THE ETP METHOD: DERIVING PASSENGER NUMBERS FROM ESCALATOR ENERGY CONSUMPTION

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ABSTRACT

This paper investigates the relationship between the number of passengers using the escalator and the power it consumes.

Seven high usage escalators (of all types of rises) have been selected for this study to investigate the relationship between power and passengers. One day surveys were carried out on each escalator. Passengers boarding or alighting were counted in one minute intervals, at the same time that a power monitoring unit was connected to the motor of the escalator to record the average power and power factor in one minute periods corresponding to the same minutes as those of the passenger counts.

The resulting data was used to find the fixed losses (i.e., the power consumed with no passengers being carried) in relation to the escalator rise in metres. A general method for calculating the fixed losses on any escalator has been outlined.

1. INTRODUCTION

When escalators are running unloaded they need some power to overcome friction in the step-band and the handrail; and inefficiencies in the motor and the gearbox. This power is referred to as fixed losses (or overheads, in analogy to overheads in a business or a factory which are not used to produce any tangible product or service; only to keep the business or the factory going and to support other functions). It is known that there is a relationship between the rise of the escalator and these fixed losses, although the exact nature is still not understood.

As passengers start boarding the escalator, the power consumed starts to rise if it is an up going escalator, or to drop if it is a down going escalator. The power needed to move passengers is termed as variable losses or variable power (in analogy to the variable costs of producing products in a factory, which will be sold and will create a revenue). Again, there is a relationship, although not yet fully understood between the number of passengers on an escalator and the variable loss or power it is consuming.

So, in addition to the fixed losses in an up moving escalator, it is imparting energy to the passengers (variable losses) and thus is consuming power. Thus, the total power consumed is equal to the summation of the power needed to move the passengers between levels to the power needed to overcome the friction within the escalator.

On the other hand, a down moving escalator, is recovering the potential energy stored in the passengers. The total energy consumed by a down moving escalator is the difference between the fixed losses and the energy recovered from the passengers. As passenger loading progressively increases on a down going escalator, the escalator gets to a point where it is consuming no power at all, because it is driven by enough passengers to generate power equal to the losses needed to drive it at no load. As passenger loading further increases, the escalator starts to feed power back into the main supply (i.e., regenerate). This crossover point depends on the level of fixed losses, and the reverse efficiency of the gearbox.

2. PREVIOUS WORK CARRIED OUT

Similar previous work has been carried out in 1993 (Al-Sharif, 1995), but was not conclusive. The escalator discussed in that study had an AC Schrage motor, with a rise of 15 m used by a small number of passengers per day. A three phase power recorder was installed, and was set up to take an average measurement of real power and power factor for a period of several days. The sampling time for the power recorder was set to one average sample every 30 minutes (i.e., the recorder recorded the average value of the real power every 30 minutes, as well as the average value of the power factor).

At the same time, a piezoelectric sensor had been fitted to the comb plate of the same escalator as part of another project. This comb-plate sensor showed the horizontal and vertical forces on the comb-plate, and thus gave a good representation of the movement of passengers on and off the escalator.

The combination of these two devices (i.e., the power monitor and the comb-plate force sensor) on the same escalator presented an excellent opportunity to find some relationship between passengers and power consumed. Unfortunately, the power measurements and the comb-plate measurements were not carried out on the same days.

The data from the comb-plate was analysed to get the number of passengers using that escalators on a number of different days. The data was grouped by the number of passengers transported in 30 minute intervals to match the sampling frequency of the power monitor. A pattern emerged which showed the number of passengers using the escalators.

The passenger traffic patterns for two different days were compared with the power monitor recording patterns for another two different days. The similarity was quite high, although the measurements were taken on different days in consecutive months. In order to quantify that similarity, the correlation coefficient (Spiegel, 1961; Pindyck *et al*, 1981) was found between the two waveforms. This showed positive correlation coefficients as high as 0.93 and above.

