Establishing a Universal Relationship between the Traffic Mix in a Building and the Stops Data

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Abstract. Previous work has used machine learning techniques to model the relationship between stops data and their locations within a building with the type of traffic mix. The methodology required knowledge of the types of floors in the building (occupant floors or entrance/exit floors), and used stops data in the up and down direction on occupant floors and entrance/exit floors to infer the mix of traffic in the building. However, previous work was based on one specific building.

This paper extends the previous work in order to show that the relationship is independent of the number of entrance floors and occupant floors. Such a universal relationship would allow the use of this derived set of equations for any building regardless of the number of floors and passenger numbers.

For this purpose, the research in this paper will employ three different sizes of buildings in terms of number of occupant floors and entrance/exit floors, as well as the variation in the car capacity (i.e., number of passengers in each round trip).

The methodology will rely on the principle of normalisation. Moreover, a Monte Carlo Simulation tool will be used to generate the data required for training the machine learning model.

1 INTRODUCTION

This paper is a continuation of a series of pieces of research that attempt to infer the type of traffic in a building based on the number and type of stops that the lift makes. The following is a historical summary:

- As a simple example, the ratio of the up stops to the down stops can be used to detect the presence of an up-peak condition [1].
- A follow-up piece of work used artificial neural networks to assess the type of prevailing traffic in the building, such as up peak, down peak, two-way traffic or off peak [2].
- The concept of attempting to infer traffic data based on the number of stops was first suggested in 1992 [3] in what was then called the I-S-P method.
- Further work on this concept was carried out in 2022 [4], whereby the tables relating the expected number of stops in the up direction and the down direction were generated based on large amounts of data generated using the Monte Carlo Simulation (MCS) method.
- Basic single-dimensional regression was used in special limited traffic cases (e.g., where incoming traffic and outgoing traffic are equal) were then used in order to try to find simple ways that can be used to find the mix of traffic based on the number of stops [5].
- Machine learning was used in [6] to arrive at the equations that allow the user to infer the three components of the traffic mix in a building (i.e., incoming, outgoing and interfloor) from the normalised number of stops in the up direction and the down direction on occupant floors and entrance/exit floors. More specifically, there are four variables related to stops (later defined in section 4): average number of stops in a round trip in the up direction on the

entrance floors (USE); average number of stops in a round trip in the up direction on the occupant floors (USO); average number of stops in a round trip in the down direction on entrance floors (DSE); average number of stops in a round trip in the down direction on the occupant floors (DSO).

This paper relies heavily on the definition of a floor in a building as either an entrance/exit floor (to be referred to later as an entrance floor) or an occupant floor [7]. The previous paper to this work [5] systematically used two-dimensional regression to find specific equations that allow the user to find the incoming traffic and the outgoing traffic percentages from the four types of stops in a round trip.

This paper attempts to make such an equation more universal by varying the building size. Section 2 generates the required data into the so-called triangular table. Section 3 provides a visualisation of the resultant surface of the normalised number of stops against the mix of traffic. Section 4 carries out the two-dimensional regression on the data and consequently introduces the two resultant universal equations. Section 5 presents the final conclusions and suggestions for further work.

2 GENERATING THE TRIANGULAR STOPS DATA

Similar to the approach followed in the previous paper [11], data for the number of stops in a round trip on average was generated using the Monte Carlo simulation method (MCS), in a method similar to what was used in [7]. This resulted in the so-called triangular data tables. These were generated for the following cases:

- A building with 2 entrance floors and 8 occupant floors. The occupant floors were assumed to have equal populations. The entrance floors have an entrance bias of 30% for the lower entrance (e.g., B1) and 70% for the upper entrance (e.g., G). The car capacity was set to 13 passengers.
- A building with 3 entrance floors and 12 occupant floors. The occupant floors were assumed to have equal populations. The entrance floors have an entrance bias of 20% for the lower basement (e.g., B2), 30% for the upper basement (e.g., B1) and 50% for the ground floors (e.g., G). The car capacity was set to 20 passengers.
- A building with 4 entrance floors and 16 occupant floors. The occupant floors were assumed to have equal populations. The entrance floors have entrance biases as follows: 10% for B3 (i.e., lowest basement); 20% for B2; 30% for B1 (i.e., the highest basement floor); and 40% for the ground floor (e.g., G).

