below shows the compiled results.

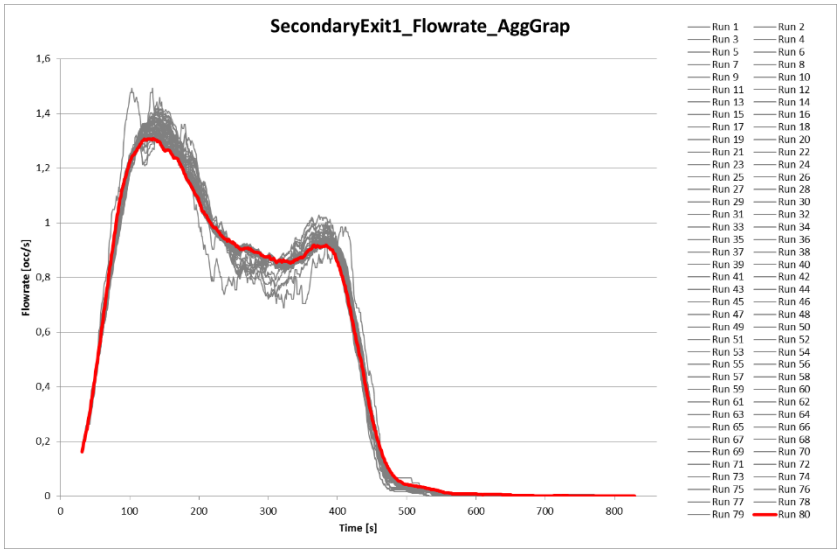
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	13	YES	13	YES	10	YES	9	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	44	YES	34
YES	30	YES	18	YES	21	YES	18	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	6	YES	7
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**44**	**YES**	**35**

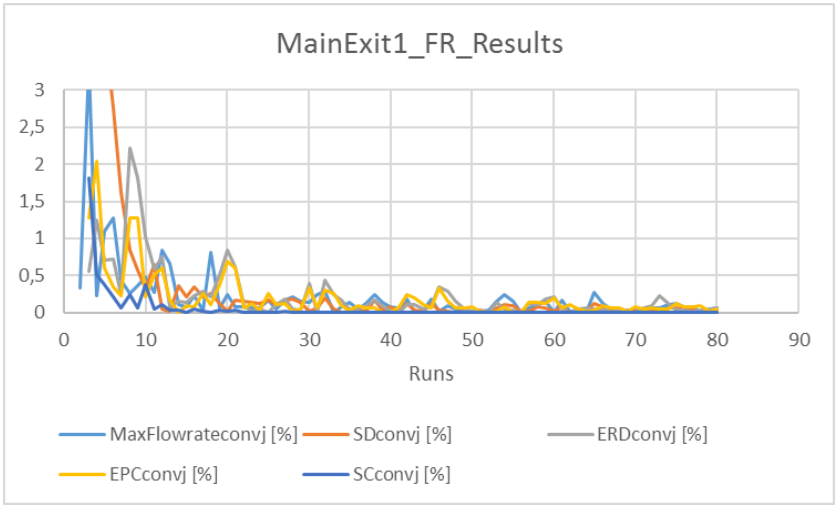
Flowrate - Maximum number of data points

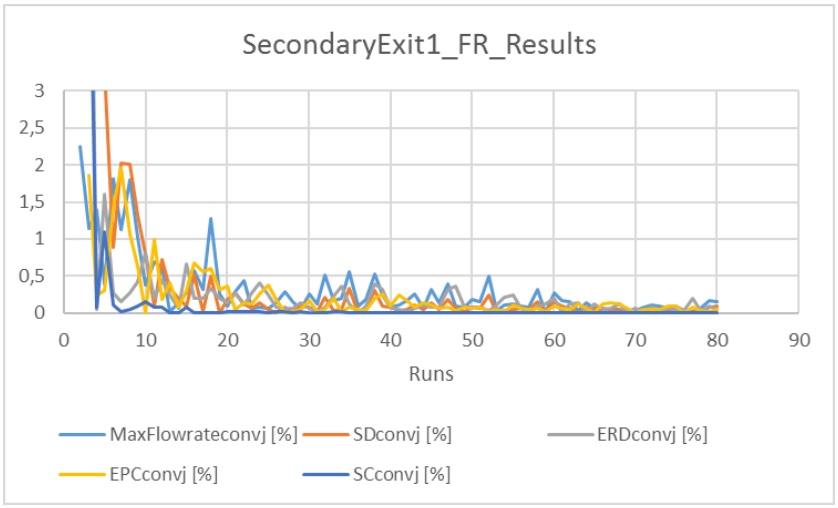
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStai	belowst	MainExit	Seconda	TET	Queuing	Atrium_I	Atrium_I	MainExit	SecondaryExit2_UE
Run 2	0,087	0,0394	0,0754	0,0545	0,0243	0,0253	0,065	0,0325	0,297	0,3398
Run 3	0,1589	0,036	0,0603	0,0499	0,007	0,0167	0,0325	0,0441	0,319	0,29
Run 4	0,0522	0,0452	0,0452	0,0534	0,0075	0,014	0,0429	0,036	0,3202	0,3271
Run 5	0,0696	0,0661	0,058	0,0383	0,0065	0,0119	0,0313	0,036	0,3063	0,3271
Run 6	0,0673	0,0313	0,0244	0,0348	0,0043	0,0129	0,0267	0,0302	0,3039	0,3202
Run 7	0,0371	0,0383	0,0394				0,0394		0,2865	0,2993
Run 8	0,1125	0,0638	0,0418						0,3063	0,3144
Run 9	0,0464	0,0371							0,3097	0,3271
Run 10	0,0278	0,0278							0,2668	0,3005
Run 11	0,0394	0,0278							0,2981	0,2935
Run 12	0,0348	0,0174							0,2668	0,2819
Run 13	0,0592	0,0603							0,2703	0,3074
Run 14	0,0348	0,0278							0,2227	0,2436
Run 15	0,0336	0,0209							0,2413	0,2529
Run 16	0,0336	0,029							0,2181	0,2367
Run 17	0,0244	0,022							0,2703	0,232
Run 18	0,0557	0,0464							0,2227	0,2715
Run 19									0,2483	0,2575
Run 20									0,1473	0,2436
Run 21									0,022	0,0638
Run 22									0,0244	0,0522
Run 23									0,0383	0,1172
Run 24									0,0835	0,1148
Run 25									0,1357	0,0638
Run 26									0,0708	0,0522
Run 27									0,0267	0,0974
Run 28									0,0255	0,1125
Run 29									0,0255	0,0673
Run 30									0,109	0,0731
Run 31									0,0267	0,0916
Run 32									0,0383	0,0789
Run 33									0,1009	0,1172
Run 34									0,1172	0,0719
Run 35									0,0499	0,0719
Run 36									0,0719	0,0545
Run 37									0,0673	0,0661
Run 38									0,0626	0,0673
Run 39									0,0719	0,0719
Run 40									0,0777	0,0522
Run 41									0,0893	0,1357
Run 42									0,1032	0,0719
Run 43									0,0719	0,0522
Run 44									0,0626	0,0835
Run 45									0,0777	0,0545
Run 46									0,1148	0,1288
Run 47									0,0708	0,094
Run 48									0,0499	0,0684
Run 49									0,087	0,0534
Run 50									0,0974	0,0626
Run 51									0,0244	0,1114
Run 52									0,0429	0,0684
Run 53									0,0383	0,0998
Run 54									0,0626	0,0684
Run 55									0,0847	0,0522
Run 56									0,0429	0,0754
Run 57									0,0673	0,0557
Run 58									0,0847	0,0731
Run 59									0,0893	0,1555
Run 60									0,022	0,0835
Run 61									0,065	0,0522
Run 62									0,1148	0,0534
Run 63									0,1334	0,1114
Run 64									0,022	0,0522
Run 65									0,0406	0,0882
Run 66									0,0267	0,0684
Run 67									0,0789	0,0789
Run 68									0,0406	0,1357
Run 69									0,0255	0,0835
Run 70									0,0847	0,0522
Run 71									0,0812	0,0638
Run 72									0,0383	0,1125
Run 73									0,0684	0,0673
Run 74									0,0835	0,0522
Run 75									0,0847	0,0835
Run 76									0,0824	0,0789
Run 77									0,1531	0,0974
Run 78									0,0719	0,0661
Run 79									0,0754	0,1172
Run 80									0,0255	0,0754

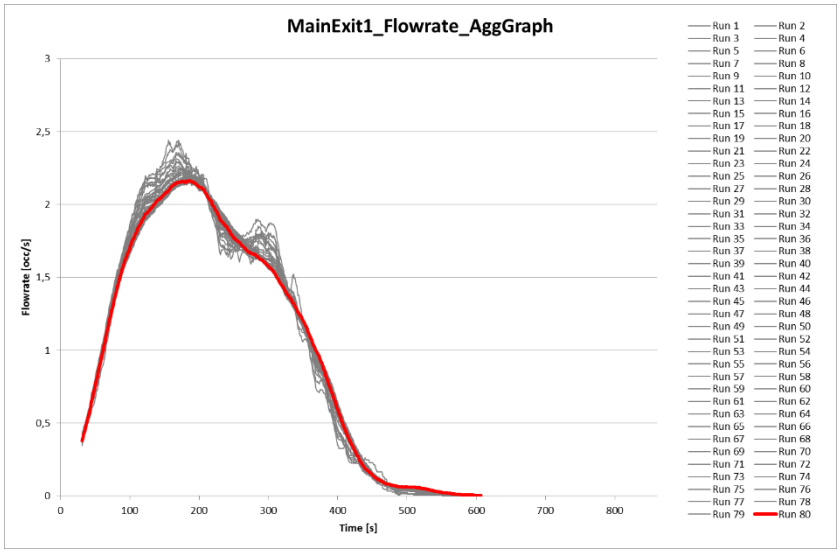
The figure below shows the compiled results.

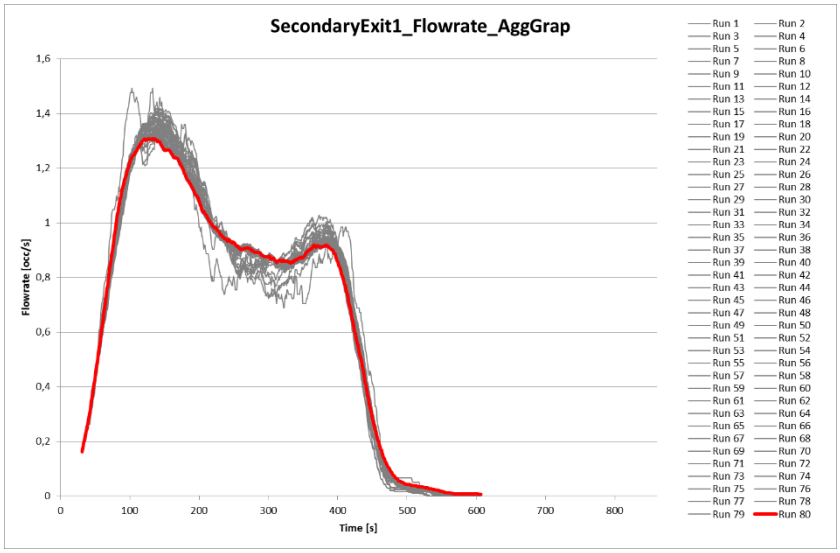
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	18	YES	18	YES	8	YES	6	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	33
YES	34	YES	30	YES	27	YES	31	YES	34
YES	12	YES	14	YES	15	YES	12	YES	13
YES	6	YES	7	YES	6	NO	-	NO	-
YES	**34**	**YES**	**38**	**YES**	**42**	**NO**		**NO**	

