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LIFT MANAGEMENT

A thesis presented to  
THE VICTORIA UNIVERSITY OF MANCHESTER  
for the degree of

DOCTOR OF PHILOSOPHY

by

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England

April 1980

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DECLARATION

None of the material contained in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institution of learning. Due recognition is given in the usual manner to the work of others, referred to in this thesis.

J.R. BEEBE

April 1980

## ABSTRACT

Current techniques for the design, specification and assessment of lift systems are reviewed and operating environments are considered. A brief survey of methods for collecting data from working lift systems is made and possibilities for improvement are discussed. The use of computers for data logging and subsequent analysis is suggested. Detection of lift system malfunctions and on-line data analysis are isolated as particularly desirable possibilities of a computer based logging system. The implications of such techniques are considered with respect to the manufacturers, owners and users of lift systems.

Proposals are made for an integrated lift management system which makes extensive use of computer technology to provide four, much needed facilities, to building managers responsible for large lift systems. The four functions offered by the lift management system are in-service testing, optimal control, diagnostic status testing and performance data monitoring and analysis.

Examples of computer logged data, made by a simple logging system, are examined. Some conclusions are reached as to the nature of the lift traffic but the accuracy and sensitivity of these results are limited by the quality of the data and malfunctions in the lift systems.

A survey of attempts to define a universal performance measurement for lift systems is included. Suggestions are then presented for

a performance index which matches the response of a lift system to the demand placed upon it. The proposed lift management system is suggested as an appropriate tool with which to test the validity of the performance index as a measure of operational lift systems.

#### ACKNOWLEDGEMENT

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I would like to record my appreciation for the patient support of my wife and family during the long task of writing this thesis.

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Chapter 1Introduction

The increasing height of buildings in densely populated urban areas can be considered as a logical consequence of rising land prices and legal restrictions on the development of rural land. Additionally, a tall and impressive tower block is regarded as a source of prestige by both architects and owners.

The attendant problem of increasing the number of floor levels in a building is that of transporting larger numbers of inhabitants to and from congested common entry levels. The population of each floor of a high rise tower may be considerable and buildings have at most the possibility of three entry levels, and usually only one. Acute problems of congestion can occur particularly when the building is filling or emptying at the start and end of the working day. As yet no alternative and effective method of vertical transportation to the passenger lift has been developed. The paternoster and escalator exist but can only be regarded as suitable for short interfloor trips by a static population.

Although the design of passenger lifts is becoming more critical as building heights increase, an architect is limited to a very restricted set of design techniques. Furthermore, once a system of passenger lifts has been proposed and installed there is no means by which to assess its performance against the original design specification or to verify that anticipated population and traffic movements have actually materialised.

In the introductory notes to the printed proceedings of a symposium entitled "Lifts in Large Buildings" held in June 1966 (BRS, 1966) at the Building Research Station, Mr. John Weston, director of BRS states:

"The ability of the lift engineer to design mechanically efficient lifts is not in question. The lift industry has made rapid progress in developing equipment with improved reliability, higher speeds and better passenger comfort and safety. Perhaps the knowledge that the industry is capable of producing lift systems which will satisfy the demands of the largest buildings has tended to create a false sense of security, for it is questionable whether the installation chosen for any particular building is always appropriate to the functional needs of that building".

Fourteen years later, it is difficult to say that the situation is much improved. While design techniques have shown considerable advancement over that period, particularly in the field of computer simulation, few designers or manufacturers have actively taken advantage of these facilities. Furthermore, hardly any effort is acknowledged to have been made by the industry to develop the means to assess whether a lift system is "appropriate to functional needs of a building". In particular, little is known about the effectiveness of lift systems once they are installed. Although a lift system performs a simple function of transporting passengers from one floor to another, the mechanisms of passenger demand and lift system response are complex and little understood. It is relatively simple to measure, acquire and store data from a lift system. What is difficult is to find a generally acceptable method for expressing traffic performance as a function of demand.

This thesis considers the problems of working with and assessing the performance of operational lift systems.

Chapter 2 discusses the historical development of lifts and design

4.

techniques for lift systems. A further section illustrates the problems of observing working lift systems and the acquisition of useful data concerning their operation. It is noted that several areas exist where improvements could be made, particularly concerning the effectiveness of management of lift systems subsequent to installation.