The mix of traffic was changed in each case by a value of 10% for each of the traffic mix elements. The traffic mix elements are incoming traffic (denoted by i/c, a number between 0 and 1); the outgoing traffic (denoted by o/g, a number between 0 and 1); and inter-floor traffic denoted by i/f, a number between 0 and 1). The sum of these three numbers should always be 1 (or 100%). The number of trials was set to 1 million for each case. This resulted in three triangular tables, each with 66 entries (11+10+9+8…..+2+1=66). These three triangular tables will be used to carry out the regression (as will be seen in section 4).

As was mentioned earlier, the raw data was generated using the Monte Carlo Simulation method. The MCS method can be used to faithfully generate large amounts of round-trip data [8, 9, 10, 11]. The MCS employs random sampling methods that ensure that the resultant data is a faithful representation of the parameters of the building. The MCS methodology does not need to generate the kinematics of the lift system or produce the speed-time profiles. Moreover, it does not need to carry out any allocation of landing calls to the cars. This makes the method independent of the dispatching algorithm. But more importantly, this is an excellent example of the abstraction capability of the MCS method, where it only generates the data that is needed for the case in question, rather

than spending time generating kinematic curves or allocation calls. This approach speeds up the generation of the raw data.

3 VISUALISING THE TWELVE SURFACES

As was done in the previous paper, 12 surfaces will be visualised in this section in order to better understand the relationships, before attempting to find the final equations.

There are three independent variables: the percentage of incoming traffic, the percentage of outgoing traffic, and the percentage of inter-floor traffic. However, only two of these three are independent, as the sum of all three values must add up to 100% (or to 1.0). Thus, in reality there are only two independent variables (e.g., incoming traffic percentage and outgoing traffic percentage), as the third value will be dependent on the values of the other two. This is assuming that the inter-entrance traffic percentage is always zero.

In addition, there are four dependent variables. These are the average number of stops in a round trip. These four variables are:

- Stops in the up direction on entrance floors, to be denoted as USE.
- Stops in the down direction on the entrance floors, to be denoted as DSE.
- Stops in the up direction on occupant floors, to be denoted as USO.
- Stops in the down direction on occupant floors, to be denoted as DSO.

These four variables will appear later in this paper in the resultant two equations, but with the “hat” operator that reflects the fact that they are estimates derived from actual real-time measurements.

As there are two dependent variables, it is very convenient to plot each of the four variables as a “surface” against the two dependent variables. This results in four “surfaces” for each of the four dependent variables that have been plotted against the two independent variables. In this case, it has been assumed that the two independent variables are the incoming traffic percentage and the outgoing traffic percentage. So, in the plots that have been shown below, the x-axis and the y-axis are the incoming traffic and the outgoing traffic percentages, respectively.

Figures 1-4 all show a “triangular” surface that has been “curved”. These figures belong to the original building (2 entrance floors, 8 occupant floors, and 13 passengers in the car per round trip) that was used in [6]. In two cases, the base of the triangle is at zero, either parallel to the x-axis or parallel to the y-axis, and the upper vertex of the triangle ends up on the other side. In the two other cases, the base of the triangle is at the top, either parallel to the x-axis or parallel to the y-axis, with the vertex near zero. The limiting number of stops is the car size and the number of occupied floors. Here, the number of stops saturate at about 6.3-6.6 stops per round trip, which is about 78.8%-82.5% of the number of occupied floors.