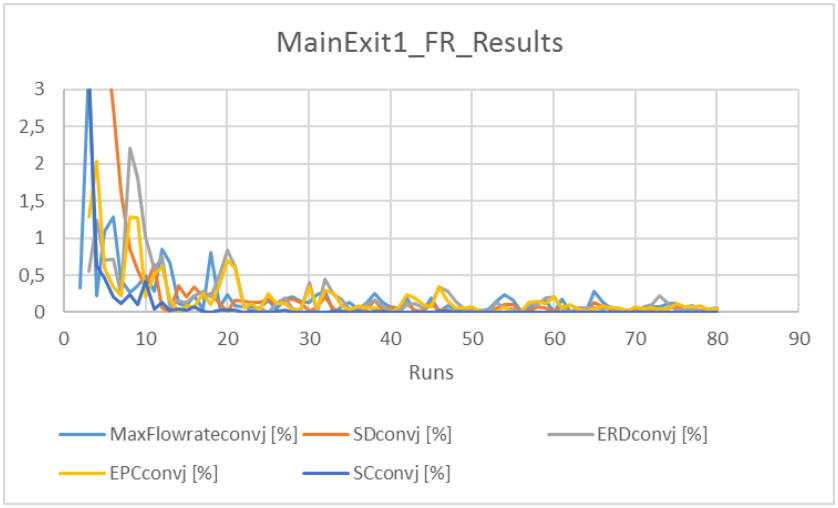
Flowrate - Average number of data points

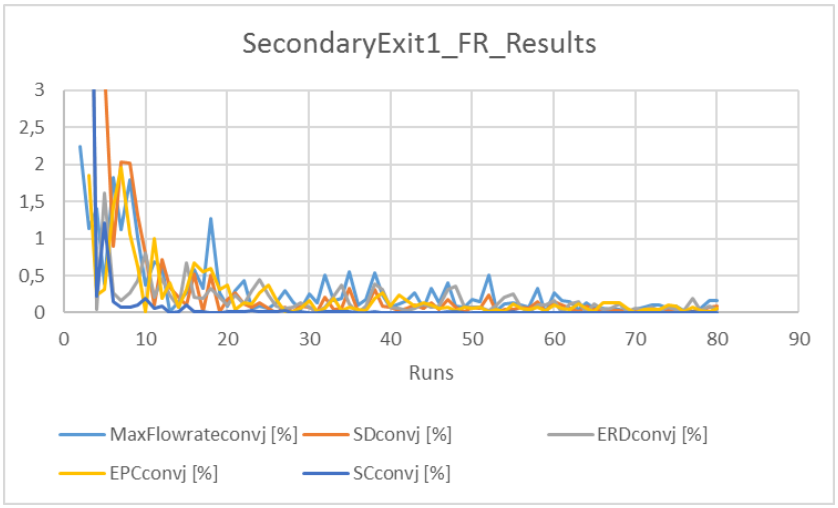
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,117188	0,053125	0,101563	0,073438	0,024259	0,025337	0,0875	0,04375	0,054687	0,1125
Run 3	0,214063	0,048438	0,08125	0,067188	0,007008	0,016712	0,04375	0,059375	0,084375	0,045312
Run 4	0,070313	0,060938	0,060938	0,071875	0,007547	0,014016	0,057813	0,048438	0,085938	0,095313
Run 5	0,09375	0,089063	0,078125	0,051562	0,006469	0,01186	0,042188	0,048438	0,067188	0,095313
Run 6	0,090625	0,042188	0,032813	0,046875	0,004313	0,012938	0,035938	0,040625	0,064062	0,085938
Run 7	0,05	0,051563	0,053125	0,046875			0,053125		0,040625	0,057813
Run 8	0,151563	0,085938	0,05625	0,051563					0,067188	0,078125
Run 9	0,0625	0,05	0,045313	0,08125					0,071875	0,095313
Run 10	0,0375	0,0375	0,03125	0,06875					0,015625	0,059375
Run 11	0,053125	0,0375		0,05625					0,05625	0,05
Run 12	0,046875	0,023438		0,045313					0,014063	0,034375
Run 13	0,079688	0,08125		0,064063					0,035938	0,078125
Run 14	0,046875	0,0375		0,045313					0,023438	0,04375
Run 15	0,045313	0,028125		0,045313						0,023438
Run 16	0,045313	0,039062								0,014063
Run 17	0,032813	0,029688								0,014063
Run 18	0,075	0,0625								0,045313
Run 19	0,064063									
Run 20	0,107813									
Run 21	0,101563									
Run 22	0,026563									
Run 23	0,035938									
Run 24	0,03125									
Run 25	0,026563									
Run 26	0,034375									

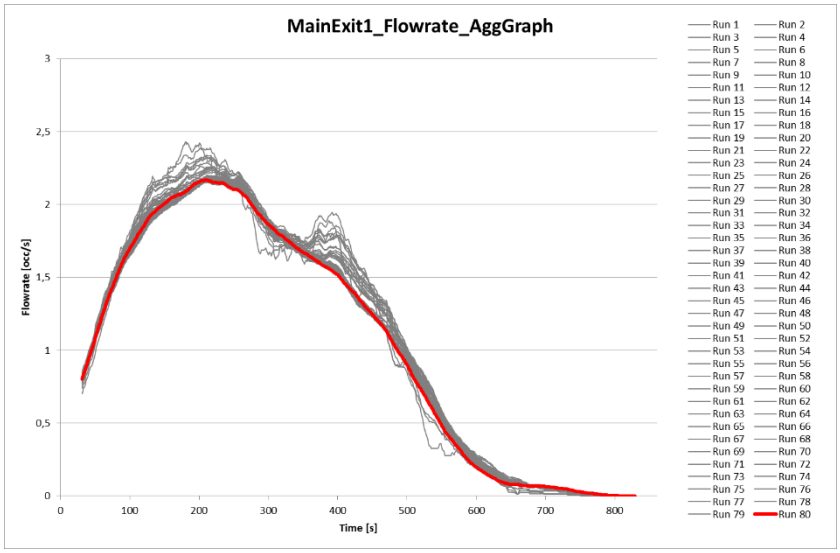
The figure below shows the compiled results.

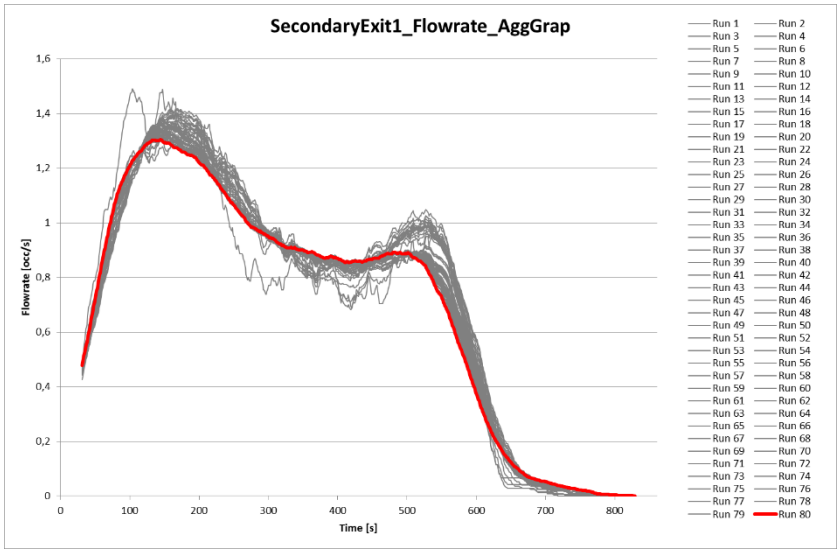
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	26	YES	18	YES	10	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	33
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	14	YES	18
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**35**

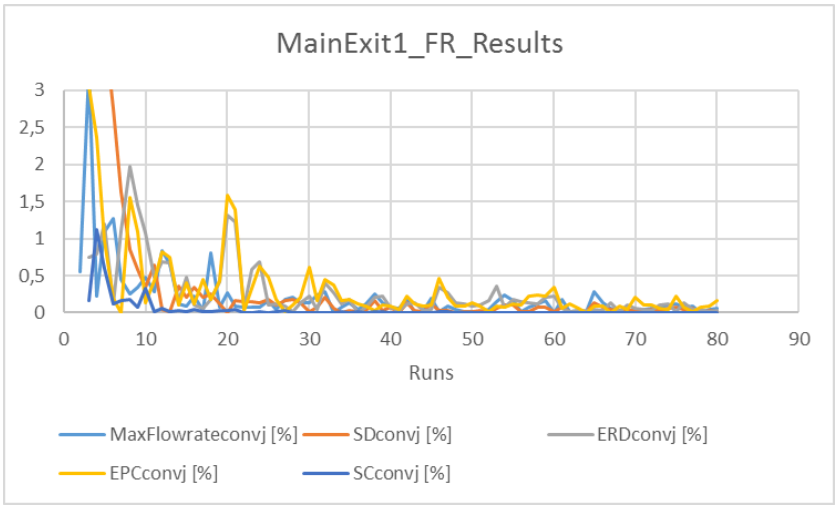
Flowrate - Normalizing data points

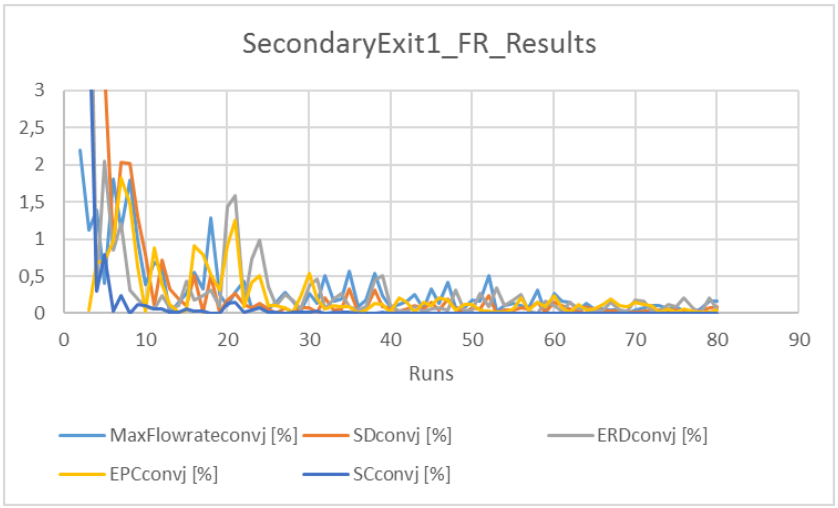
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

The figure below shows the compiled results.