After considering the various difficulties presented to building managers, in both the commercial and residential environments, by the management of large lift systems, chapter 3 continues with a proposal for an integrated, largely automatic lift management system. In addition to being a highly effective commercial product, the lift management system offers a solution to a number of impediments which obstruct the progress of research into the operation of lift systems.

The functional details and implementation of the lift management system are presented in chapter 4.

Having established a means of reliably obtaining and analysing lift system data, chapter 5 considers possible methods of analysis and examines the usefulness of data, already obtained, in identifying traffic flows due to time and also building dependent phenomena.

Chapter 6 presents a history of work, executed in the search for a performance evaluation for lift systems. This chapter concludes with the discussion of a performance index, for the dynamic evaluation of the service provided by a lift system, which is thought to be sufficiently independent of building and lift configurations to allow a comparison of dissimilar lift systems.

Suggestions for further work are presented in chapter 7. Chapter 8 considers the conclusions which may be drawn from the work presented in this thesis.

Chapter 2

Historical Perspective



## 2.1 General Discussion

The first passenger carrying lift appears to have been designed by Elisha Otis and installed in a New York store in 1857 (Barney, 1977, preface). Since then, lifts have been promoted from the status of a novelty to an essential service in high rise buildings. As building populations have increased, groups of lift cars have replaced single car installations in order to cope with heavier demands for vertical transportation. Other devices such as the paternoster and escalator have been devised but do not operate at the speeds required for high rise travel.

The introduction of multicar lift systems heralded the replacement of manually operated lift cars by automatic control from a central supervisory system. This strategy was necessary to co-ordinate the movements of all the lift cars in a group and thus enable efficient handling of passenger traffic. The traditional technology, with which automatic group control has been implemented, is cumbersome and inflexible and this, amongst other factors, has limited the sophistication of control schemes. The lift industry is only now awakening to the implications of the advances achieved in the last decade in the field of integrated circuit computer technology.

Few engineers and mathematicians have thought it necessary to conduct academic studies of lift technology or the treatment of lifts as analytical systems. Though an elementary single car lift with a unidirectional traffic flow provides an illuminating example of statistical theory, the problem becomes extremely complex if an attempt is made at realism. Alexandris and Harris (Alexandris, 1979, 182) are two workers who have considered this problem and have had to invoke advanced mathematical techniques to achieve their conclusions.

Finally, there has been very little published work conducted to observe the systematic operation of a group of lifts, or to quantify features which relate directly to the service which passengers receive.

Thus the potential to improve upon current levels of understanding with regards design, analysis and operation of lift systems is great. However, the subject covers a diversity of specialised areas of knowledge and therefore any academic treatment must be broadly based.

## 2.2 Design Techniques

### 2.2.1 Calculation

Until recently the design techniques used by architects and lift system planners considered only peak traffic conditions and often only the up peak traffic. Assumptions are made to simplify calculations, some of which severely limit the applicability of these analytical methods. The three assumptions listed below, fall into this category.

- i) Calculation of lift system characteristics under peak conditions does not allow for light traffic flow against the peak traffic direction. However this situation is more probable than a purely unidirectional traffic flow and handling the extra traffic could severely degrade the service provided to the main flow of passengers.
- ii) During up peak traffic lift cars are assumed to always leave the main terminal with a load of 80% of their rated maximum capacity. This loading is shown by Barney and Dos Santos (1977, p 204) to be a realistic figure for a fully loaded system. However, it may be desired to design a

lift system which will be less heavily loaded by this traffic flow and therefore provide improved service.

- iii) A constant rate of passenger arrivals at a landing level is assumed. However Alexandris (1976) from observations in three buildings concludes that the Poisson process is a more realistic assumption .

Barney and Dos Santos (1977) discuss the limitations of conventional design calculations and offer alternative procedures which allow for both variable car loadings (p 51) and Poissonian arrival rates (p 47). As an alternative to analytical techniques Dos Santos (1972) suggests the use of simulation. This overcomes the problems of mixed traffic flows which cannot be considered in conventional calculations.

#### 2.2.2 Simulation

A simulation allows the designer to specify parameters relating to the building, the lift system and the traffic flows and densities. For analysis of system behaviour under varying traffic conditions, simulation provides the closest approach to reality that is possible while a building is still being designed. The simulator described by Dos Santos uses a large time-sharing computer system (Digital Equipment Corporation PDP10) to provide an interactive design tool which can accept a complete specification, simulate an hour of lift activity and present a graphical analysis of the simulated activity in a few minutes of real time.