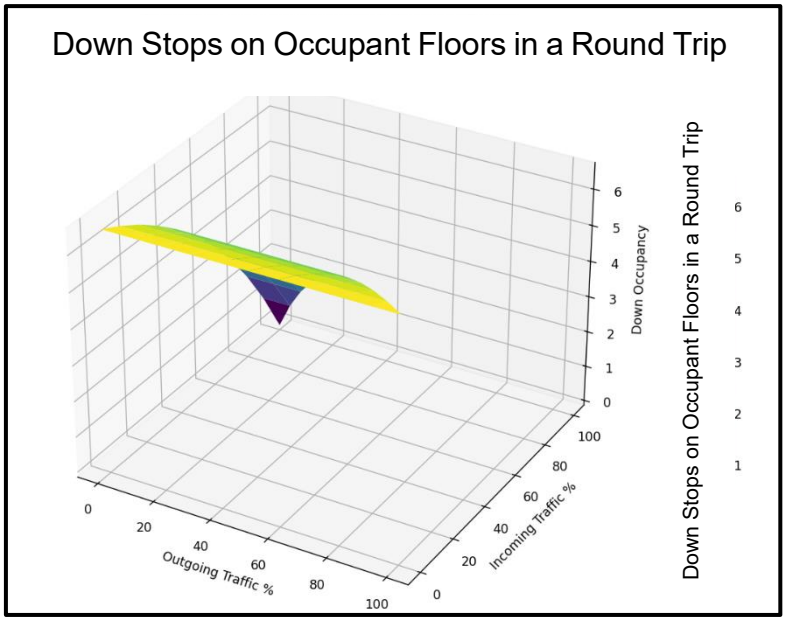


Figure 1 The plot of the surface that shows the number of down stops on the occupant floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage

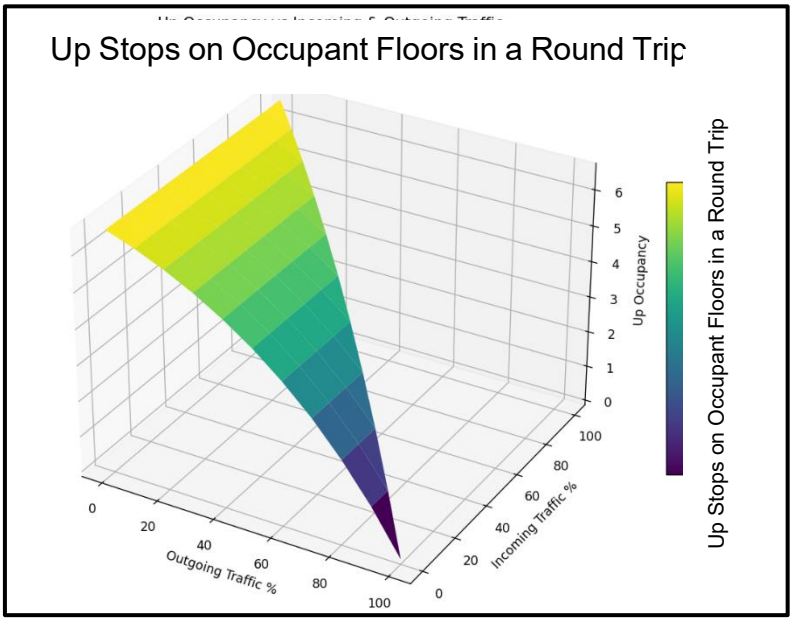


Figure 2 The plot of the surface that shows the number of up stops on the occupant floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage

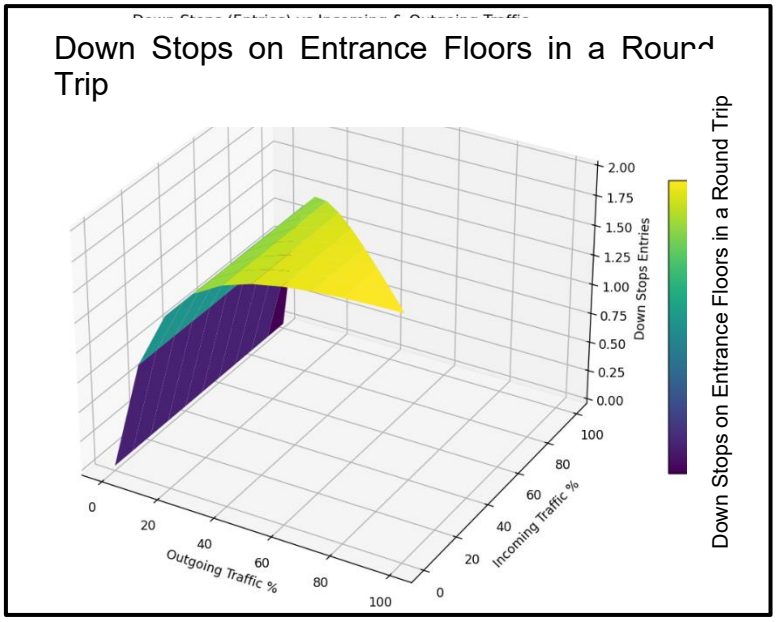


Figure 3 The plot of the surface that shows the number of down stops on the entrance floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage