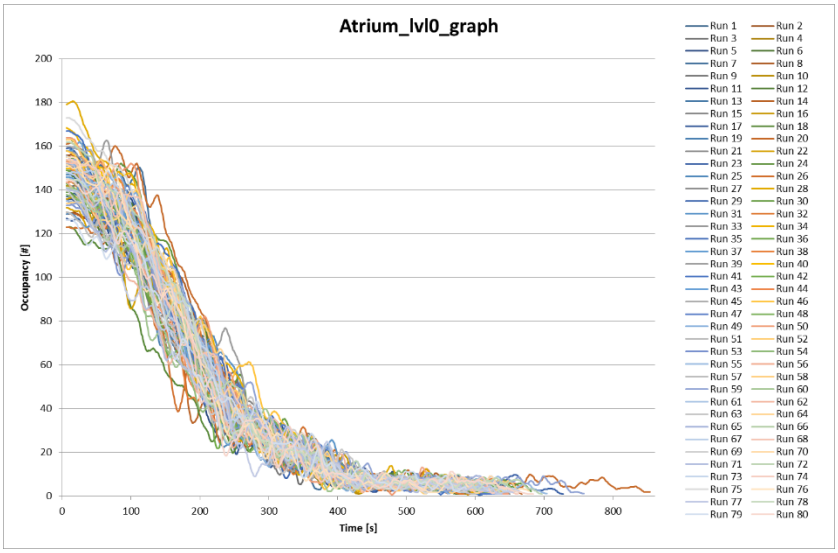
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

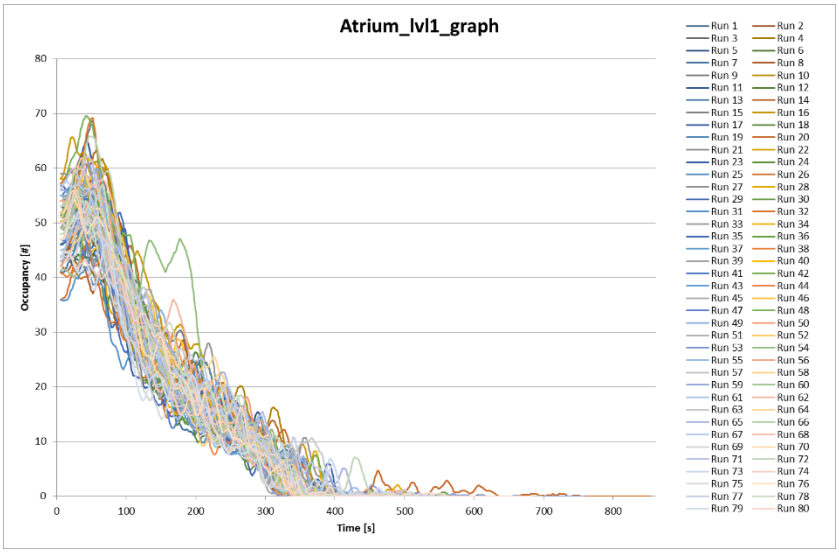
Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

Spatial location

When flowrate has been calculated, a moving average of ±5s has been utilized.

The two figures below display the graphs over the retrieved runs.



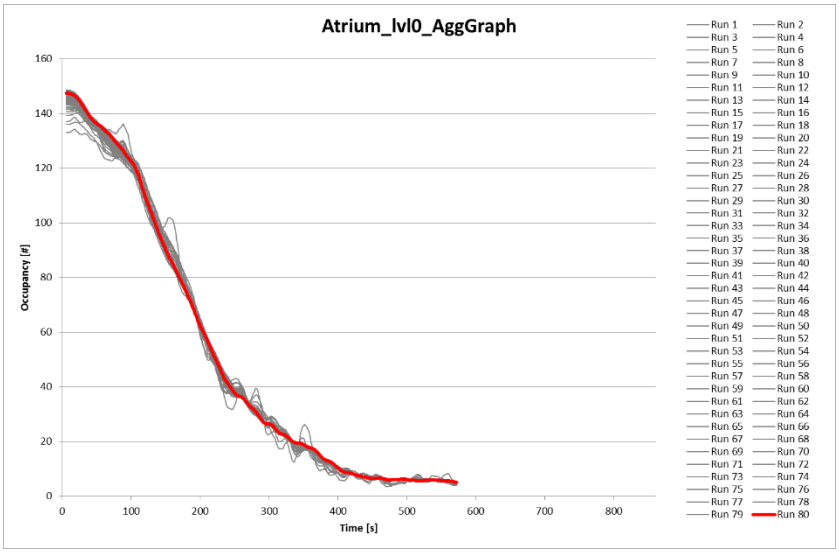


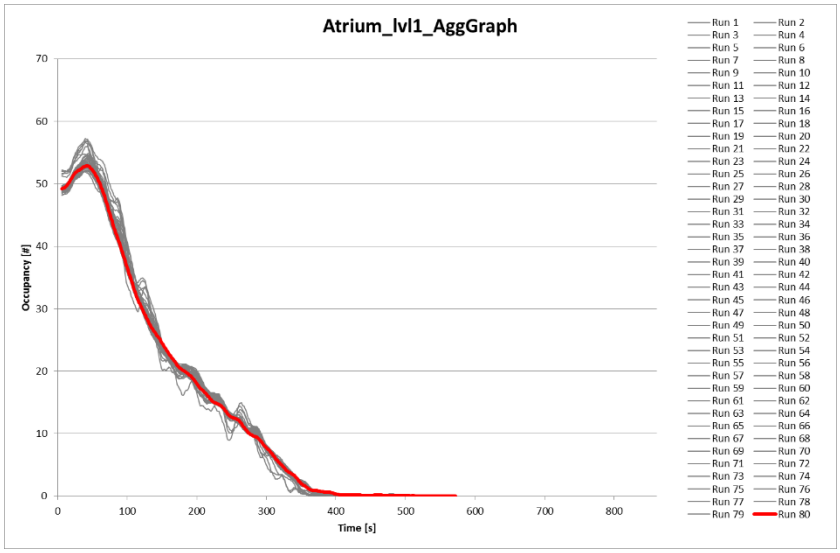
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

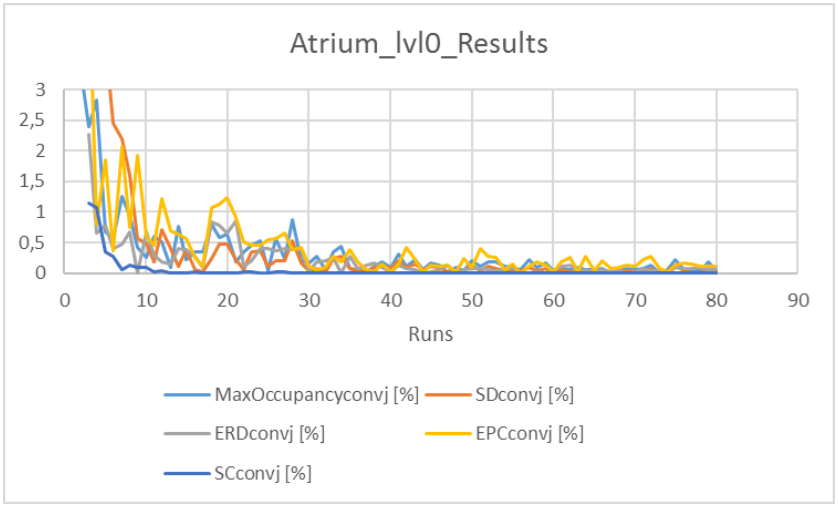
Spatial location - Minimum number of data points

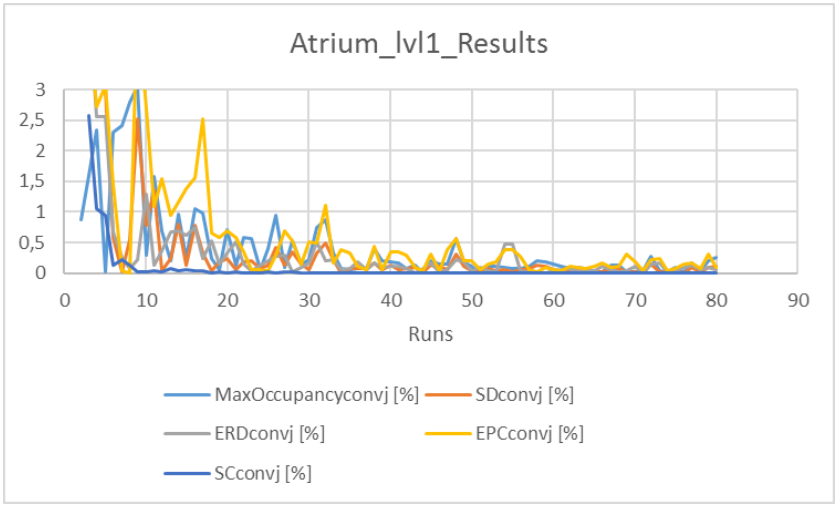
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,12931	0,058621	0,106897	0,081034	0,024259	0,025337	0,096552	0,048276	0,037931	0,096552
Run 3	0,236207	0,053448	0,087931	0,074138	0,007008	0,016712	0,048276	0,065517	0,05	0,032759
Run 4	0,077586	0,067241	0,067241	0,07931	0,007547	0,014016	0,063793	0,053448	0,037931	0,036207
Run 5	0,103448	0,098276	0,082759	0,056897	0,006469	0,01186	0,046552	0,053448	0,024138	0,031034
Run 6	0,1	0,046552	0,036207	0,051724	0,004313	0,012938	0,039655	0,044828	0,024138	0,024138
Run 7	0,055172	0,056897	0,058621	0,051724			0,058621			0,017241
Run 8	0,167241	0,094828	0,062069	0,056897						
Run 9	0,068966	0,055172	0,05	0,055172						
Run 10	0,041379	0,041379	0,034483							
Run 11	0,058621	0,041379								
Run 12	0,051724	0,025862								
Run 13	0,051724	0,02931								

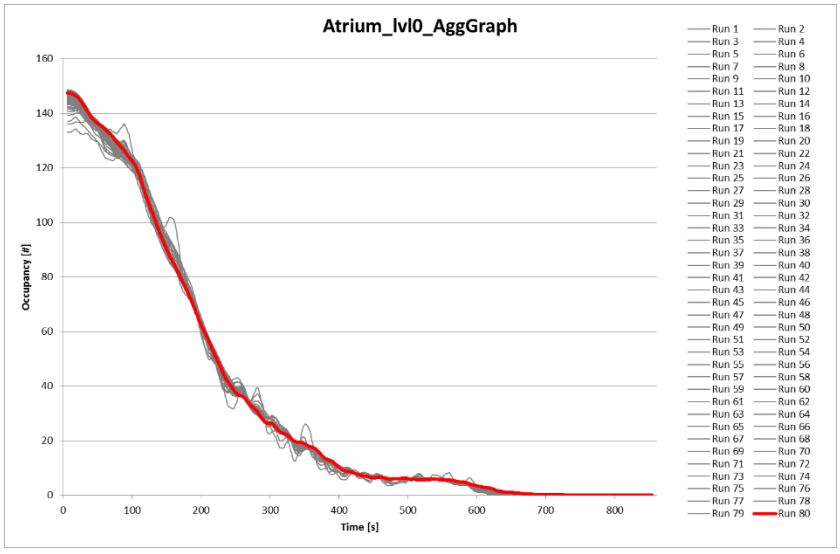
The figure below shows the compiled results.

