ASSET MANAGEMENT OF PUBLIC SERVICE ESCALATORS

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ABSTRACT

Public service escalators are vital to the continued operation of public service terminals (e.g., airports, railway stations). The traffic profiles are characterised by heavy traffic flows, occurring in surges which coincide with the type of traffic that they serve (e.g., surge of passengers from trains; surge of passengers in an airport). For these reasons, it is important to understand and analyse their availability and reliability, in order to be able to predict future performance, and identify gaps in maintenance or design.

The paper starts by discussing the differences between standard escalators and public service escalators, which are dominantly heavy duty. It outlines the differences in the operating environment and the higher performance requirements for the public service escalators and how these necessitate a different design.

The paper then discusses the asset management process for these escalator, as applied in a public transport context. Six stages are involved in asset management cycle: Data gathering, analysis of relationships and trends, modelling, developing a plan, appraisal of the options and implementation. The cycle is a continuously iterative one, and the process keeps on repeating to keep up to date with any new developments.

The paper discusses each of these stages in detail, outlining a general methodology for data gathering, and how appraisal is used in different applications.

1. INTRODUCTION

For businesses whose products or services depend to a large extent on physical assets, management of those assets was already an important activity in ensuring their success. Today, more pro-active asset management is becoming a very important tool in planning asset expenditure and performance. It offers the following advantages to the Asset Manager and the Operator:

- It allows the prediction of the performance of the assets in the future.
- It allows the Asset Manager to predict the future capital expenditure and operational expenditure required to meet future performance levels.
- It allows both the Operator and the Asset Manager to see the effect of varying certain critical parameters and assumptions.
- It helps the appraisal of various options and the selection of the best value for money option.

Banyard & Bostock (1998) give an overview of how the asset management process is being applied in the water service industry. This paper attempts to give a similar overview of how this process might be applied to public service escalators in general, and it is based on the experience within London Underground. Al-Sharif (1998a) contains a more detailed overview of this process.

Figure 1 is a diagrammatic overview of the stages of asset management. The first stage involves identifying and gathering the necessary data about the assets. The second stage involves analysing this data for trends and relationships. The third stage involves building a model of the behaviour of the system. The fourth step involves developing a plan of what is to be done and when, based on the outcome of the previous steps. This is further developed in the next stage, which involves appraising all the options available and selecting the best value for money option. The last stage is the implementation of the plan.

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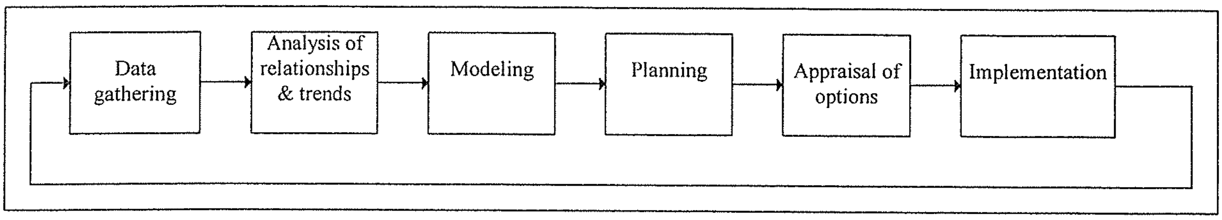

Figure 1: The asset management cycle process.

It is worth noting that this is not a one pass process, but a continuous one, which is based on more data coming in during implementation, thus producing a refinement in the analysis of data and possibly adjustment to the plan. Only by having a truly live and dynamic plan, responding to changes in operational requirements and to changes in the environment, could this asset management system be of use to the Operator and Asset Manager.

The implementation stage is effectively a project management activity. Although this has strong links to the previous stages in terms of planning and data feedback, it has been deemed to be outside the scope of this paper and thus has not been discussed.

Before discussing these stages in detail, the next section give a brief introduction to the concept of heavy duty escalators, and the reasons why they are usually selected for public service applications.

In this paper the two terms: Operator and Asset Manager are used, and are defined as follows. The Operator is the operating company which runs the public service and defines the level of performance required of the asset. The Asset Manager is the contractor responsible for planning and carrying out the maintenance and replacement works for the assets.