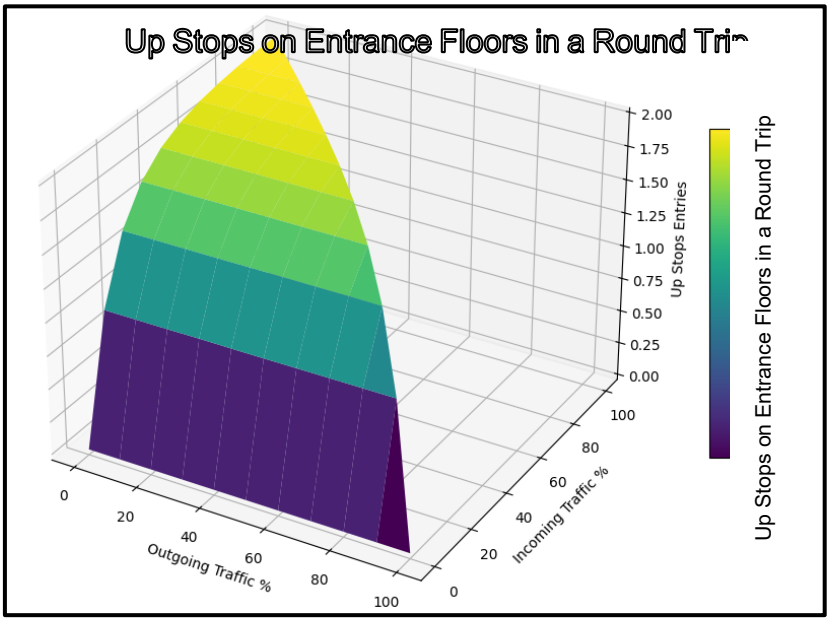


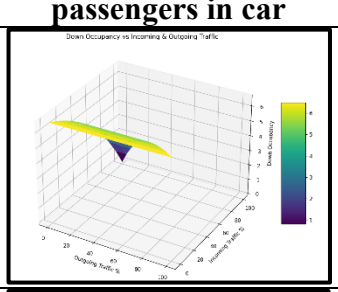
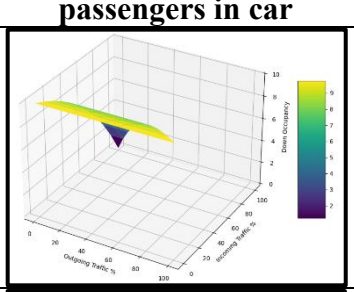
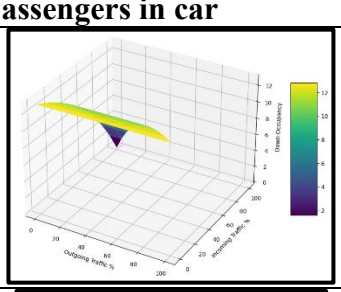
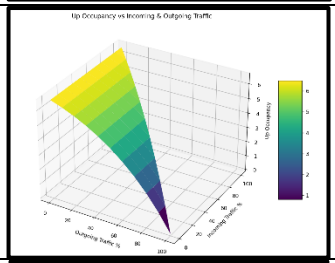
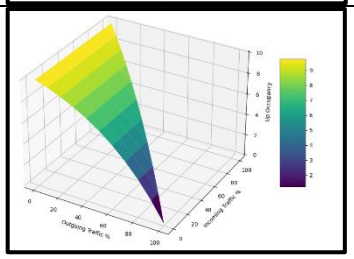
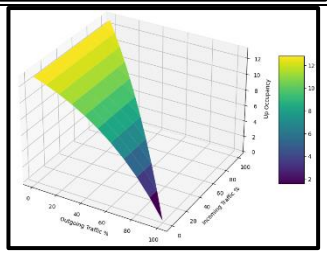
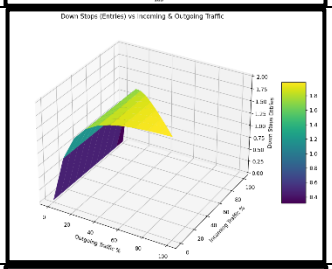
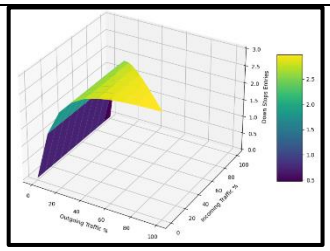
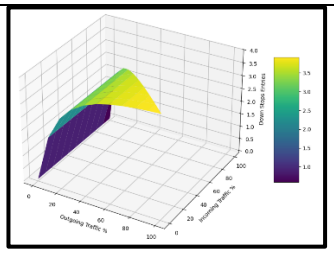
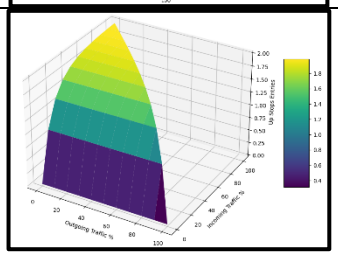
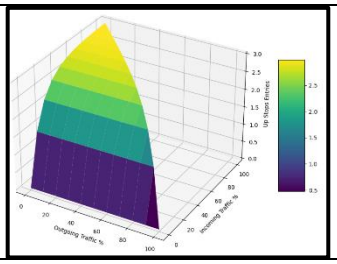
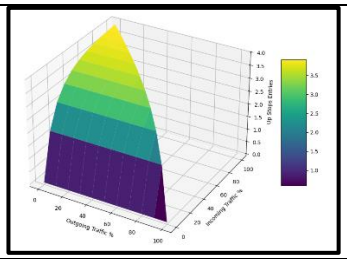
Figure 4 The plot of the surface that shows the number of up stops on the entrance floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage

It is also worth noting that the z-axis in all four cases (i.e., the average number of stops in a round trip) has not been normalised and has been shown in absolute number of stops. Using further processing (as will be seen in the next section), the number of stops can be normalised by dividing by the maximum possible number of stops in the entrance floors (in this case 2) and by dividing by the maximum number of stops in the occupant floors (in this case 8). This will produce a "cube" that is normalised and in which each of the three sides is equal to 1 (or 100%).

These plots have been extended to another two sizes of buildings. In addition to the original building (2 entrance floors, 8 occupant floors, and 13 passengers in the car per round trip), two buildings were added: one with 3 entrance floors, 12 occupant floors and 20 passengers per car in a round trip; and a building with 4 entrance floors, 16 occupant floors and 26 passengers per car in a round trip. The set of 12 figures is shown in Table 1 below. It is worth noting that, for the purposes of normalisation, the number of passengers in the car was increased proportionately with the increase in the number of floors in the buildings (13 passengers for a total of 10 floors; 20 passengers for a total of 15 floors; and 26 passengers for a total of 20 floors: a ratio of around 1.3 passengers for every floor of the building).

By examining the 12 figures for the 3 buildings, it is obvious that the figures are nearly identical for the variables DSO, USO, DSE and USE. This shows that the characteristic of universality is valid. The behaviour of the normalised number of stops as a function of the mix of traffic in a building seems to be repetitive regardless of the size of building.