#### 2.2.3 Performance Estimation

Dos Santos (1974) gives a performance figure to describe the quality of service under conditions of up peak

traffic. Moussalati (1974) extended this work to include balanced interfloor traffic where passengers arrive randomly at all landings with no discernible pattern of destinations. This type of traffic is probably a close approximation of the traffic in many commercial buildings for most of the day. The average waiting time of all travellers in the building over a five minute period is used as a measure of quality of service for the performance figure while normalisation is provided to accommodate different lift system configurations by dividing the average waiting time by the up peak interval. The up peak interval is the average time between successive lift car arrivals at the main terminal floor when up peak traffic conditions exist and cars are loaded to 80% of their maximum capacity. Both waiting time and interval are dependent on the number of floors in the building, the number and capacity of cars and the operating times for car and door movements.

Thus the quotient:

$$\text{Performance figure} = \frac{\text{AWT}}{\text{UPP/INT}} = \frac{\text{av. waiting time for all building over 5 mins.}}{\text{Calculated up peak interval}}$$

can be expected to show independence of building and lift system parameters. Moussalatti's results verify this although some dependence on the number of floors in the building is still displayed. Dos Santos (1974) conducted a similar analysis of performance under down peak traffic conditons when passengers arrive at all floors except the main terminal, desiring to travel to the main terminal. In common with the up peak, the down peak traffic condition in a real building will only be manifested for a short period and then probably against a background of traffic of a different nature.

By comparison of the performance figures obtained for a variety of lift system controllers under the three identified traffic flow patterns it was possible to draw conclusions as to the efficiencies of the various controllers (Swindells, 1975).

The conclusions of this exercise were that the best performance might be obtained from a lift controller which used a "best mix" of control strategies complementing the techniques of established manufacturers with original policies and switching between these according to which is most efficient under the prevailing traffic conditions.

#### 2.2.4 Validation of design procedures

Simulation allows certain conclusions to be reached concerning the performance of a proposed lift system configuration during the design of a building. However, once installed, there is no effective method of determining whether the predicted traffic flows have been realised, or whether the lift system is handling traffic as efficiently as suggested by the simulation. Additionally, even if the expected traffic flows and lift performance are achieved in a new installation there is no established method of identifying subsequent changes in either, though movements of tenants and mechanical wear are both likely causes of such changes. These observations highlight the need for techniques with which to analyse data obtained from real lift systems. However, before this can be attempted, facilities must be developed for gathering data from lift systems in a form that is flexible enough to allow a variety of analysis techniques.

## 2.3 Data Collection Techniques

Several workers have approached the problem of gathering data from lift systems. Their efforts can be classified into two distinct categories: manual surveys and automatic data collection. The methods used and the nature of the information thus obtained reflect different objectives of the various workers.

### 2.3.1 Manual Surveys

Robertson et al (1976) report a traffic study conducted in a residential block where demand is light. An average of between 30 to 60 passengers were found to travel in each direction in an hour. Even so, it was necessary to employ two observers (three in busy periods) to record just the number of passengers and their respective waiting times in the entrance lobby. However, they were not able to record any information about passenger activity at other floors. This would become a problem if demand throughout the building could not be assumed to be uniform as, for example, in an office block.

Barney and Dos Santos (1977, p 268) detail techniques for conducting surveys using human observers to record data on:-

- passenger arrival rates
- passenger destinations
- lift car journeys

This data can be used to evaluate variables such as the round trip time, interval, highest reversal floor and number of stops, etc. which were estimated at the design stage. Such a survey provides comprehensive information but does not generate any information about system response times or waiting times and thus cannot be utilised in performance analysis.

At least one observer is required for each car to record passengers in/out and stops and one observer to record the number of arrivals.

In order to record the required information for performance analysis in a building with unequal population distribution, it would be necessary to deploy at least one observer on every floor and one in every car. It might be possible to replace the travelling observers by fewer stationary ones if a dispatcher panel could be observed. This panel is provided with some lift systems in the entrance hall and gives a visual display of the position of each lift car, landing and car calls, etc. in the building. In either case, a large number of observers is required for a tall building with several lift cars and a long-term survey would thus prove very expensive. Observers also contribute to the congestion within the lift system and sometimes disturb the passengers to such an extent that they avoid contact with the observers. Both factors disturb the patterns of movement which are to be observed.