2. HEAVY DUTY ESCALATORS

The public service escalator is an expression used to describe escalators used in main transport terminals, which form part of the passengers' journey and are more heavily used than the standard escalators used in shopping centres. The term is also used within the European standard for escalators and passenger conveyors (CEN, 1995). They are sometimes referred to as heavy duty escalators, as opposed to the standard escalators which are sometimes referred to as "compact" or "store type" escalators. Public service escalators will be referred to during the rest of this paper as PSE's.

As the performance requirements and the environment of PSE's are different to their store type counterparts, this is reflected in the engineering design, life of design and thus cost of these escalators. The following is an overview of the main differences and their effect on design:

1. High rise: In London, most PSE's are situated inside Underground stations, serving depths in excess of 15 metres (up to 30 metres in some cases). PSE's exist in similar situations throughout the world. These high rises bring special problems in terms of the stresses on the step chain at the upper end of the machine, and require special measures in design to reduce these stresses. The issue of high rise also has other more far reaching implications, discussed in the following points.
2. Difficulty of access: Due to the nature of their location underground and their large size (see previous note), it is usually not possible to pre-assemble, transport and install these escalators in one piece. It is always necessary to build them in situ.[2] This precludes the use of the compact escalator, the main advantage of which is that it is pre-assembled in the factory, and transported in one piece. This is specifically one of the reasons for the lower cost of compact escalators.

[2] Some progress however has been achieved recently, with the so-called 'modules', which are complete pre-assembled truss sections, which can be installed and connected to each on site. This usually consists of identical modules for the incline area, and two additional modules for the upper end and the lower end of the escalator.

3. Criticality: The reliable operation of PSE's is very critical to the continued operation of the transport facility they are serving. Taking an underground metro system as an example, they are critical in the following ways:
   - At rises exceeding 15 metres, they form an integral part of the passengers' journey, and their failure would lead to unacceptable increases in journey time. In comparison, a store type escalator, at an average rise of 4 metres is a "nice to have", and passengers would normally accept using the stairs as an alternative.
   - Due to the fact that in most cases they form part of the evacuation route and the only means of evacuation during fires, their failure to operate could lead to station closures. This also necessitates carrying out maintenance over night, when stations are closed to passengers, which contributes to the higher cost of maintenance of PSE's.
   - Again, due to their high rise, out of service PSE's could present a serious health hazard to the elderly and passengers with heart problems.

   These factors require a high level of performance in terms of reliability and availability. While an availability figure of 85% would be acceptable for a "store type" escalator, a minimum of 98% availability is usually stipulated for a PSE contract, and 99.5% is usually achieved for a new machine. To achieve this high level of availability, a good understanding of the failures and problems of wear and breakdown is needed in order to produce a suitable engineering design.

   It is worth noting that this issue of criticality can be addressed on new systems by having redundancy in the number of escalators on a station. This results in lower long term costs in terms of tolerating a lower level of availability and allowing maintenance during daytime hours. This has in fact been carried out on the new Jubilee Line Extension, which has an average of 10 escalators per station, as compared to the average number of 4 escalators per station on the existing system.
4. Long operating hours: Usually required to operate 7 days a week, and in excess of 20 hours per day.
5. High passenger usage: As compared to store type escalators, PSE's carry a larger number of passengers per day. A usage of 30,000 passenger per day is not atypical. This presents onerous wear on the escalator, which has to be taken into consideration in the design.
6. Special usage: As PSE's usually form part of public transport systems, they are used by people with luggage, usually heading for railway stations and airports. This has implications in terms of area per passenger and in terms of concentrated loads, which necessitate special care in the design of their steps. Moreover, in view of London Underground's requirement that passengers stand on the right and walk on the left, this creates a difference in terms of the step chain wear, and causes step "crabbing" which imposes strong forces on the steps, and necessitates extra tests to ensure that the step design can withstand these onerous condition without failure.
7. Risk of avalanche falls: Every time an escalator stops, it presents a risk of avalanche fall to the passengers (for more details see: LUL Technology Services, 1996; Al-Sharif, 1996). An avalanche fall is where one passengers loses his/her balance and falls on the next passenger, who in turn falls on the next passenger, causing multiple falls. The risk increases with the number of passengers using the escalator at the time of stoppage, and is also compounded on PSE's by the fact that some passengers carry luggage and others might be under the influence of alcohol. For these reasons, the PSE has to have as good a reliability as possible, and thus should stop as few times as possible.
8. Use during maintenance: Due to its criticality, a PSE should be available for use as fixed stair, if a sudden failure takes place within the drive system or the control system. This will allow repairs to be undertaken on these parts, while allowing passengers to use it as a fixed stair. This leads to the design feature of installing the drive system outside the escalator, and not inside it as is usually done in compact escalators. (Obviously, the PSE