Table 1 Twelve figures showing the curved surfaces for the three buildings

	2 entrance floors/8 occupant floors/ 13 passengers in car	3 entrance floors/12 occupant floors/ 20 passengers in car	4 entrance floors/16 occupant floors/ 26 passengers in car
DSO			
USO			
DSE			
USE			

4 TWO-DIMENSIONAL REGRESSION RESULTS

As was done in the previous piece of work, MATLAB, two-dimensional regression tools were used in order to find the best fit equation that allows the user to find the percentage of the incoming traffic (i/c), the percentage of outgoing traffic (o/g), and the percentage of the inter-floor traffic (i/f) based on the four types of stops that take place on average during a round trip. The equations below were developed using two-dimensional regression tools. It is worth noting that these equations use the normalised values of the stops data, by dividing the average number of stops in a round trip by the maximum number of possible stops (i.e. the number of floors). The following is a list of the variables used in the equations below:

- i/c: incoming traffic (number between 0 and 1).
- o/g: outgoing traffic (number between 0 and 1).
- i/f: inter-floor traffic (number between 0 and 1).
- USE: The average number of up stops on the entrance floors in a round trip, normalised by dividing it by the number of entrance floors in the building.
- USO: The average number of up stops on the occupant floors in a round trip, normalised by dividing it by the number of occupant floors in the building.
- DSE: The average number of down stops on the entrance floors in a round trip, normalised by dividing it by the number of entrance floors in the building.
- DSO: The average number of down stops on the occupant floors in a round trip, normalised by dividing it by the number of occupant floors in the building.

Varying the number of floors (and fixing the ratio of passengers to floors) and carrying out the regression has resulted in the coefficients shown in Table 2 below.

Table 2 Coefficients that result from the regression analysis

	Number of Entrance floors	Number of Occupant floors	Number of passengers in the car	Constant	Up stops, Entrance floors (USE)	Down stops, entrance floors (DSE)	Up stops, occupant floors (USO)	Down Stops, Occupants floors (DSO)
Incoming Traffic Percentage	2	8	13	85.1098	22.0421	1.6454	3.4023	-109.0788
	3	12	20	85.7038	22.0810	1.7499	3.7070	-109.8847
	4	16	26	83.9512	23.6487	1.7416	3.2794	-109.1081
			Average	**84.9216**	**22.5906**	**1.7123**	**3.4629**	**-109.3572**
	Number of Entrance floors	Number of Occupant floors	Number of passengers in the car	Constant	Up stops, Entrance floors (USE)	Down stops, entrance floors (DSE)	Up stops, occupant floors (USO)	Down Stops, Occupants floors (DSO)
Outgoing Traffic Percentage	2	8	13	85.0430	1.8327	21.8450	-109.2628	3.7193
	3	12	20	85.6942	1.7356	22.0933	-109.8515	3.3576
	4	16	26	83.9551	1.7384	23.6424	-109.1039	3.2824
			Average	**84.8974**	**1.7689**	**22.5269**	**-109.4061**	**3.4531**

Doing the regression using the average values of the coefficients from the three buildings resulted in the two equations shown below. The variables USE, DSE, USO and DSO are the same variables defined on page 3 earlier in this paper, but the "hat" sign added here refers to the fact that the values in the equation are estimates. The first is the resultant regression equation to find the value of the incoming traffic:

$$i/c = \mathbf{84.9216} + \mathbf{22.5906} * \widehat{USE} + \mathbf{1.7123} * \widehat{DSE} + \mathbf{3.4629} * \widehat{USO} + (\mathbf{-109.3572}) * \widehat{DSO} \quad (1)$$

The second equation is the resultant regression equation to find the value of the outgoing traffic:

$$o/g = \mathbf{84.8974} + \mathbf{1.7689} * \widehat{USE} + \mathbf{22.5269} * \widehat{DSE} + (\mathbf{-109.4061}) * \widehat{USO} + \mathbf{3.4531} * \widehat{DSO} \quad (2)$$

The correlation coefficient from the two regression analysis results is very high and nearly close to one, showing an excellent correlation between the number of stops and the mix of traffic parameters:

i/c equation: R^2 Score: 0.990461

o/g equation: R^2 Score: 0.990467

Obviously, as the inter-entrance traffic has been assumed to be equal to 0, the inter-floor traffic can be found by subtracting the incoming traffic and the outgoing traffic from 1, as shown below:

$$i/f = 1 - i/c - o/g \ldots\ldots\ldots\ldots (3)$$

For example, if we know that incoming traffic is equal to 10% and the outgoing traffic is equal to 30%, then the interfloor traffic would be equal to 1-0.1-0.3 = 0.6= 60%.