The use of observers comes closest to making available all the information that could possibly be obtained. In the extreme case each individual passenger could be followed right through the system from arrival to departure at the destination floor and the operation of each lift car could be recorded. Then all possible arrival and departure rates, waiting and journey times could be obtained for the passengers (demand) and all the journeys performed by the lift system could be determined (response). Obviously this method would be impossible in terms of expense and the subsequent analysis of the data.

### 2.3.2 Automatic Data Collection.

An alternative to human observers is the use of electrical or

electronic equipment to collect data. In addition to being free from the shortcomings already attributed to humans, automatic equipment records events exactly as they happen and suffers neither from error generation nor boredom. However, use of such equipment does incur penalties of its own. Most significantly, it is not practical to record movements of individual passengers, since automatic devices to detect such activity would be very costly and complex. Thus recordings must be restricted to events occurring within the lift system equipment. In this case, some link will be required to be established between lift car movements and the obtaining traffic conditions.

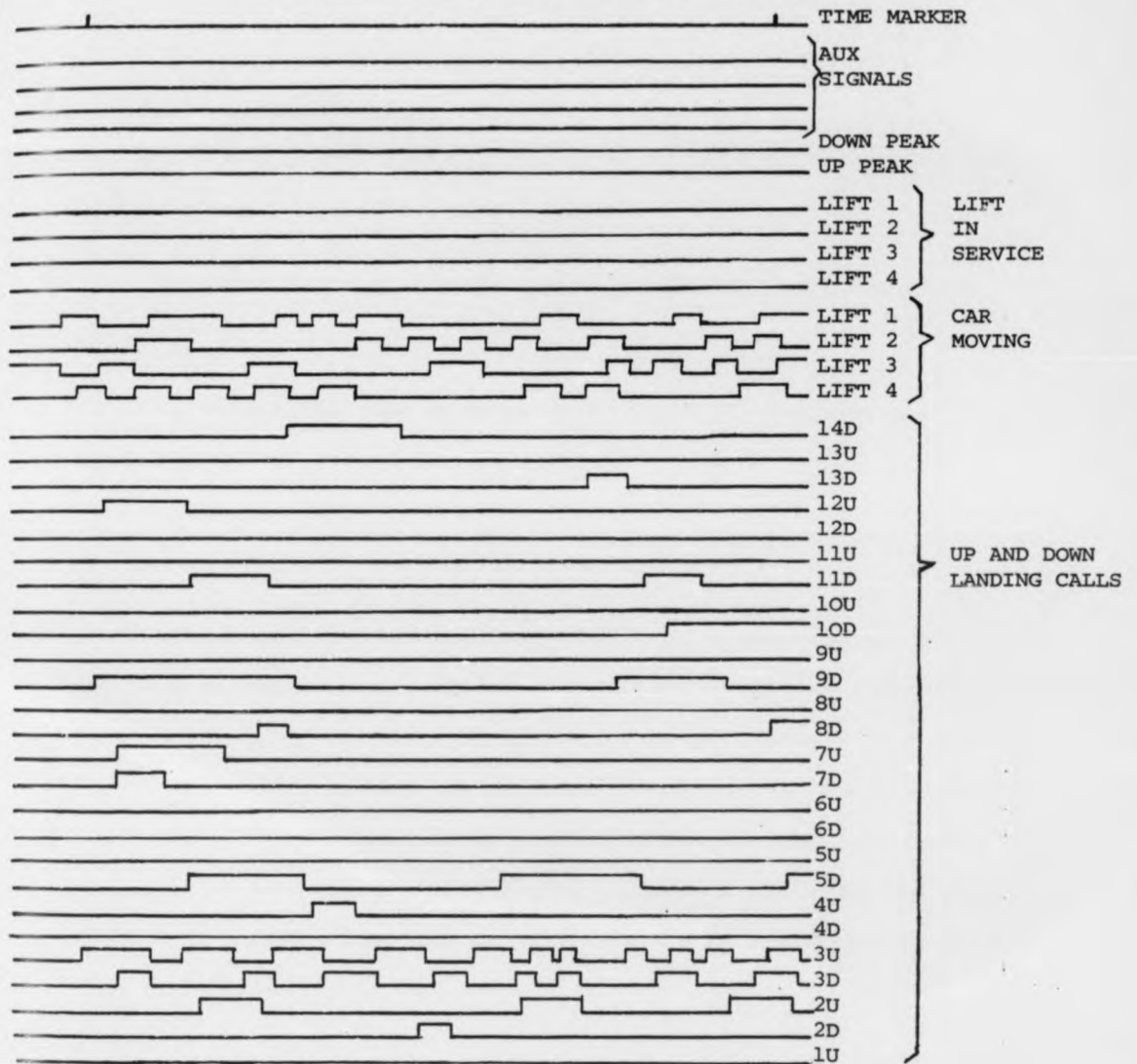
Bedford (1966) developed an electrical pen recorder with 40 independent channels for recording lift system activity. Each pen has two possible positions (either "energised" or "at rest") which represent the condition of relays within the lift system controller. Paper from a continuous roll is passed under the pens at a constant rate thus creating a time related record of the position of the pens (figure 2.1). Each landing call button throughout a building is associated with a single channel of the pen recorder. Thus, a passenger arriving at a floor and pressing a call button causes the associated pen to move into the "energised" position. The period for which the pen remains in this state is the interval between the call being placed and a lift car arriving to answer the call, defined by Barney and Dos Santos (1977, p 273) (after McKay, 1976) as System Response Time.