will have to be taken out of service completely in cases of failure of steps, the tracking system, the step chain or the handrails).

9. Ease of inspection and maintenance: As PSE's are usually more maintenance intensive than compact escalators, they require much easier access. This prohibits the "tank" type construction usually used in compact escalators, where the escalator is fully enclosed.

Having introduced the Public Service Escalator, the stages of the asset management process will be discussed in the following sections, in general and particularly as applied to PSE's in a transport environment.

3. DATA GATHERING

Any decision to be taken has to be based on accurate data. This section discusses some of the aspect of data gathering.

The following list gives an example of the type of data which needs to be gathered for PSE's:

- Escalator number and location.
- Escalator type.
- Last date data updated.
- Vertical rise in metres.
- Normal direction of travel (up/down).
- Normal speed.
- Angle of inclination.
- Power supply: This is the main drive supply: AC 415 or 630 V DC.
- Inching speed.
- Number of steps.
- Retained truss: Was the truss retained when it was last replaced?
- Manufacturer.
- Installer.
- Maintenance contractor.
- Maintenance contract number.
- Passengers per day.
- Passenger disbenefits per week: The social disbenefits caused by having the escalator out of service.
- Availability: The normalised availability in the last 13 periods (a period is equivalent to 4 weeks).
- Reliability: The number of times the escalator has stopped in the last 13 periods.
- Condition: A quantified measurement of condition of the machine based on visual inspection.
- Year entered service.
- Last refurbished: The date of the last refurbishment.
- Historical costs of replacement and refurbishment.
- Historical figures for duration of replacement and refurbishment.

However, this data might be available to different levels of accuracy. The next sub-section suggests how this issue can be addressed.

3.1 Classification level pyramid

This section discusses the level at which data is gathered.

For the purposes of rationalising the data gathering process, I have outlined here what I have called the Classifications Level Pyramid (CLP). This is a concept which allows the Asset Manager to gather data at a level consistent with the data available and the timescales given.

The CLP concept can be applied to any asset area. It basically runs as follows. When attempting to gather data for an asset group, one should try to find one parameter which can describe the behaviour of all members in the asset group as an average. This will be Level 1 data gathering. All members in the asset group are treated as identical, and using one value of data to describe their behaviour or characteristic. If there are distinct types of the asset which have similar characteristics, then data could be gathered based on these types. This is level 2. Level 3 involves gathering data on each asset member (e.g., a full escalator), and level 4 gathers data on specific components within each member.

The various levels in the CLP are shown in Figure 2, which shows the four levels of classification. A similar method of data gathering is outlined in an ISO document (see references).