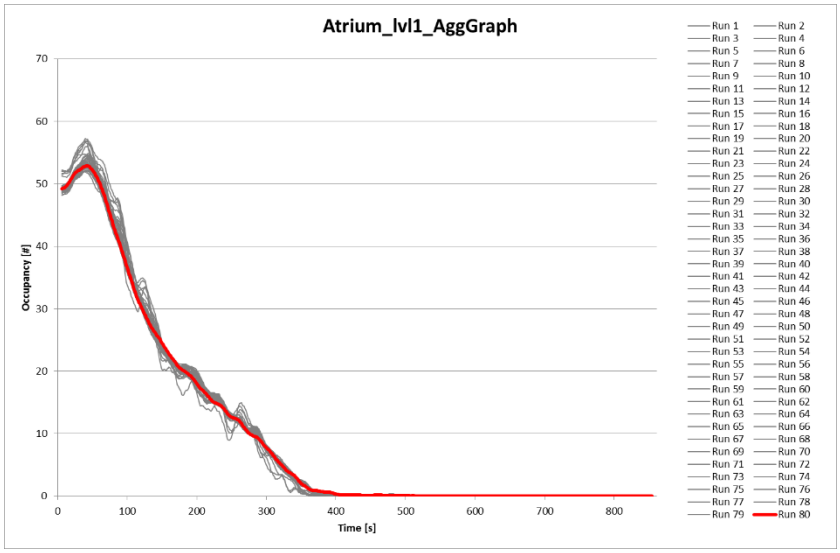
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	13	YES	13	YES	10	YES	9	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	44	YES	34
YES	30	YES	18	YES	21	YES	18	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	6	YES	7
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**44**	**YES**	**35**

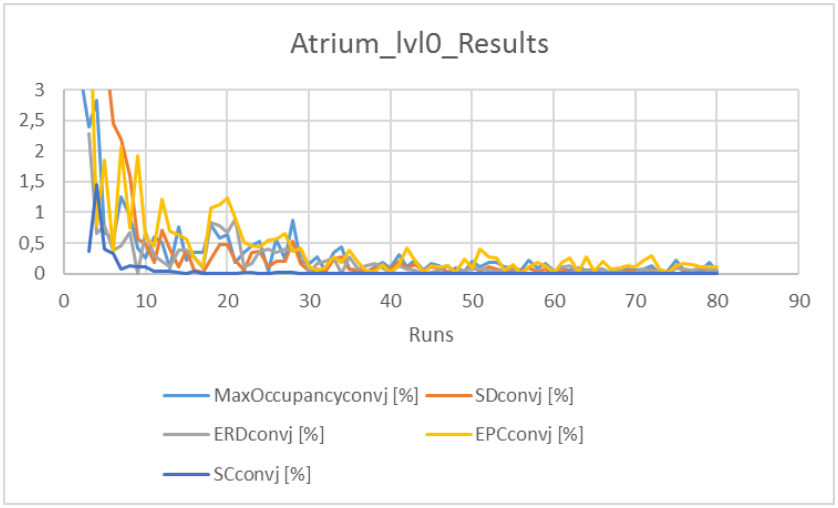
Spatial location - Maximum number of data points

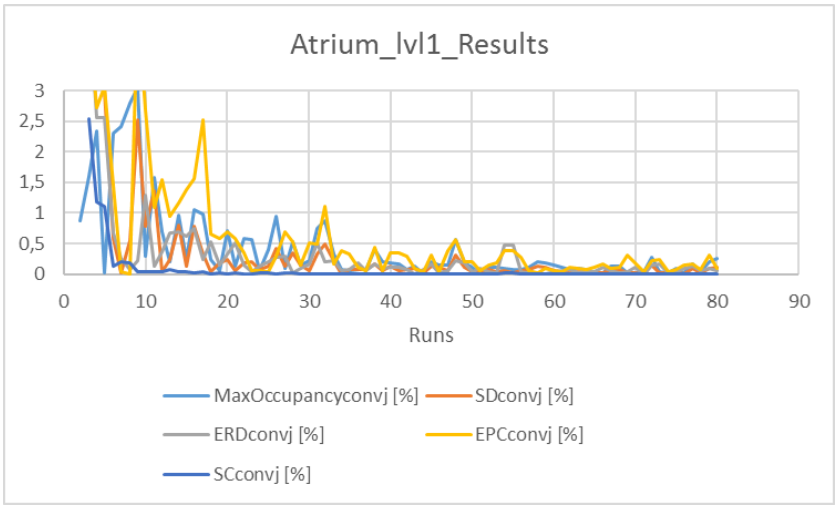
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStai	belowsta	MainExit	Seconda	TET	Queuing	Atrium_I	Atrium_I	MainExit	SecondaryExit2_UE
Run 2	0,087	0,0394	0,0754	0,0545	0,0243	0,0253	0,065	0,0325	0,297	0,3398
Run 3	0,1589	0,036	0,0603	0,0499	0,007	0,0167	0,0325	0,0441	0,319	0,29
Run 4	0,0522	0,0452	0,0452	0,0534	0,0075	0,014	0,0429	0,036	0,3202	0,3271
Run 5	0,0696	0,0661	0,058	0,0383	0,0065	0,0119	0,0313	0,036	0,3063	0,3271
Run 6	0,0673	0,0313	0,0244	0,0348	0,0043	0,0129	0,0267	0,0302	0,3039	0,3202
Run 7	0,0371	0,0383	0,0394				0,0394		0,2865	0,2993
Run 8	0,1125	0,0638	0,0418						0,3063	0,3144
Run 9	0,0464	0,0371							0,3097	0,3271
Run 10	0,0278	0,0278							0,2668	0,3005
Run 11	0,0394	0,0278							0,2981	0,2935
Run 12	0,0348	0,0174							0,2668	0,2819
Run 13	0,0592	0,0603							0,2703	0,3074
Run 14	0,0348	0,0278							0,2227	0,2436
Run 15	0,0336	0,0209							0,2413	0,2529
Run 16	0,0336	0,029							0,2181	0,2367
Run 17	0,0244	0,022							0,2703	0,232
Run 18	0,0557	0,0464							0,2227	0,2715
Run 19									0,2483	0,2575
Run 20									0,1473	0,2436
Run 21									0,022	0,0638
Run 22									0,0244	0,0522
Run 23									0,0383	0,1172
Run 24									0,0835	0,1148
Run 25									0,1357	0,0638
Run 26									0,0708	0,0522
Run 27									0,0267	0,0974
Run 28									0,0255	0,1125
Run 29									0,0255	0,0673
Run 30									0,109	0,0731
Run 31									0,0267	0,0916
Run 32									0,0383	0,0789
Run 33									0,1009	0,1172
Run 34									0,1172	0,0719
Run 35									0,0499	0,0719
Run 36									0,0719	0,0545
Run 37									0,0673	0,0661
Run 38									0,0626	0,0673
Run 39									0,0719	0,0719
Run 40									0,0777	0,0522
Run 41									0,0893	0,1357
Run 42									0,1032	0,0719
Run 43									0,0719	0,0522
Run 44									0,0626	0,0835
Run 45									0,0777	0,0545
Run 46									0,1148	0,1288
Run 47									0,0708	0,094
Run 48									0,0499	0,0684
Run 49									0,087	0,0534
Run 50									0,0974	0,0626
Run 51									0,0244	0,1114
Run 52									0,0429	0,0684
Run 53									0,0383	0,0998
Run 54									0,0626	0,0684
Run 55									0,0847	0,0522
Run 56									0,0429	0,0754
Run 57									0,0673	0,0557
Run 58									0,0847	0,0731
Run 59									0,0893	0,1555
Run 60									0,022	0,0835
Run 61									0,065	0,0522
Run 62									0,1148	0,0534
Run 63									0,1334	0,1114
Run 64									0,022	0,0522
Run 65									0,0406	0,0882
Run 66									0,0267	0,0684
Run 67									0,0789	0,0789
Run 68									0,0406	0,1357
Run 69									0,0255	0,0835
Run 70									0,0847	0,0522
Run 71									0,0812	0,0638
Run 72									0,0383	0,1125
Run 73									0,0684	0,0673
Run 74									0,0835	0,0522
Run 75									0,0847	0,0835
Run 76									0,0824	0,0789
Run 77									0,1531	0,0974
Run 78									0,0719	0,0661
Run 79									0,0754	0,1172
Run 80									0,0255	0,0754

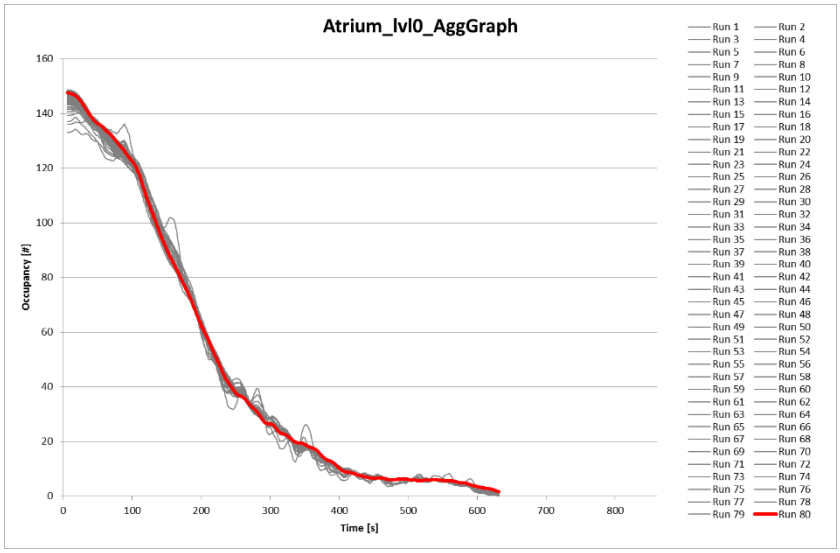
The figure below shows the compiled results.

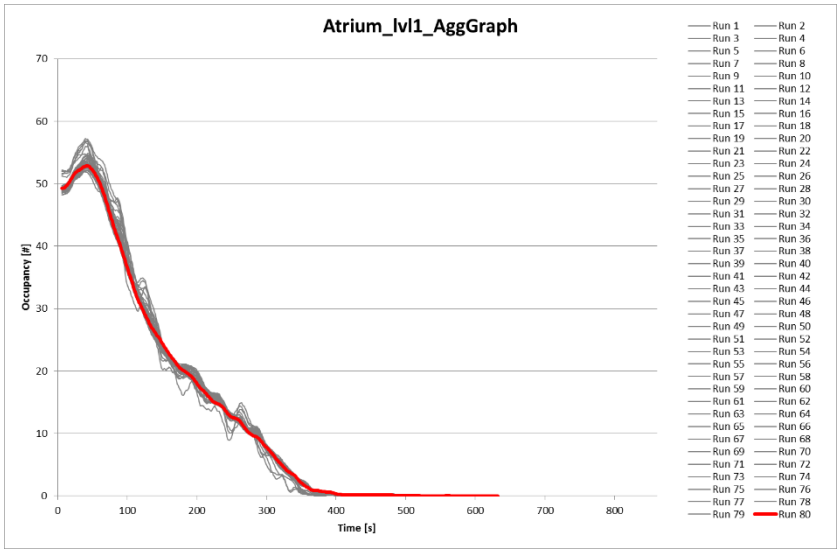
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	18	YES	18	YES	8	YES	6	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	33
YES	34	YES	30	YES	27	YES	31	YES	34
YES	12	YES	14	YES	15	YES	12	YES	13
YES	6	YES	7	YES	6	NO	-	NO	-
YES	**34**	**YES**	**38**	**YES**	**42**	**NO**		**NO**	

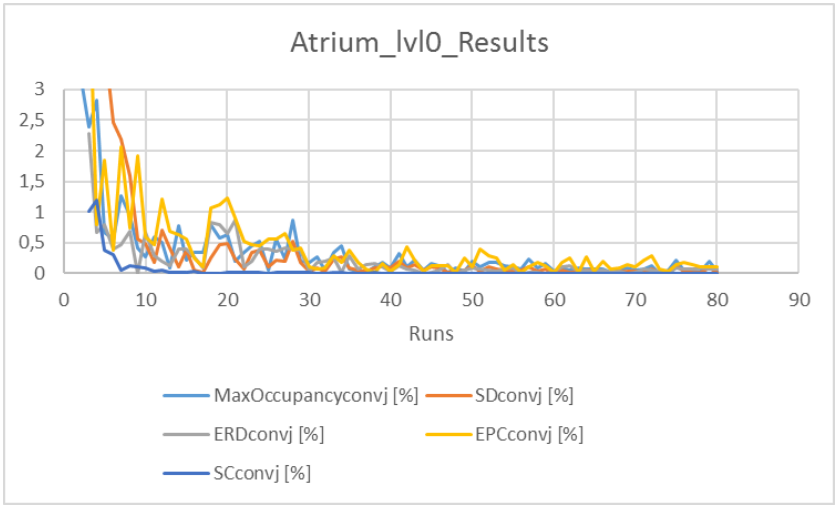
Spatial location - Average number of data points