The study also derived the general formula for converting between the number of passengers transported in a period of time, and the energy consumed in the same period of time, based on an assumed average passenger mass of 75 kg. Using this formula it derived the calculated number of passengers from the power data, and compared the resulting patterns to the measured passenger patterns from the comb-plates.

However, that study was not conclusive because of the low intensity traffic and the long smampling period. The work described here differs mainly in that the passengers have been counted manually, and in that the sampling period is much smaller (1 minute in this study as compared to 30 minutes in the 1993 study). This smaller sampling period allows more accurate interpretation of the results, and shows more clearly any regeneration which takes place even if it lasts for one or two minutes. Larger sampling periods tend to wipe out any variations around the mean, and thus tend to mask any extreme values which, although are a deviation from the mean, are important in understanding the changes in a variable. For these reasons a smaller sampling period was taken in the surveys described in this paper and higher usage escalators were selected.

3. METHOD OF MEASUREMENT AND PASSENGER SURVEY

The types of escalators selected for this study included AC and DC escalators.

As for DC machines, the measurement unit was connected through an isolator to the DC traction supply (nominal 630 V) and another input to the unit was connected to a calibrated shunt inserted in the path of the DC current. The unit internally multiplied the current and voltage and recorded the power consumed, along with the DC voltage.

The recorded value is the *average for the whole minute* and not an instantaneous value.

The passenger surveys were only carried out at one end of the escalator (either the top or bottom depending on the physical constraint). The more accurate, but more complicated, alternative would have been to have one team at the top and one team at the bottom, and subtract their counts to find the actual number of people on the escalator at each point in time. This was deemed too complicated, and the benefits of such accuracy were outweighed by the complication. Moreover, a one minute sampling interval was deemed sufficient to give good accuracy, as opposed to the original proposition of using a 30 second interval.

All surveys were carried out on weekdays, so that the results will be more representative of the usual traffic, and in order to be able to give reasonably accurate annual energy costs.

3.1 The seven escalators used in the study

The seven escalators, with their categories, rise and usage are shown in Table 1. LR stands for low rise, MR stands for medium rise and HR stands for high rise; HU stands for high usage (i.e., used by a large number of passengers per day).

Table 1: Selection of seven escalators used in this study (N.B.: U and D stand for up and down).

Category	Escalator	Rise (m)	Usage (pass/day)
MR/HU	A	14.630	27825 (U)
MR/HU	B	14.630	27825 (U)
MR/HU	C	14.630	52622 (D)
LR/HU	D	7.623	22456 (U)
LR/HU	E	7.623	24910 (D)
HR/HU	F	17.221	12179 (U)
HR/HU	G	17.221	17696 (D)

4. FIXED LOSSES

The fixed losses are the energy losses used to keep the escalator running with no passengers on. They mainly depend on the rise of the escalator, and partially on the mechanical system. Two method for deriving them for a specific escalator have been developed, termed A and B (Al-Sharif, 1996a). As a general rule, the fixed losses in kilowatts are equal to half the rise in metres plus two kilowatts.

5. CORRELATION BETWEEN POWER AND PASSENGERS: THE ETP METHOD

In the last section, fixed losses were discussed and related to the rise of the escalator. In this section at the variable power losses of the escalators as they are boarded by passengers are discussed, along with the method of predicting these losses from the numbers of passengers or vice versa.

5.1 Introduction to the concept of correlation

The use of correlation coefficients is a powerful tool, which ascribes the change of one variable to the change of another. The coefficient of correlation or determination as it is sometimes called (Spiegel, 1961, p243), is "the ratio of explained variation to the total variation of the dependent variable" (i.e., variable y on the scatter diagram).

$$r = \pm\sqrt{\frac{Explained\ Variation}{Total\ Variation}} \quad \ldots . A$$

A correlation coefficient between two variables near one shows a direct high dependence between them, while a negative value near -1 shows high inverse dependence. A value near 0 shows that no relationship exists between the data.