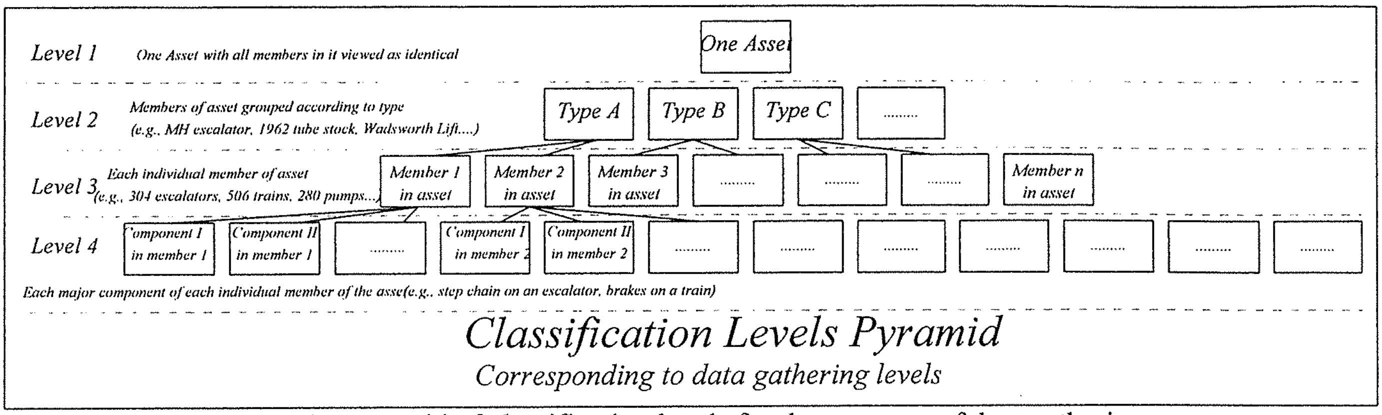

Figure 2: The pyramid of classification levels for the purposes of data gathering.

Table 1 discusses the various levels, along with a description of each level, and indication of the expected number of pieces of data needed for an asset group to operate at that level. The example is based on 304 escalators within a fleet of 18 different types, and 11 major components within each escalators.

Table 1: Description of data levels within Classification Levels Pyramid.

Level of data gathering	**Description**	**Estimated number of entries for escalators as an example**
General for an asset	One figure assumed for all members in the asset	1 asset, thus only one piece of data is needed for each parameter
General for type within that asset	One figure assumed for members of the same type in an asset	18 types of escalator thus 18 pieces of information for each parameter
Specific for each individual member of the asset	One figure for each member in the asset	304 escalators, thus 304 pieces of data for each parameter
Specific for each major component of each individual member of the asset	One figure for each major component in each member in the asset group	3344 major components on the system (assuming 11 major components per escalator) thus 3344 pieces of data for each parameter

The main point that Table 1 illustrates is the large number of data to be gathered, even if data is collected at Level 3. It has to be kept in mind that time is another dimension which adds to the complication, as in some cases it is necessary to collect historical data dissaggregated by time, in order to be able to see the changing trend in that parameter.

3.2 Definition of availability

Availability is one of the most important parameters for predicting future performance. However, the definition of availability depends on it use. Two types are usually used: Raw availability and normalised availability.

The difference between Normalised Availability (NA) and Raw Availability (RA) is explained as follows. RA takes into its calculation all downtime (whether planned or unplanned). This is necessary from the point of view of customers and reporting of performance. However, if one is trying to predict the future performance of an escalator and in order to compare like for like, the planned downtime should be eliminated (e.g., replacement or refurbishment) from the calculation. If for example, an escalator is being replaced this year, and the replacement lasts for 9 months, then the RA this year would be a maximum of 25%, and more likely around the 22% mark when in-service failures are accounted for. As the escalator would not be replaced or refurbished in the following year, the figure of 22% would be meaningless for trying to predict the future performance of that escalator.

For this reason we need to use the NA, which takes out the planned downtime (planned downtime is something which is under the Asset Manager and Operator's control, as opposed to unplanned downtime). Thus, the RA availability is the percentage of time which the escalator was in service, when it was supposed to be. In the previous example, this would be 22% divided by 25% which comes to 88%. From a future performance point of view, this is a better representation of the expected performance of that machine. In other words, if we stopped all replacements or refurbishments, the NA is the level of availability which would be obtained from the whole network. NA is a true indication of the performance of the machines, as it removes the effects of planned downtime.

So to summarise, for performance to customers, RA should be used. But for purposes of future analysis, NA should be used. The reduction in planned downtime, however, can be used an incentive between the Asset Manager and Operator, in terms of building a reward system within the contract.

4. ANALYSIS OF RELATIONSHIPS AND TRENDS

This phase involves analysis of the data gathered, in order to develop general relationships. As an example, this would involve understanding how the cost of replacement or refurbishment is related to the rise of the escalator or the scope of the work.

The following two examples are by no means exhaustive, but give an idea of the analysis process.