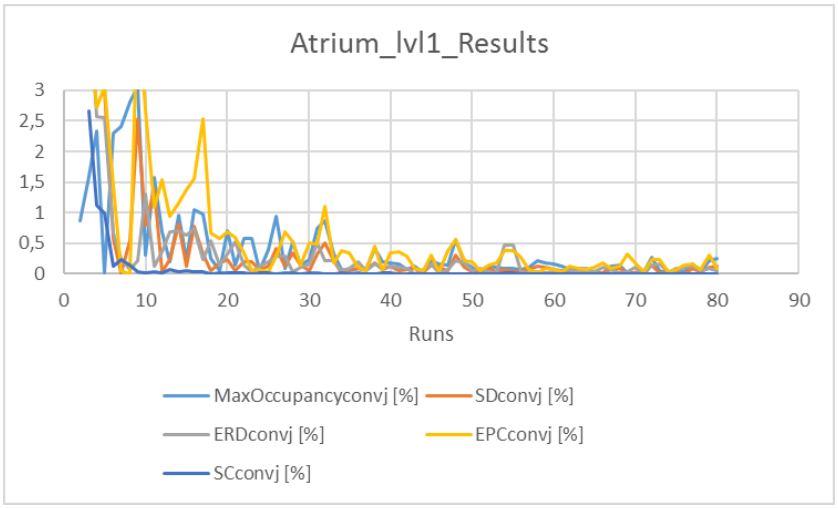
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondar	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,117188	0,053125	0,101563	0,073438	0,024259	0,025337	0,0875	0,04375	0,054687	0,1125
Run 3	0,214063	0,048438	0,08125	0,067188	0,007008	0,016712	0,04375	0,059375	0,084375	0,045312
Run 4	0,070313	0,060938	0,060938	0,071875	0,007547	0,014016	0,057813	0,048438	0,085938	0,095313
Run 5	0,09375	0,089063	0,078125	0,051562	0,006469	0,01186	0,042188	0,048438	0,067188	0,095313
Run 6	0,090625	0,042188	0,032813	0,046875	0,004313	0,012938	0,035938	0,040625	0,064062	0,085938
Run 7	0,05	0,051563	0,053125	0,046875			0,053125		0,040625	0,057813
Run 8	0,151563	0,085938	0,05625	0,051563					0,067188	0,078125
Run 9	0,0625	0,05	0,045313	0,08125					0,071875	0,095313
Run 10	0,0375	0,0375	0,03125	0,06875					0,015625	0,059375
Run 11	0,053125	0,0375		0,05625					0,05625	0,05
Run 12	0,046875	0,023438		0,045313					0,014063	0,034375
Run 13	0,079688	0,08125		0,064063					0,035938	0,078125
Run 14	0,046875	0,0375		0,045313					0,023438	0,04375
Run 15	0,045313	0,028125		0,045313						0,023438
Run 16	0,045313	0,039062								0,014063
Run 17	0,032813	0,029688								0,014063
Run 18	0,075	0,0625								0,045313
Run 19	0,064063									
Run 20	0,107813									
Run 21	0,101563									
Run 22	0,026563									
Run 23	0,035938									
Run 24	0,03125									
Run 25	0,026563									
Run 26	0,034375									

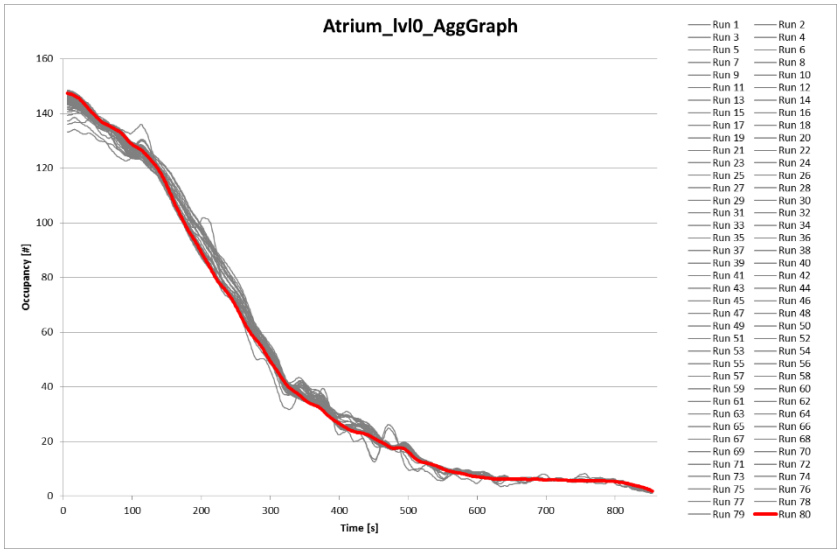
The figure below shows the compiled results.

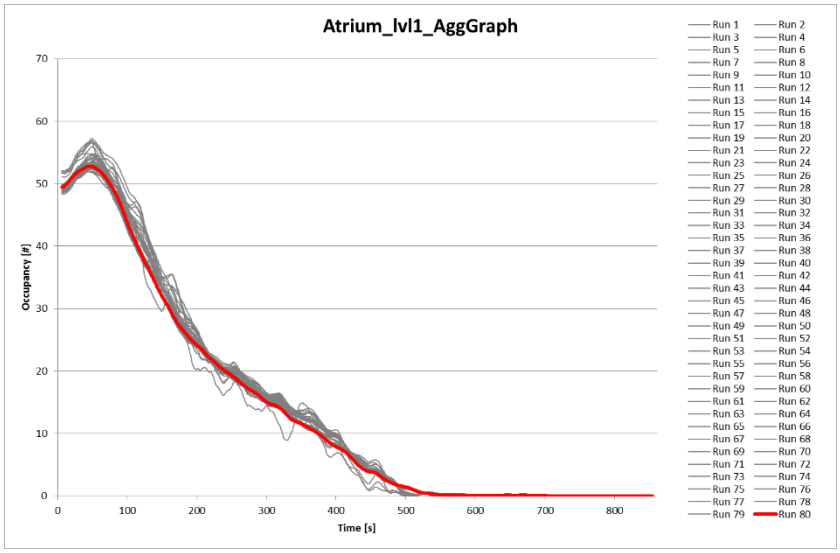
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	26	YES	18	YES	10	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	33
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	14	YES	18
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**35**

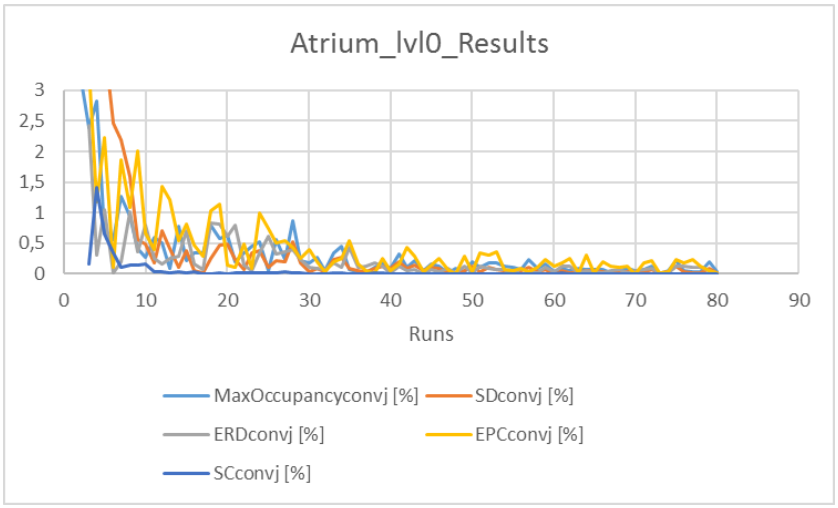
Spatial location - Normalizing data points

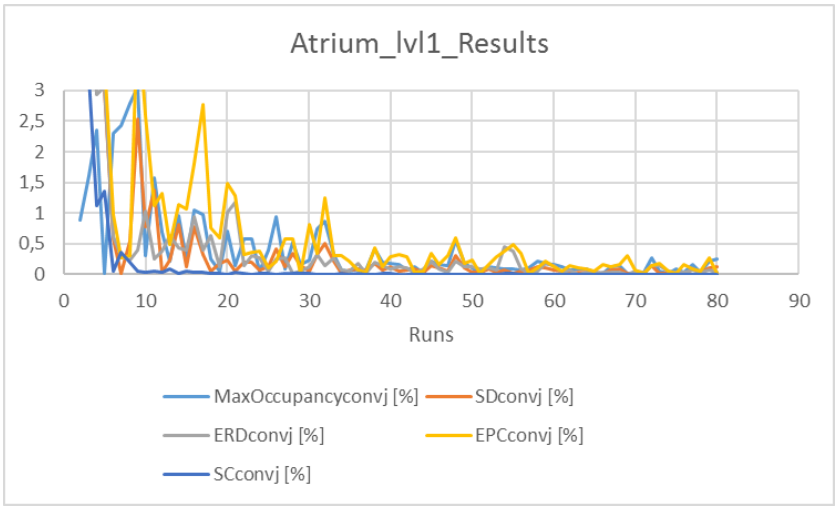
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

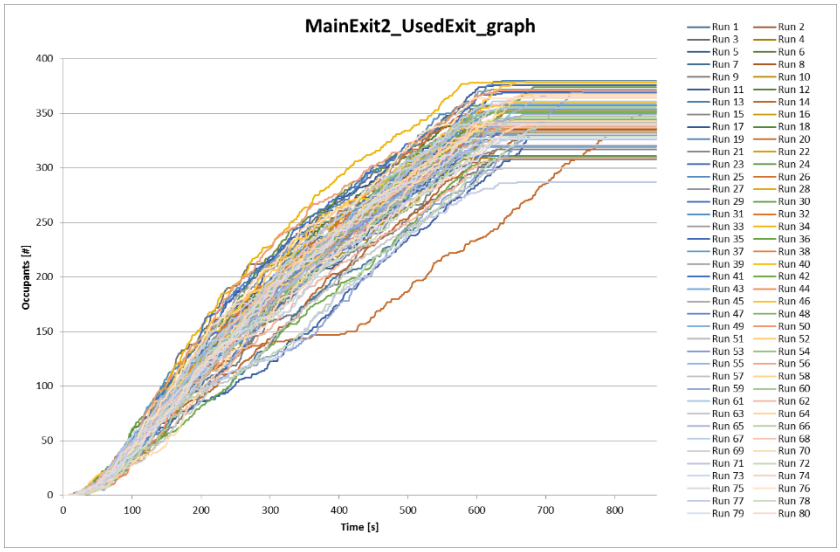
The figure below shows the compiled results.

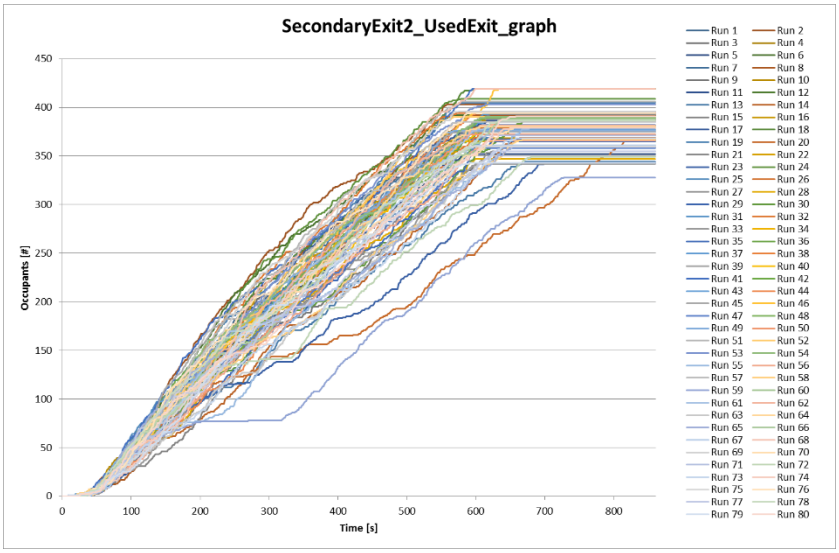
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**

Used exit

The two figures below display the graphs over the retrieved runs.