Note that no subsequent arrival of passengers, desiring to travel in the same direction, can be recorded until the call has been serviced. In addition each lift car is associated with 3 recorder channels which represent:-



FIGURE 2.1

EXAMPLE OF TRACE FROM 40 CHANNEL PEN RECORDER



- i) Lift car in service
- ii) Lift car moving
- iii) Next car to leave main terminal (a function of some control policies) when in the "energised" position.

An additional single trace demarcates time in intervals of ten minutes.

Once installed this equipment will record the location and direction of all calls and the incidence of car movements. Only occasional attendance is required, in order to ensure a constant supply of paper, otherwise operation is automatic.

This method represents a considerable improvement in the data collection process when compared with the human observer. However, although data is obtained very easily, it is not recorded in a format which is directly usable. It is necessary to process this information by hand into a form which is more easily comprehensible before any analysis of activity may be conducted. Collating data from the pen traces is indeed a laborious and error prone task and severely limits the usefulness of this device.

Once the recorded data has been manually processed, graphs can be drawn to display:

- i) incidence of calls (figure 2.2)
- ii) number of calls answered within a specific system response time (figure 2.3)
- iii) percentage of total calls answered within a specific system response time (figure 2.4)

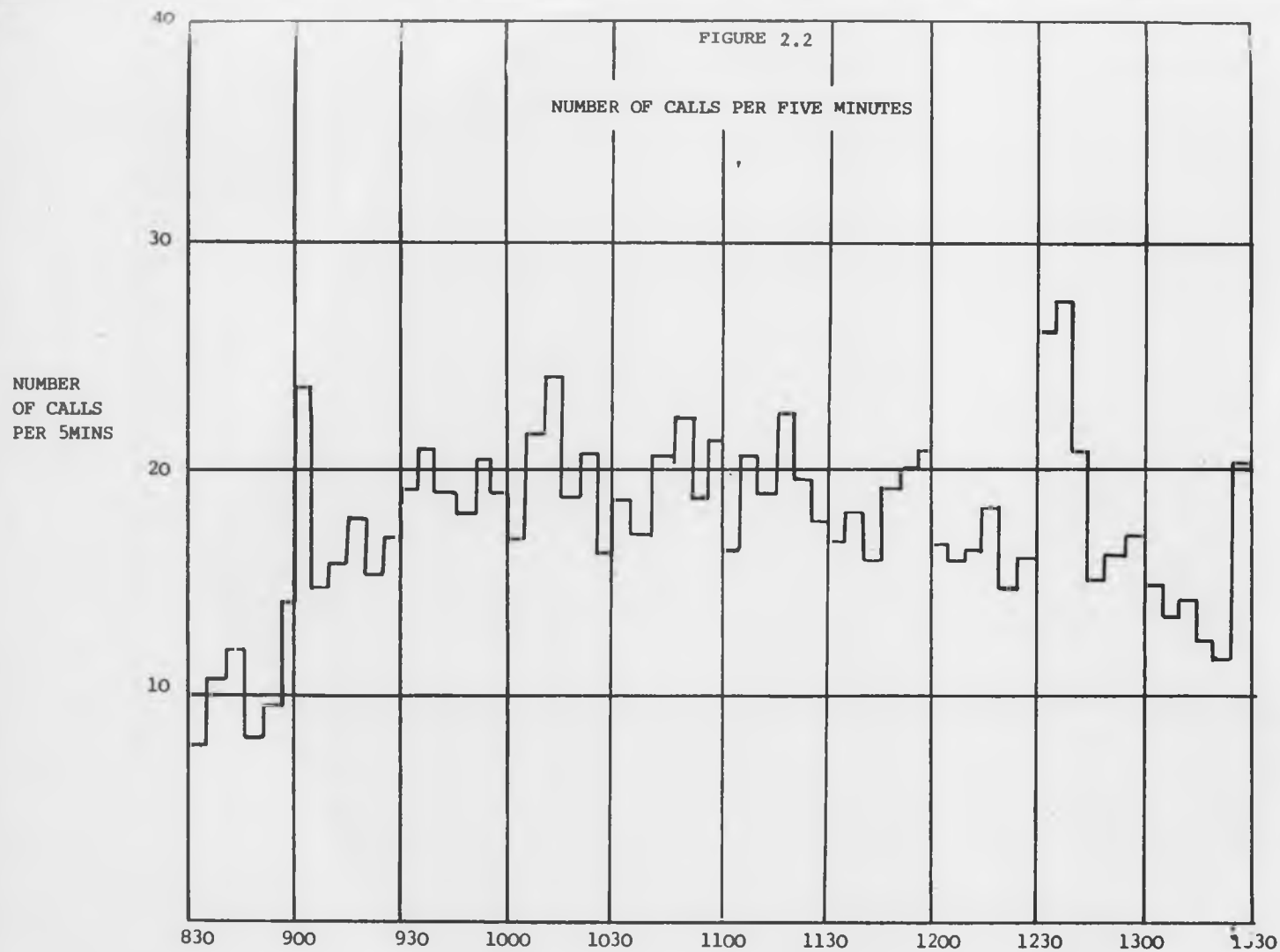


FIGURE 2.3

NUMBER OF CALLS PLOTTED AGAINST INDIVIDUAL SYSTEM RESPONSE TIMES

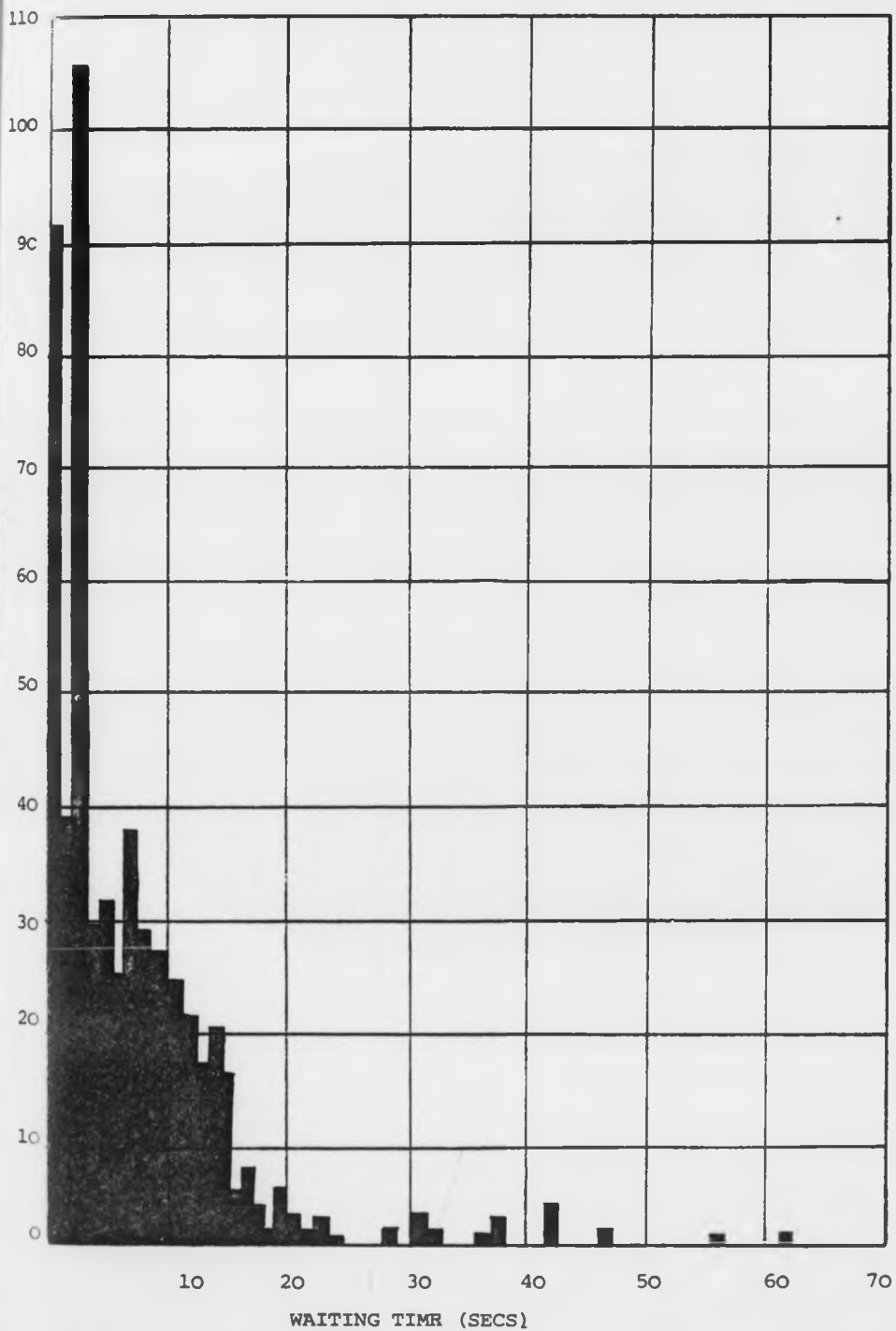
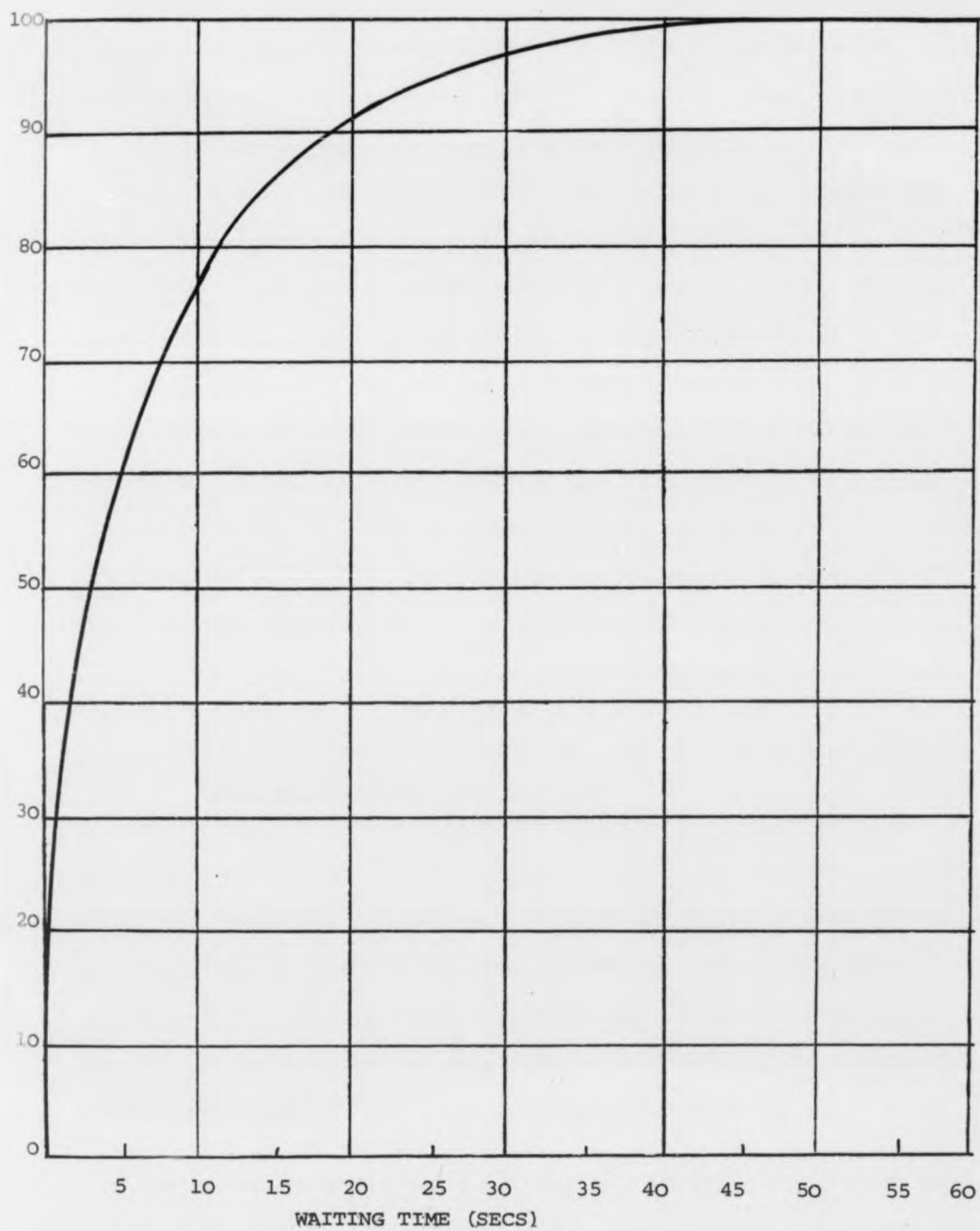