4.1 Change in availability over time

One of the important pieces of data which needs to be derived from the gathered data, is the change in availability of a machine over time. Intuitively, this will be related to a number of factors, such as the age of machine, availability of spare parts, level of preventive maintenance. An example of how the availability of an old machine changes with time, is shown in the 5 year plot of four weekly availability figure shown in Figure 3.

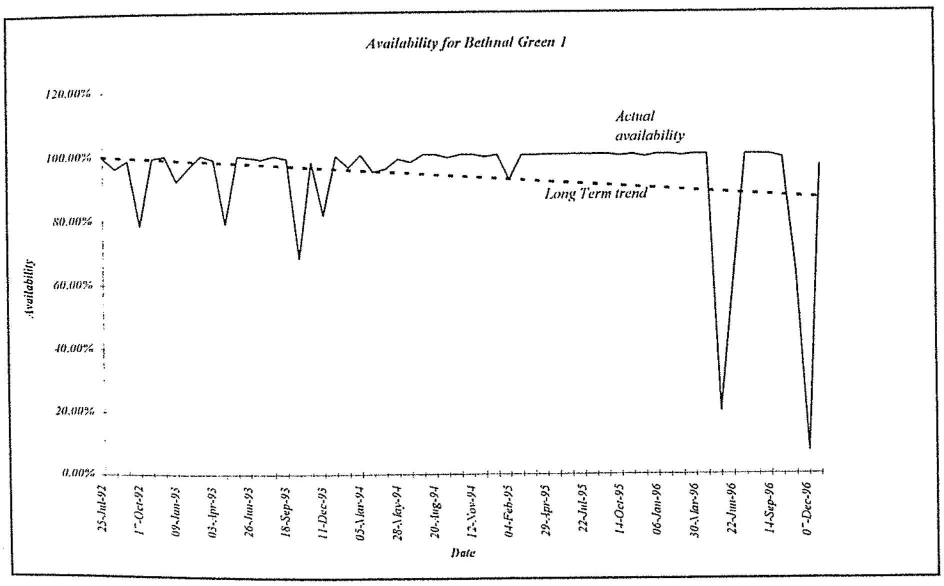

Figure 3: Availability of a 40 year old machine over the 5 years.

As seen in the figure, although the trend is not even, a general long term decline can be seen by finding the linear fit over the five years, which gives a downward sloping straight line. By relating this to the age of the machine and the level of maintenance, and repeating the same process for a large number of different machines, a general formula for the annual decline in availability can be found as a function of these two parameters.

4.2 Cost of maintenance

Another important relationship is the cost of maintaining a machine and producing a certain level of availability. Age is an important parameter, as it will increase the cost of maintenance in order to achieve the same availability.