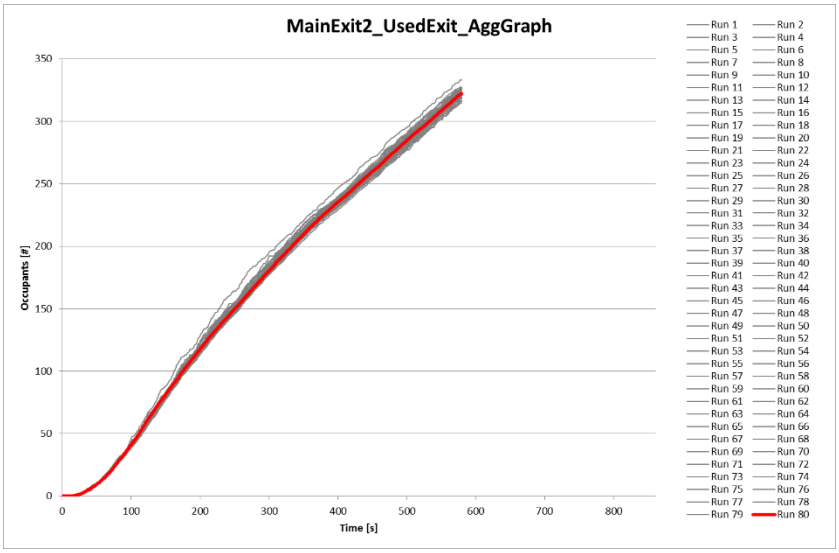


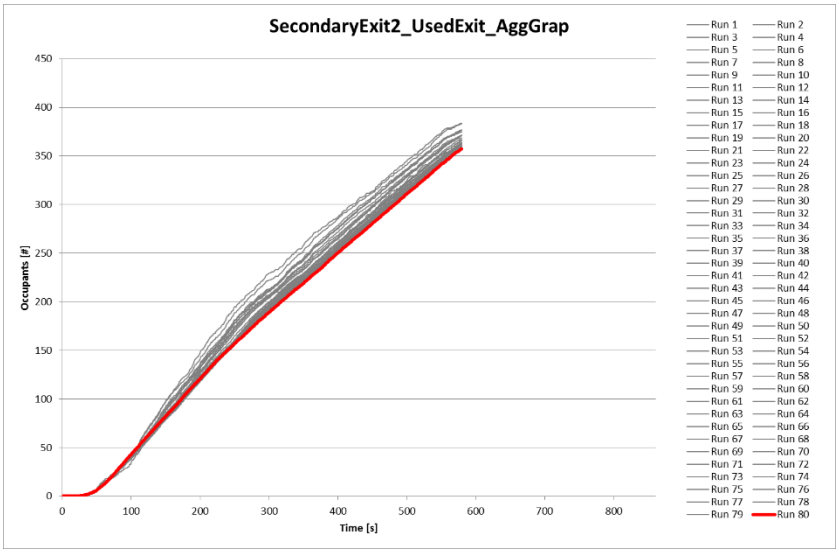
The figure below displays the descriptive statistics.

	Max	Min	Standard deviation	Average	95% CI (UB)	95% CI (LB)
LastStair_Max density [occ/m2]	3,04	1,43	0,48	2,17	2,27	2,06
belowstairs_Max density [occ/m2]	2,62	0,72	0,51	1,58	1,69	1,47
MainExit1_Max flowrate [occ/s]	2,61	1,95	0,13	2,39	2,42	2,36
SecondaryExit1_Max flowrate [occ/s]	1,75	1,07	0,13	1,43	1,46	1,40
TET [s]	860,03	578,43	42,77	637,88	647,21	628,56
Max queuing time [s]	589,18	292,55	43,87	354,35	363,92	344,78
Atrium_lvl0_Max occupancy [occ]	180,64	123,09	11,20	148,39	150,83	145,95
Atrium_lvl1_Max occupancy [occ]	69,55	41,36	5,87	55,22	56,49	53,94
MainExit2_Max usage [occ]	380,00	287,00	19,67	342,90	347,18	338,62
SecondaryExit2_Max usage [occ]	419,00	328,00	19,65	377,44	381,70	373,17

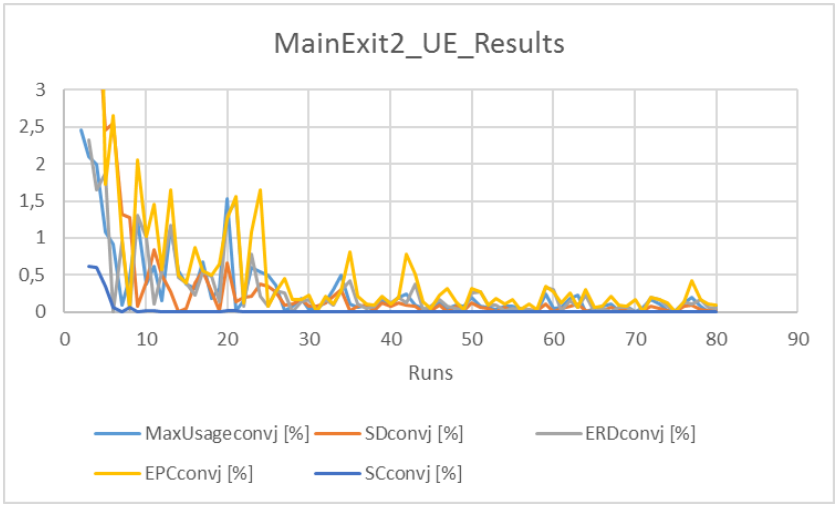
Used exit - Minimum number of data points

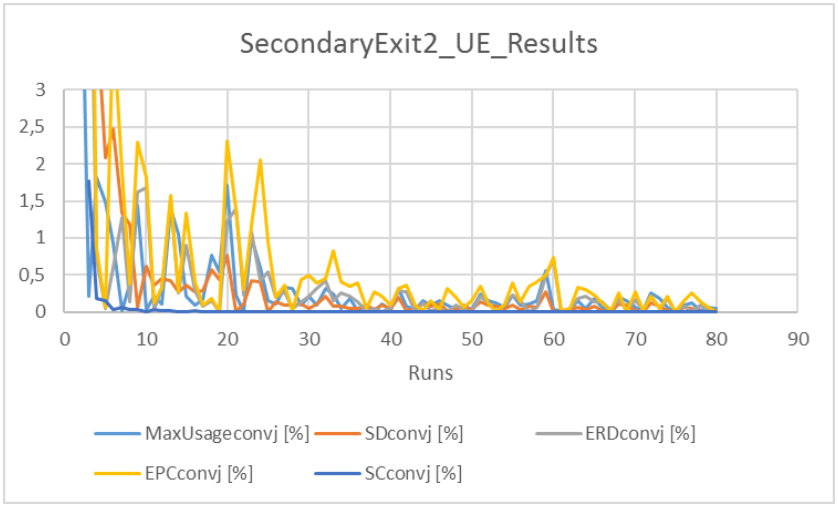
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,12931	0,058621	0,106897	0,081034	0,024259	0,025337	0,096552	0,048276	0,037931	0,096552
Run 3	0,236207	0,053448	0,087931	0,074138	0,007008	0,016712	0,048276	0,065517	0,05	0,032759
Run 4	0,077586	0,067241	0,067241	0,07931	0,007547	0,014016	0,063793	0,053448	0,037931	0,036207
Run 5	0,103448	0,098276	0,082759	0,056897	0,006469	0,01186	0,046552	0,053448	0,024138	0,031034
Run 6	0,1	0,046552	0,036207	0,051724	0,004313	0,012938	0,039655	0,044828	0,024138	0,024138
Run 7	0,055172	0,056897	0,058621	0,051724			0,058621			0,017241
Run 8	0,167241	0,094828	0,062069	0,056897						
Run 9	0,068966	0,055172	0,05	0,055172						
Run 10	0,041379	0,041379	0,034483							
Run 11	0,058621	0,041379								
Run 12	0,051724	0,025862								
Run 13	0,051724	0,02931								

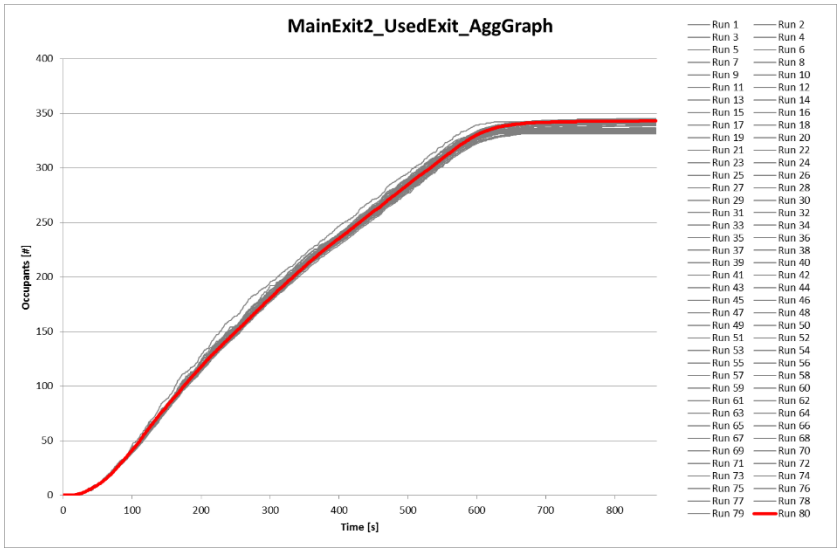
The figure below shows the compiled results.

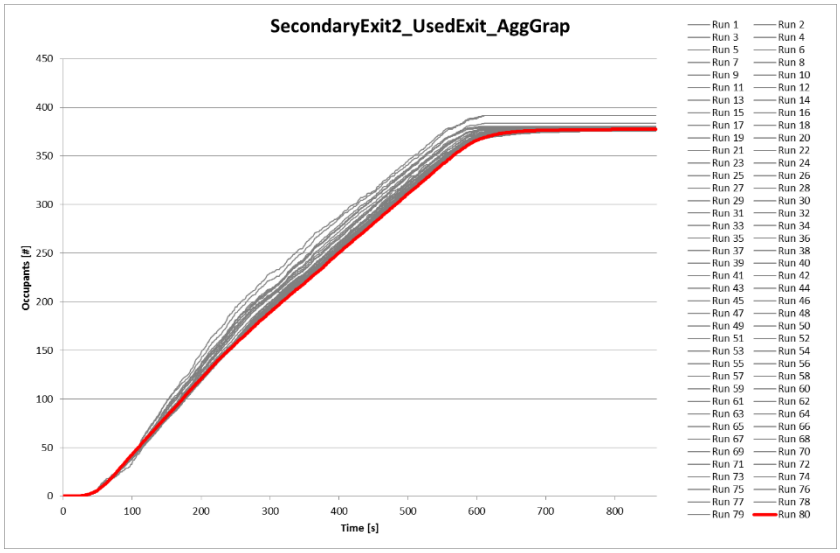
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	13	YES	13	YES	10	YES	9	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	44	YES	34
YES	30	YES	18	YES	21	YES	18	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	6	YES	7
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**44**	**YES**	**35**