5.2 Relationship between passenger numbers and power consumed

In this sub-section, the details of the relationship between the passenger numbers and the variable power losses are discussed. The concept of correlation, described in the last sub-section, is used as a tool to show the dependence between the two variables.

When discussing the passenger numbers, two variables can be used:

- The number of passengers moved between the two levels in a period of time t (n_t), or...
- The number of passenger on an escalator at any point in time, termed instantaneous passengers (n_i).

Some of the scatter diagrams between power and passengers are shown below.

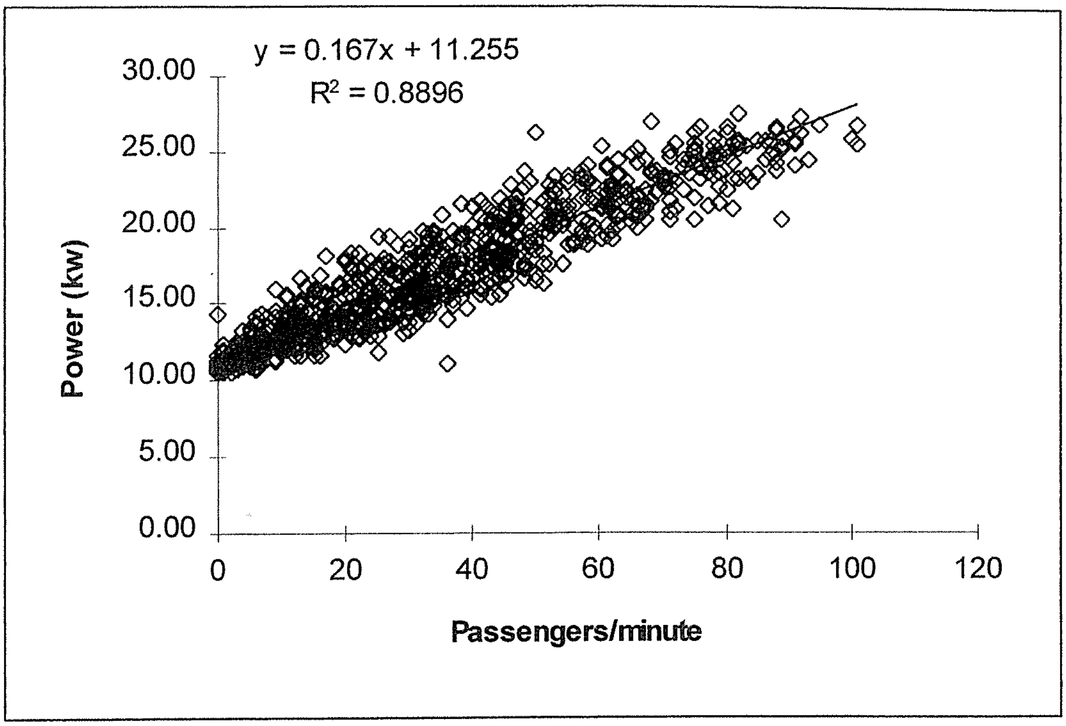

Figure 1: Scatter diagram for escalator A.