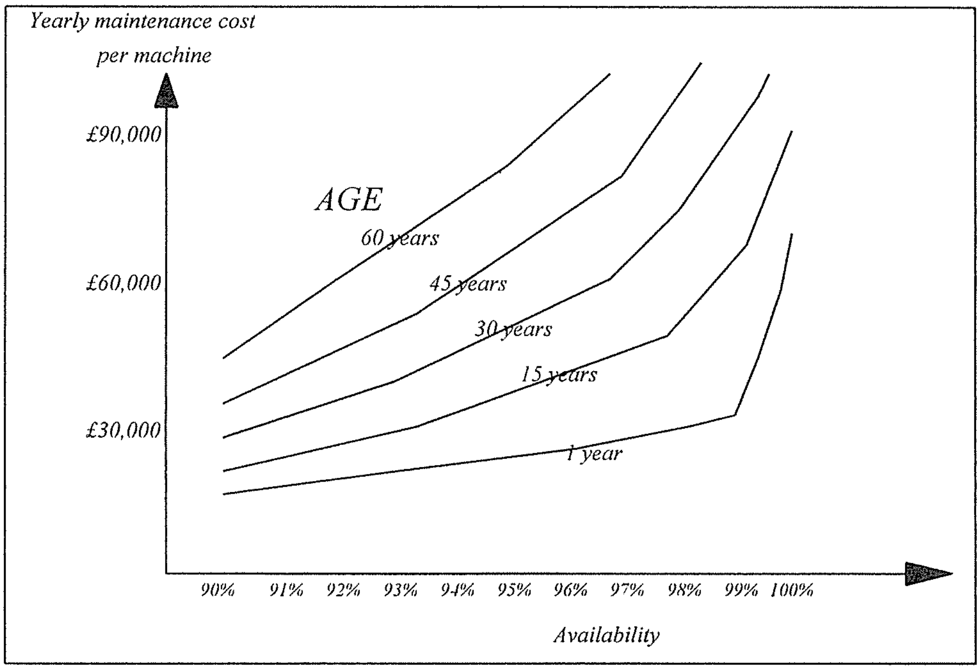

Figure 4: Estimated relationship between cost of maintenance, age of machine and resulting availability.

A sample of this relationship is shown in Figure 4, where it can be seen that higher costs are incurred as the age of the machine increases, to achieve the same level of availability. Also, for machines of the same age, a higher expenditure would achieve a higher level of availability.

5. MODELLING

All the data gathered and the analysis carried out is used to model the behaviour and the expected expenditure. Although this could be done manually, using spreadsheets or databases speeds up the process, and makes scenario analysis much more practical.

An outline of the suggested model structures used for whole life asset planning is contained within Al-Sharif (1998b). A suggested structure for a performance cost model for lifts and escalators is shown in Figure 5.

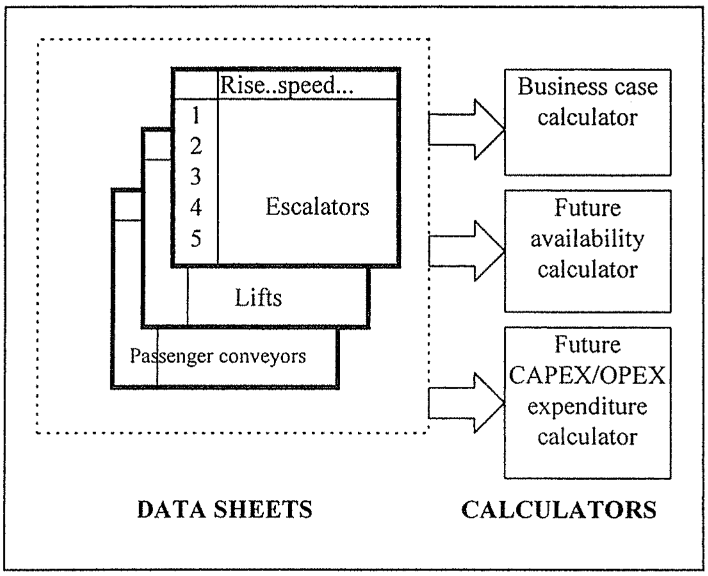

Figure 5: Structure of a vertical transportation system whole life asset planning model.

The model is used to read all the basic data, and by entering the relationships in formulae in the model, a plan can be produced which prioritises the assets based on a certain criterion, and then produces for that plan the expected future expenditure and performance.

6. PLANNING

As mentioned in the last section, a model can be used to develop a plan based on any number of parameters. Some of the factors which can be used, either solely, or in combination with others are as follows:

- Availability
- Reliability
- Safety
- Operational
- Condition
- Age
- Project implementation constraints
- Appraisal
- Regulatory requirements
- Funding constraints

This highlights the difficulty of developing a program of works which satisfies all the criterion above. In practice, the model is used to generate an automatic first iteration, and then the program is iterated based on human experience and consultation with the Operator.

7. APPRAISAL

Once a plan is in place, financial authority has to be sought. For that to take place, an appraisal of the suggested schemes has to take place, to ensure that a value for money decision is being taken.

Financial appraisal has two important roles in the asset management process:

- **Finding the cheapest option:** Comparing different payment structures, assuming the same level of performance. In this case, this method of appraisal is merely a net present value (NPV) calculator and analyser, selecting the option which gives the cheapest NPV cost.
- **Selecting the best value for money option:** On the other hand, when the level of service and the performance of the different options is not the same, the above method cannot be used. This is because one option, although cheaper as a net present value, delivers a lower level of performance than that delivered by a second option, which is dearer in NPV terms.