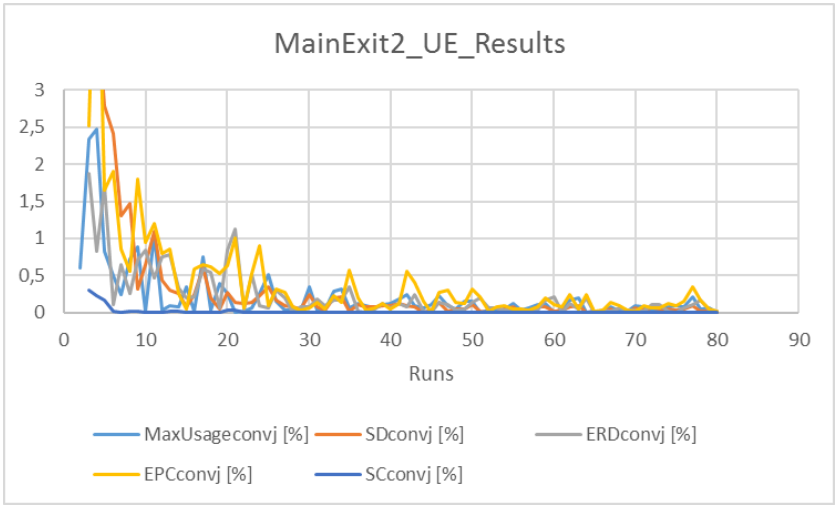
Used exit - Maximum number of data points

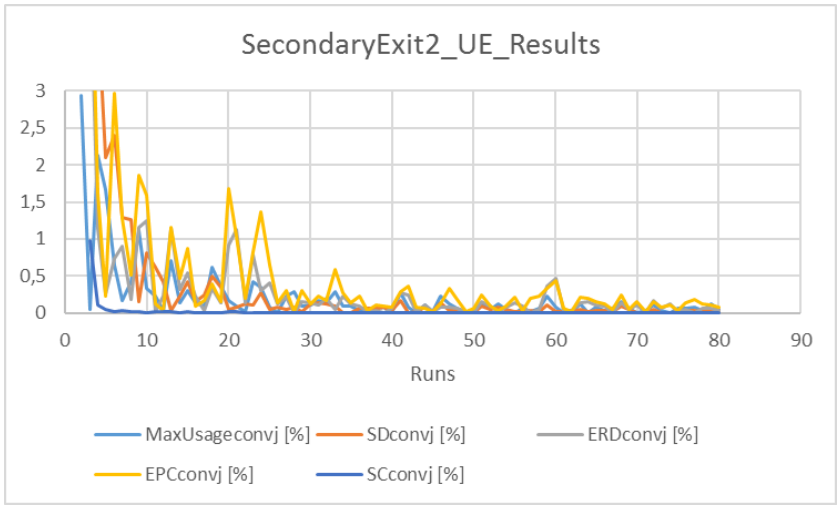
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStai	belowsta	MainExit	Seconda	TET	Queuing	Atrium_I	Atrium_I	MainExit	SecondaryExit2_UE
Run 2	0,087	0,0394	0,0754	0,0545	0,0243	0,0253	0,065	0,0325	0,297	0,3398
Run 3	0,1589	0,036	0,0603	0,0499	0,007	0,0167	0,0325	0,0441	0,319	0,29
Run 4	0,0522	0,0452	0,0452	0,0534	0,0075	0,014	0,0429	0,036	0,3202	0,3271
Run 5	0,0696	0,0661	0,058	0,0383	0,0065	0,0119	0,0313	0,036	0,3063	0,3271
Run 6	0,0673	0,0313	0,0244	0,0348	0,0043	0,0129	0,0267	0,0302	0,3039	0,3202
Run 7	0,0371	0,0383	0,0394				0,0394		0,2865	0,2993
Run 8	0,1125	0,0638	0,0418						0,3063	0,3144
Run 9	0,0464	0,0371							0,3097	0,3271
Run 10	0,0278	0,0278							0,2668	0,3005
Run 11	0,0394	0,0278							0,2981	0,2935
Run 12	0,0348	0,0174							0,2668	0,2819
Run 13	0,0592	0,0603							0,2703	0,3074
Run 14	0,0348	0,0278							0,2227	0,2436
Run 15	0,0336	0,0209							0,2413	0,2529
Run 16	0,0336	0,029							0,2181	0,2367
Run 17	0,0244	0,022							0,2703	0,232
Run 18	0,0557	0,0464							0,2227	0,2715
Run 19									0,2483	0,2575
Run 20									0,1473	0,2436
Run 21									0,022	0,0638
Run 22									0,0244	0,0522
Run 23									0,0383	0,1172
Run 24									0,0835	0,1148
Run 25									0,1357	0,0638
Run 26									0,0708	0,0522
Run 27									0,0267	0,0974
Run 28									0,0255	0,1125
Run 29									0,0255	0,0673
Run 30									0,109	0,0731
Run 31									0,0267	0,0916
Run 32									0,0383	0,0789
Run 33									0,1009	0,1172
Run 34									0,1172	0,0719
Run 35									0,0499	0,0719
Run 36									0,0719	0,0545
Run 37									0,0673	0,0661
Run 38									0,0626	0,0673
Run 39									0,0719	0,0719
Run 40									0,0777	0,0522
Run 41									0,0893	0,1357
Run 42									0,1032	0,0719
Run 43									0,0719	0,0522
Run 44									0,0626	0,0835
Run 45									0,0777	0,0545
Run 46									0,1148	0,1288
Run 47									0,0708	0,094
Run 48									0,0499	0,0684
Run 49									0,087	0,0534
Run 50									0,0974	0,0626
Run 51									0,0244	0,1114
Run 52									0,0429	0,0684
Run 53									0,0383	0,0998
Run 54									0,0626	0,0684
Run 55									0,0847	0,0522
Run 56									0,0429	0,0754
Run 57									0,0673	0,0557
Run 58									0,0847	0,0731
Run 59									0,0893	0,1555
Run 60									0,022	0,0835
Run 61									0,065	0,0522
Run 62									0,1148	0,0534
Run 63									0,1334	0,1114
Run 64									0,022	0,0522
Run 65									0,0406	0,0882
Run 66									0,0267	0,0684
Run 67									0,0789	0,0789
Run 68									0,0406	0,1357
Run 69									0,0255	0,0835
Run 70									0,0847	0,0522
Run 71									0,0812	0,0638
Run 72									0,0383	0,1125
Run 73									0,0684	0,0673
Run 74									0,0835	0,0522
Run 75									0,0847	0,0835
Run 76									0,0824	0,0789
Run 77									0,1531	0,0974
Run 78									0,0719	0,0661
Run 79									0,0754	0,1172
Run 80									0,0255	0,0754

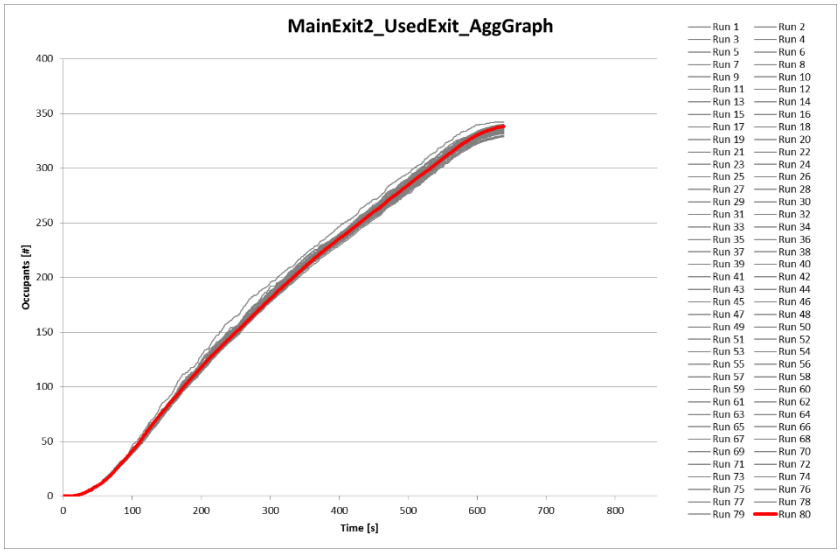
The figure below shows the compiled results.

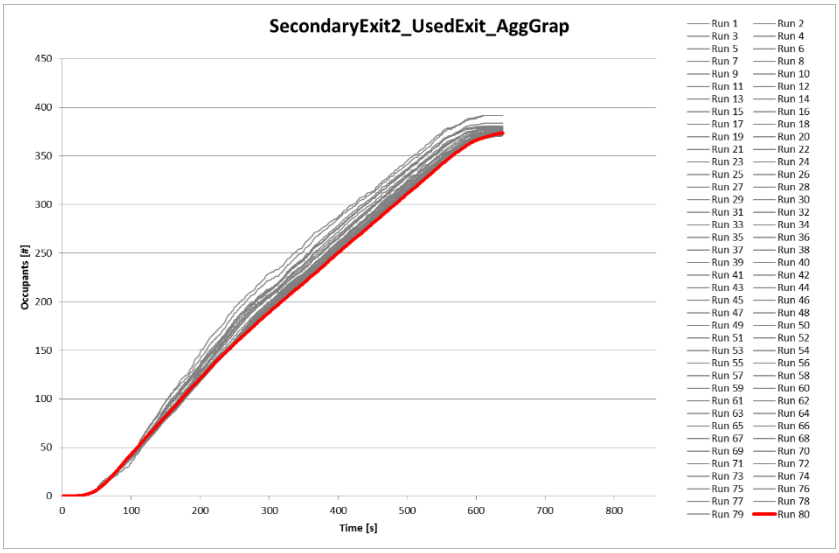
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	18	YES	18	YES	8	YES	6	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	33
YES	34	YES	30	YES	27	YES	31	YES	34
YES	12	YES	14	YES	15	YES	12	YES	13
YES	6	YES	7	YES	6	NO	-	NO	-
YES	**34**	**YES**	**38**	**YES**	**42**	**NO**		**NO**	

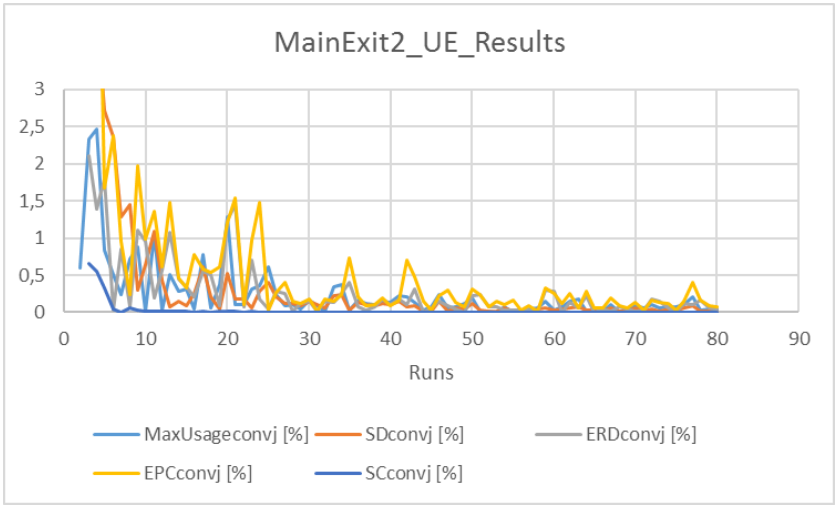
Used exit - Average number of data points