It is worth noting that this methodology has assumed the inter-entrance traffic is always zero for simplicity. Future work will remove this constraint and allow the inter-entrance traffic to take on non-zero values. However, in such a case, the number of independent variables will rise to three (e.g., incoming traffic, outgoing traffic, and inter-floor traffic that does not add to one, as the inter-entrance traffic will not be equal to zero in this case). As such, it will not be possible to visualise the resultant "hyper-surface", because it will have four dimensions. Nevertheless, the fact that it cannot be visualised does not prevent finding the equation that links the mix of traffic to the value of the four types of stops. In such a case, three equations will be found for the incoming traffic, outgoing traffic and the inter-floor traffic. The inter-entrance traffic will be found by simply subtracting the three resultant values of traffic from 1.

5 CONCLUSIONS AND FURTHER WORK

This paper has attempted to build on previous work that explored the relationship between the normalised number of stops in the up direction and down direction on occupant floors and entrance/exit floors and the mix of traffic in a building (incoming traffic; outgoing traffic; interfloor traffic). This paper has further developed this work by attempting to show that such a relationship is universal.

The previous work developed the equations for one building only (namely 2 entrance floors; 8 occupant floors; and 13 passengers in the car per each round trip). This paper carried out the same analysis on two additional buildings: the first building had 3 entrance/exit floors, 12 occupant floors, and 20 passengers in the car for each round trip; the second building had 4 entrance/exit floors, 16 occupant floors, and 26 passengers in the car for each round trip.

Two dimensional regression was repeated for the relationship between the mix of traffic (namely for the incoming traffic percentage, a number between 0 and 1; and for the outgoing traffic mix, a number between 0 and 1) and the four types of stops (normalised stops in the up direction on occupant floors; normalised stops in the down direction on occupant floors; normalised stops up direction on entrance/exit floors; and normalised stops in the down direction on entrance/exit floors). All of these variables were normalised before applying the regression to them, in order to ensure that universality is found, assuming that it exists. Normalisation was carried out by dividing each of the stop variables

by the corresponding number of floors in the building (e.g., the number of stops in the up direction on the occupant floors divided by the number of occupant floors in the building).

The results of the two-dimensional regression showed excellent similarity between the coefficients of the two equations (one equation to evaluate the value of the incoming traffic; one equation to evaluate the value of the outgoing traffic) with an extremely high value of the correction coefficient. The average of the four coefficients from the three sizes of buildings was suggested as the basis for the two universal equations.

There was no need to evaluate an equation for the interfloor traffic as it has been assumed that the inter-entrance traffic was always zero. Thus, the value of the interfloor traffic (a number between 0 and 1) could be simply found by subtracting the incoming and the outgoing traffic values from 1.

The next pieces of research will concentrate on the following:

- It is worth mentioning that as the building size was increased, the number of passengers in the car was increased by the same ratio. Thus, it is important to further understand the effect of the variation of the number of passengers in one round trip (i.e., the car size) on the coefficients of the two equations when such a ratio is varied.
- Applying the equations in practice on simulated data to assess the effectiveness of the method in finding the mix of traffic in a building based on real-time stops data.

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BIOGRAPHICAL DETAILS



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Eng. Tahani Ghobon has been working as a teaching assistant at the Electrical Engineering Department at Al Hussein Technical University (HTU) for the last 6 years. She completed her undergraduate degree in electrical engineering (Electrical Power) from the Jordan University of Science and Technology (JUST). Eng. Tahani has vast experience in the area of Machine Learning and its applications in electrical engineering applications.



Richard Peters has a degree in Electrical Engineering and a Doctorate for research in Vertical Transportation. He is a director of Peters Research Ltd. He has been awarded Fellowship of the Institution of Engineering and Technology, and of the Chartered Institution of Building Services Engineers. Dr Peters is the principal author of Elevate, elevator traffic analysis and simulation software.



Matthew Appleby is a software engineer at Peters Research Ltd. He is involved in project managing the new Elevate Online and leads front-end development. He joined Peters Research in 2019 and graduated with a first-class (Hons) degree in Software Development in 2024.