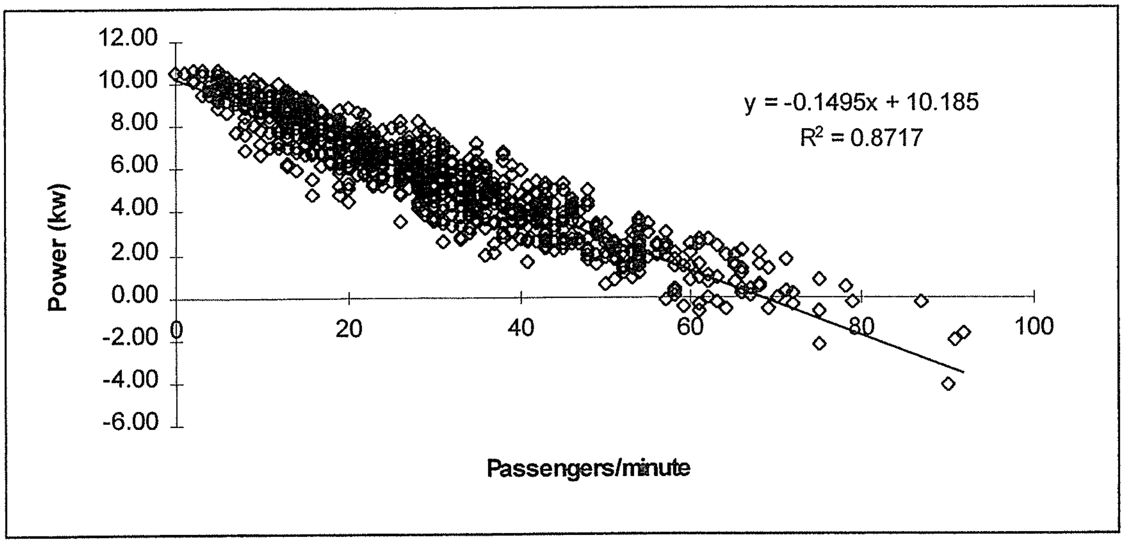

Figure 2: Scatter diagram for escalator G.

The correlation coefficients between the power and passengers for all seven escalators have been derived and are shown in Table 2. Negative correlation coefficients occur for down moving escalators, while positive coefficients occur for up moving escalators.

Table 2: Correlation results for all seven escalators between power and passengers.

Escalator	Direction	Correlation
A	U	0.9431883
B	U	0.924314
C	D	-0.9418555
D	U	0.9016531
E	D	-0.9685938
F	U	0.6163523
G	D	-0.93366

Figure 3 summarises the results arrived at in this and the last sub-sections. It shows the general behaviour of an escalator being progressively loaded with passengers, and how its power consumption varies in the cases when it is run in the up direction or the down direction.

The two most important points are the fixed losses point, which is the same for an up escalator and a down escalator, and is approximately found by using the equation derived in Al-Sharif (1996a).

$$\text{Fixed losses} = 0.55 \times \text{rise} + 1.95 \ldots (B)$$

If we assume that the escalator runs for 20 hours per day, then the total losses per day in kWhr, will be:

$$\text{Fixed losses (kWhr per day)} = (0.55 \times \text{rise} + 1.95) \times 20 \ldots (C)$$

The fixed losses represent the losses incurred with no passengers transported. The other important point is the one at which regeneration starts (which I have termed the crossover point), and represents the point where the escalator does not draw or return any power to the mains.

The formula for the crossover point is shown on the figure, and is initially based on the formula in Al-Sharif (1996a). However, when comparing the formula to the practical results obtained, a correction factor had to be used to correct the formula.

This factor is shown as the 1.43 in the figure, and is caused by the number of passengers who walk up or down an escalator. Passengers walking up an escalator for example, are spending less time on the escalator, and thus the energy to move them up the escalator comes partly from the escalator motor, and partly from the muscles. This factor of 1.43 is important and will re-occur in this paper, sometimes as its inverse, 0.70 (1/1.43=0.7). [For more details on this walking factor, see Al-Sharif, 1996b.]