This is usually referred to as the cost-benefit analysis method, and is widely used in public sector organisations, especially where the main motivation for the work is not increased revenue, but maximising social benefit.

An example of the rules used in the public sector for cost benefit analysis appraisal method is contained in (LT Corporate Planning, 1997) and an example of how it is applied in the field of public service escalators is contained in Al-Sharif (1997).

The main difference with this appraisal method is that it takes the whole passenger disbenefit overview into consideration. As an example, the time taken to repair/replace an escalator in the LUL environment will be significant and, as this in itself creates a passenger disbenefit, this will normally be taken into account in the option selection process. The modelling process discussed earlier, can also be used to automate the appraisal process.

One example follows on the use of appraisal as a simple net present value calculator. For the use as a cost benefit analyser, refer to the references.

7.1 Example: Appraisal of different payment structures

A comparison is being made between the cost of three alternative escalators, with different maintenance costs and different payments. All three proposals however, deliver the same passenger benefits and the same levels of performance. Thus by calculating the net present value of each, a decision can be made by choosing the option which gives the lowest cost in terms of net present value.

Scenario number	Scenario 1
Discount rate	6%
Design life	40
Year zero cost	£0
Yearly payments	£147,423
Mid life refurbishment cost	£0
Project overheads	20%
Yearly maintenance cost	£0
Heavy repair	£0
yearly benefit	£150,000
NPV (over 40 years)	£109,383

Figure 6: Scenario 1 (instalments) parameters and results.

Scenario number	Scenario 2
Discount rate	6%
Design life	40
Year zero cost	£700,000
Yearly payments	£0
Mid life refurbishment cost	£200,000
Project overheads	20%
Yearly maintenance cost	£35,000
Heavy repair	£15,000
yearly benefit	£150,000
NPV (over 40 years)	£550,236

Figure 7: Scenario 2 (Low capital/high maintenance) parameters and result.

Scenario number	Scenario 3
Discount rate	6%
Design life	40
Year zero cost	£1,000,000
Yearly payments	£0
Mid life refurbishment cost	£400,000
Project overheads	20%
Yearly maintenance cost	£25,000
Heavy repair	£10,000
yearly benefit	£150,000
NPV (over 40 years)	£341,098

Figure 8: Scenario 3 (high capital) parameters and NPV result.

As shown in Figure 6, Figure 7 and Figure 8, the three scenarios offer different costs of net present values. Provided they all deliver the same benefits, and carry the same level of financial risk, then scenario number 1 is the preferable option.

8. CONCLUSIONS

Public service escalators operate in a different environment and have more stringent performance requirements than standard type escalators. This dictates special design features.

The asset management process involves a number of stages, in an iterative manner. Data gathering can be carried out at a number of levels, depending on the accuracy of data and the time available. The data is then analysed to find relationships between the various parameters and understand the behaviour of the machine. These are then entered into a model, to generate a plan, and predict future performance and expenditure. Manual iterations of the plan are necessary to take into consideration all the factors which affect the order of carrying out the work. The various options are then financially appraised to choose the most optimum. Implementation can then start.

The whole process is an iterative process, which is continually updated, as the environment changes, or as the requirements of the Operator change.

The asset management process in this form delivers great benefit to the Operator and the Asset Manager, in terms of predicting future performance and expenditure, planning for the works in advance and getting the best value for money options.

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AUTOBIOGRAPHICAL NOTES

The author graduated in Electrical Engineering in 1987, and worked for two years as an electrical and electronic lift systems design engineer. He received his M.Sc. in Remote Lift Monitoring in 1990, and his Ph.D. in Artificial Intelligence Applications in 1992 from UMIST (Manchester, U.K.). He was then appointed as Senior Electrical Engineer for Lifts & Escalator at London Underground, and is still working for London Underground, currently as Team Leader. As a second role within London Underground, he is the developer of the model structures for the Whole Life Asset Plans for the Underground's assets, and the chief modeller for the station based assets. He is also a Chartered Electrical Engineer, and a part time lecturer in electronics and electronic systems at the South Bank University.

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