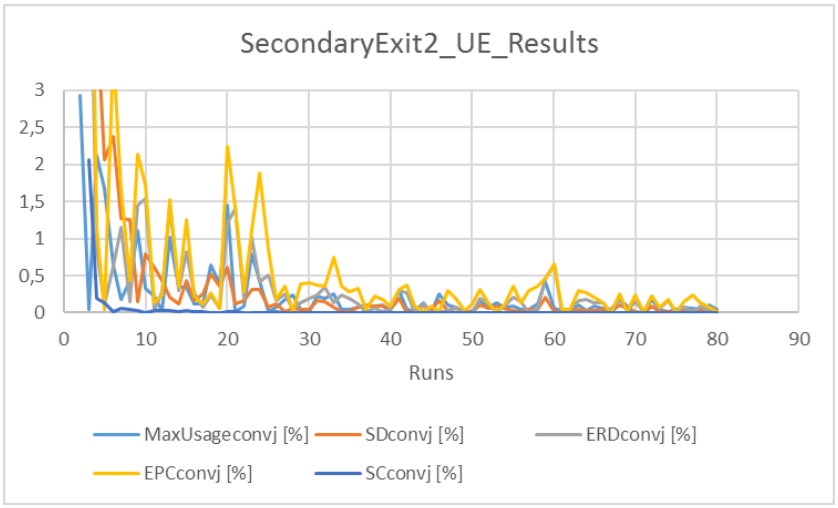
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,117188	0,053125	0,101563	0,073438	0,024259	0,025337	0,0875	0,04375	0,054687	0,1125
Run 3	0,214063	0,048438	0,08125	0,067188	0,007008	0,016712	0,04375	0,059375	0,084375	0,045312
Run 4	0,070313	0,060938	0,060938	0,071875	0,007547	0,014016	0,057813	0,048438	0,085938	0,095313
Run 5	0,09375	0,089063	0,078125	0,051562	0,006469	0,01186	0,042188	0,048438	0,067188	0,095313
Run 6	0,090625	0,042188	0,032813	0,046875	0,004313	0,012938	0,035938	0,040625	0,064062	0,085938
Run 7	0,05	0,051563	0,053125	0,046875			0,053125		0,040625	0,057813
Run 8	0,151563	0,085938	0,05625	0,051563					0,067188	0,078125
Run 9	0,0625	0,05	0,045313	0,08125					0,071875	0,095313
Run 10	0,0375	0,0375	0,03125	0,06875					0,015625	0,059375
Run 11	0,053125	0,0375		0,05625					0,05625	0,05
Run 12	0,046875	0,023438		0,045313					0,014063	0,034375
Run 13	0,079688	0,08125		0,064063					0,035938	0,078125
Run 14	0,046875	0,0375		0,045313					0,023438	0,04375
Run 15	0,045313	0,028125		0,045313						0,023438
Run 16	0,045313	0,039062								0,014063
Run 17	0,032813	0,029688								0,014063
Run 18	0,075	0,0625								0,045313
Run 19	0,064063									
Run 20	0,107813									
Run 21	0,101563									
Run 22	0,026563									
Run 23	0,035938									
Run 24	0,03125									
Run 25	0,026563									
Run 26	0,034375									

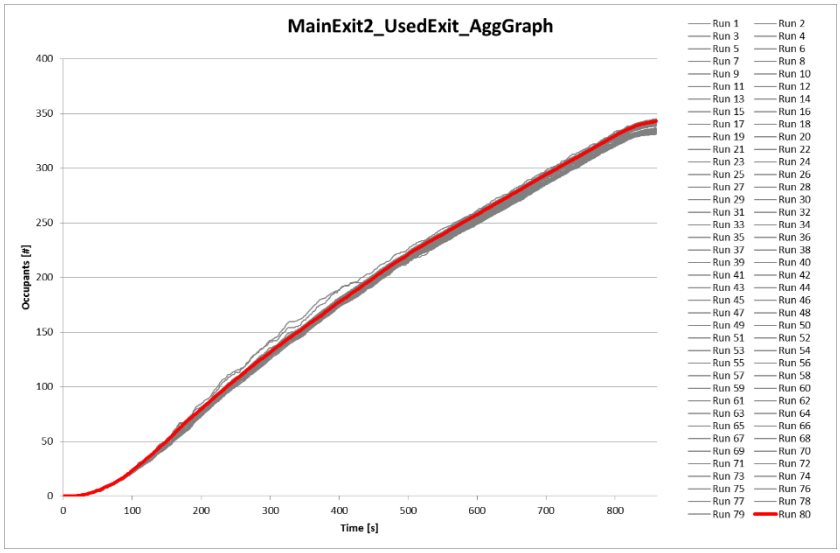
The figure below shows the compiled results.

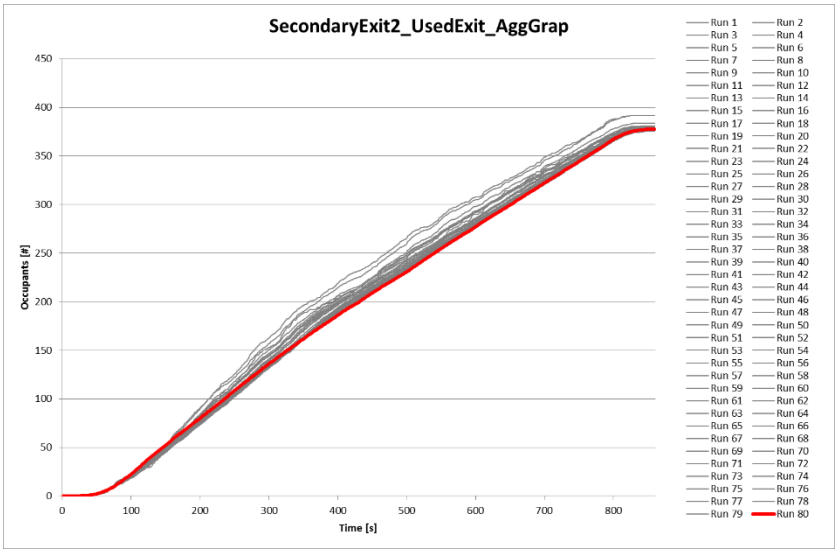
	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	31	YES	25	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	14	YES	15	YES	12
KS-test	YES	26	YES	18	YES	10	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**31**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	33
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	31	YES	41	YES	33	YES	35
YES	34	YES	30	YES	27	YES	34	YES	34
YES	12	YES	14	YES	15	YES	14	YES	13
YES	6	YES	7	YES	6	YES	14	YES	18
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**35**

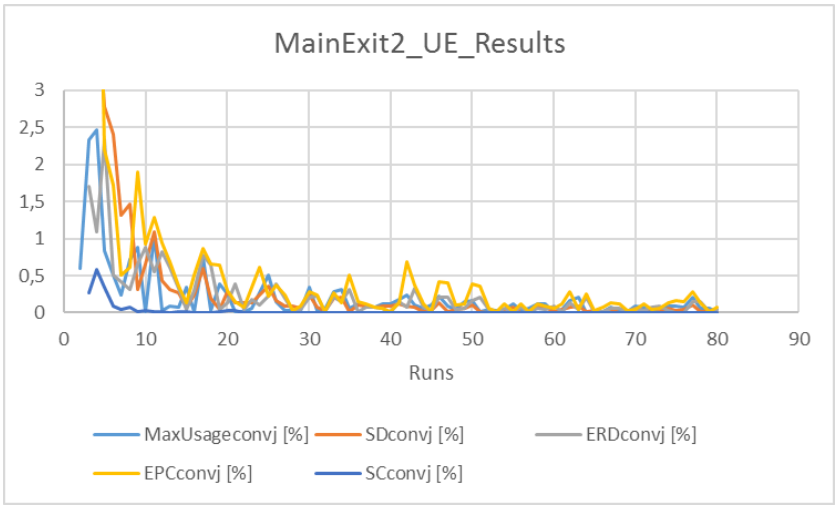
Used exit - Normalizing data points

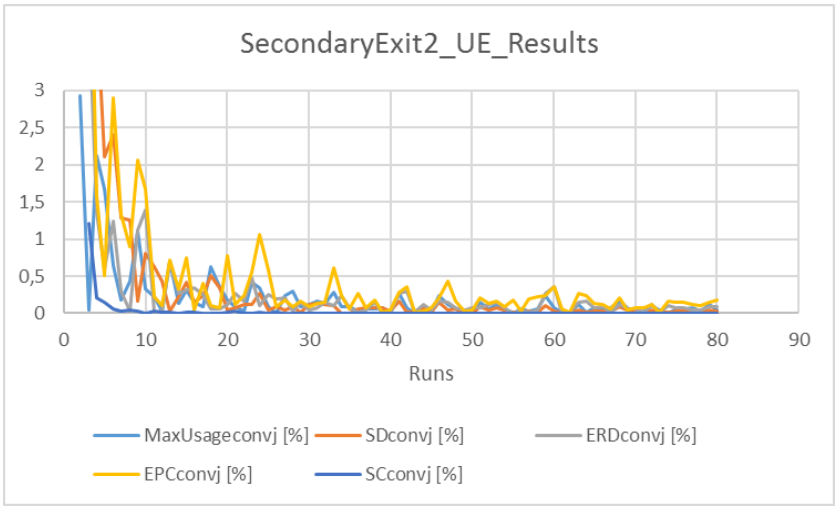
The two figures below display the graphs over the aggregated runs.





The two figures below show the results from the calculations on convergence of the five first convergence criteria.





The figure below shows the result from the calculations of the Kolmogorov-Smirnov test.

	LastStair	belowstai	MainExit1	Secondary	TET	Queuing T	Atrium_lv	Atrium_lv	MainExit2	SecondaryExit2_UE
Run 2	0,102088	0,080046	0,087007	0,12181	0,024259	0,025337	0,088167	0,048724	0,053364	0,089327
Run 3	0,168213	0,051044	0,088167	0,051044	0,007008	0,016712	0,070766	0,035963	0,066125	0,040603
Run 4	0,059165	0,062645	0,049884	0,064965	0,007547	0,014016	0,058005	0,076566	0,070766	0,082367
Run 5	0,091647	0,062645	0,061485	0,049884	0,006469	0,01186	0,047564	0,038283	0,044084	0,074246
Run 6	0,078886	0,059165	0,038283	0,034803	0,004313	0,012938	0,046404	0,041763	0,033643	0,056845
Run 7	0,032483	0,073086	0,051044	0,039443			0,048724	0,042923	0,026682	0,041763
Run 8	0,134571	0,105568	0,066125	0,052204			0,035963	0,046404	0,039443	0,051044
Run 9	0,081206	0,064965	0,033643	0,063805				0,045244	0,041763	0,062645
Run 10	0,059165	0,027842	0,024362	0,061485						0,045244
Run 11	0,037123	0,048724	0,056845	0,040603						0,038283
Run 12	0,032483	0,032483	0,023202	0,038283						0,018561
Run 13	0,027842	0,031323	0,037123	0,032483						0,046404
Run 14	0,031323	0,045244		0,033643						0,020882
Run 15	0,039443			0,026682						

The figure below shows the compiled results.

	Has convergence been met? At what run?									
	LastStair		belowstairs		MainExit1_FR		SecondaryExit1_FR		TET	
Phi	YES	45	YES	58	YES	28	YES	28	YES	44
SD	YES	30	YES	30	YES	17	YES	19	YES	19
ERD	YES	19	YES	42	YES	34	YES	17	YES	43
EPC	YES	46	YES	47	YES	19	YES	18	YES	13
SC	YES	28	YES	19	YES	15	YES	15	YES	12
KS-test	YES	15	YES	14	YES	13	YES	15	YES	6
	YES	**46**	**YES**	**58**	**YES**	**34**	**YES**	**28**	**YES**	**44**

Queuing Time		Atrium_lvl0		Atrium_lvl1		MainExit2_UE		SecondaryExit2_UE	
YES	30	YES	38	YES	42	YES	35	YES	28
YES	30	YES	18	YES	21	YES	21	YES	18
YES	33	YES	35	YES	31	YES	28	YES	23
YES	34	YES	29	YES	31	YES	21	YES	20
YES	12	YES	15	YES	15	YES	14	YES	13
YES	6	YES	8	YES	9	YES	9	YES	14
YES	**34**	**YES**	**38**	**YES**	**42**	**YES**	**35**	**YES**	**28**