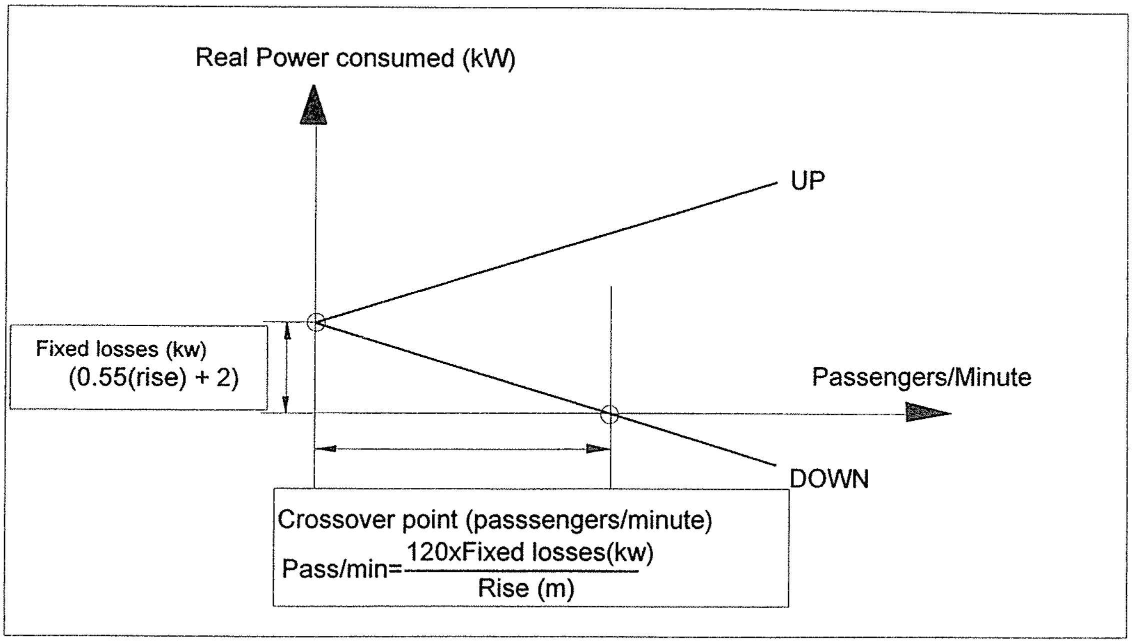

Figure 3: Diagram which shows the general relationship between passengers transported and power consumed.

Figure 3 is quite an important graph, as it summarises most of the information needed to find the power characteristics versus passengers for both up and down escalators.

6. APPLICATIONS OF THE METHOD (THE ETP METHOD)

The method of converting passenger numbers into power consumed or converting power drawn into passenger numbers (called the ETP method, Energy To Passengers) can be used to derive the number of passengers from the energy consumption of escalators on an Underground station.

6.1 Derivation of instantaneous passenger flow in stations

The ETP method can be used for converting the power drawn by a machine to the number of passengers transported in a period of time. To illustrate this application, a plan of an Underground station has been shown with all the escalators in Figure 4. Fictitious passenger flow rates (in passengers/minute) have been shown on the diagram.

The method could be applied successfully to derive the passenger flow rates on the station in real time as they are happening, just by measuring the power drawn by each escalator, and communicating this to a central point. By looking at the numbers in the whole station, other flow rates on stairs for example could be derived. This could be used to study bottlenecks on the station and problems of flow.

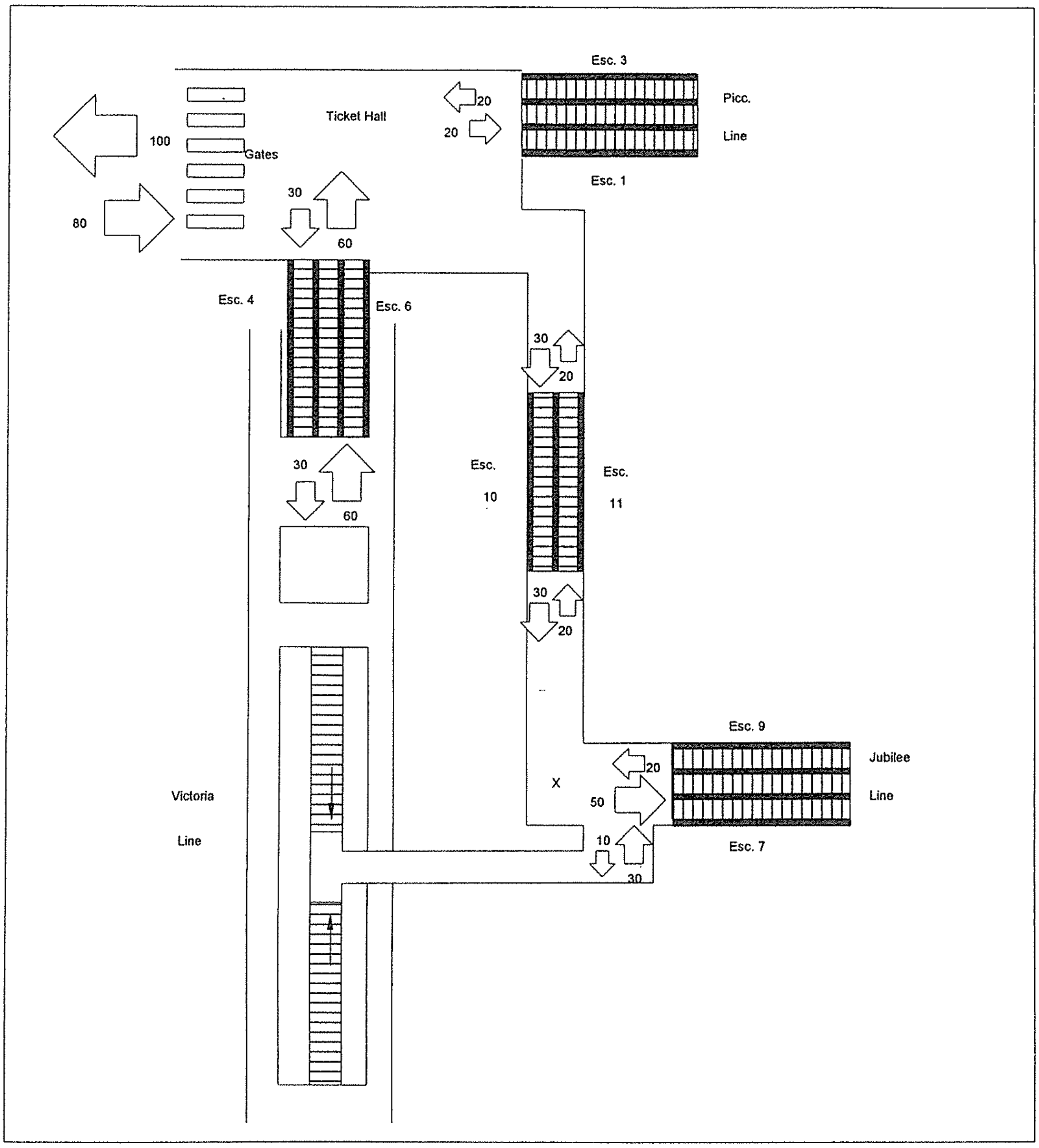

Figure 4: Plan of Green Park Station, showing fictitious passenger flows (in passengers per minute).

The method can also be applied to derive the complete passenger flow traffic pattern for the full day from the power consumption measurement, as has been shown previously (Al-Sharif, 1995).

6.2 Calculation of energy consumption from passenger numbers

By counting the number of passengers travelling on an escalator, it is possible to estimate the energy consumed by the escalator. This is based on the fact that the fixed losses of a machine can be found from the equation derived earlier, which relates the rise of the escalator to the power it draws. This represents the power it will draw if it was not loaded with passengers. As for the variable losses, they are proportional to the number of passengers moved in a day and the rise of the escalator.

The steps for calculating the energy consumption:

- The fixed losses are calculated for the escalator based on the equation derived in this paper (fixed losses are proportional to rise (in m) plus a fixed amount; an estimate of this equation is that the fixed losses in kW are equal to half the rise in metres plus 2 kW). The total fixed losses in kWh are found by multiplying the fixed losses in kW by the number of hours in a day (running hours: 20 hours).
- The next step is to calculate the variable losses, by using the number of passengers and the rise of the escalator. The variable losses in kWh in a day will be equal to the number of passengers multiplied by 9.81 m/s^2, multiplied by the mass of one passengers multiplied by the rise of the escalator. This will give the energy consumed in Joules. However, the unit of Joules is very small to measure demand.

  $$ar.\ losses(kWhr\ per\ day) = \frac{No.\ of\ \ pass. \times 9.81 \times rise \times 75}{3600 \times 1000} \times K \ldots (D)$$

  ...where the division by 3600x1000 is to convert from Joules to kWhr, 75 is the average mass of a passenger (75 kg) and 9.81 m/s^2 is the acceleration due to gravity. K (around 0.7) is a correction factor found in practical measurements, caused by the fact that some passengers walk up the escalator and thus do not consume as much energy as expected.
- The total power consumed for a day is the sum or the difference between the fixed losses and the variable losses (depending on whether the escalator is running up or down, respectively).
- The number of kWh per day is multiplied by the number of operating days in a year (this assumes that a weekend is the same as a weekday, which might not be true).

7. CONCLUSIONS

The following conclusions can be drawn from the paper:

- When an escalator is running up or down empty, the energy it consumes is termed fixed losses. Two methods are available, termed method A and B, for calculating these fixed losses for a specific escalator. The main factor in deciding losses is the rise of the escalator, and the fixed losses are nearly equal to half the rise in metres plus two kilowatts.
- As passengers start boarding the escalator, the escalator starts consuming or regenerating additional power termed variable losses or variable power. It has been shown that there is a very high correlation between these variable losses and passenger numbers. Correlation coefficients as high as 0.93 have been calculated.
- A moderately loaded down escalator will get to a point where it is not consuming any power from the supply. This point has been termed the crossover point. At passenger levels above this point, the escalator will start sending energy back into the mains. This will take place, at a passenger flow rate (passenger/minute) of nearly 120 multiplied by the

fixed losses and divided by the rise in metres. This can be used as a rule of thumb to find out when an escalator will start regenerating.

- The high correlation found between passenger numbers and energy consumed can be used as a method for converting from one to the other. If power is measured continuously on all escalators on a station, this could be used as a powerful tools for traffic recording and analysis for station capacity studies.

BIOGRAPHICAL NOTES

The author graduated in electrical engineering in 1987, and then worked as an electronic design engineer for lift logic and speed controllers for two years. He received his M.Sc. in 1990, his Ph.D. in 1992 from UMIST, and his D.B.A. from the University of Westminster in 1995. He joined London Underground in the Lift & Escalator Department in 1992, and is currently Team Leader for Lift Projects and Electrical Design. He writes regularly in Elevatori, Elevation and Lift Report, and is a Chartered Electrical Engineer.

REFERENCES AND BIBLIOGRAPHY

Al-Sharif, L.R., 1995, "The use of power measurement to calculate the number of passengers travelling on an escalator", Lift Report, Issue 2/96.

Al-Sharif, L.R., 1996a, "Lift and escalator energy consumption, Part I: The relationship between escalator power consumption and escalator handling capacity (The ETP method)", January, 1996, Internal report, London Underground, number LE-RP-5007.

Al-Sharif, L.R., 1996b, "Escalator handling capacity: Standards versus practice", Elevatori, 4/96, 5/96.

CEN, 1995, "Safety rules for the construction and installation of escalators and passengers conveyors", EN 115: January 1995.

Fruin, J.J., 1987, "Pedestrian planning and design", Revised Edition, 1987, Elevator World, Inc., Educational Services Division.

London Underground Ltd., 1995a, "Escalator energy consumption survey power measurement", D696 LE-SP-0300 R2, November 1995.

London Underground Ltd., 1995b, "Escalator energy consumption survey and associated passenger counts", D696 LE-SP-0302 A1, November 1995.

London Underground Ltd., 1995c, "LUL station planning guidelines", April 1995.

Pindyck, S.R. & Rubinfeld, D.L., 1981, "Econometric models and economic forecasts", McGraw Hill International Editions, Second Edition, 1981.

Spiegel, M.R., 1961, "Theory and problems of statistics", Schaum's Outline Series, McGraw Hill Book Company, 1961.