FIGURE 2.4

PERCENTAGE OF TOTAL CALLS ANSWERED WITHIN SPECIFIC S.R.T.



A similar recording technique is used by Otis (1976). More recently, Otis Elevator Company has developed a device, probably utilising a microprocessor, which can be used in lift system analysis. No information has been published to specify how it functions or the modes in which it may be used. However, from advertising literature and correspondence with the manufacturer (Otis 1979) it would appear that the device (registered trade mark COMPUT-O-CHECK) functions are a development of the pen recorder system (Otis 1976). Output from the COMPUT-O-CHECK device is a tabulation, in terms of incidence of parameters such as landing calls against range of system response time (figure 2.5). This is reproduced on an electric teletypewriter. Thus the tedious task of deciphering the pen recordings has been replaced by an automatic process. However, a graphical representation (as in figures 2.2 - 2.4) is preferable to a tabulation. Trends can be easily recognised and previously obtained results can be readily used for comparison. The production of graphs still requires considerable manual effort. Other data loggers built around a mini computer are known to exist (eg the Traffic Analyser of the Express Lift Company) but no details have been obtained .

### 2.3.3 Computer Based Data Collection

Barney and Dos Santos (1977) acknowledge the shortcomings of manual surveys and propose an automatic data collecting system which also has additional processing facilities. This system is constructed around an electronic digital computer and can be used as a sophisticated and versatile device for recording lift activity. Its applicability is enhanced by the fact that by using different programs, the same equipment can perform diagnostic and traffic performance analysis.

The system described has a multiplicity of input lines which are connected to relays in the lift system controller. The connections are similar to those used for the pen recorder but in addition, signals



relating to door functions and position by floor number are obtained from each lift car. These lines are continuously scanned in sequence and patterns of doors opening and closing and car arrivals and departures are identified. Each time a lift car leaves a floor level where it has been stationary a string of alphanumeric characters is produced. These characters are coded to represent all the relevant activity of the lift car since it last started moving. The data produced includes:-

- i) Time (accurate to one second)
- ii) Floor at which car stopped
- iii) Car identification
- iv) Direction
- v) Incremental weight in lift car
- vi) Systems response time
- vii) Time stopped at floor
- viii) Flight time
- ix) Door opening time
- x) Door closing time

Time in hours and minutes is also output at the start of each minute. The string of characters is typed on listing paper for human comprehension and stored on punched paper tape or floppy disc, to be further processed by computer at a later date. By storing data in this machine readable form, any amount of processing, including automatic graph plotting, may be performed easily where and when desired.

A data logger of this kind was built at UMIST for the Building Research Establishment. Its use in eight residential building is described by McKay (1980b). In addition BRE and Lift Design Partnership have used it to investigate lift system activity in office buildings; as yet this work is unpublished.

Simple analysis programs for the PDP 11 have been written, primarily by G Beech of UMIST under contract to BRE. Analysis of data obtained by LDP has been carried out at UMIST using a BRE suite of programs known as LAN 1 written by S Brae de of UMIST; further development of this package has been carried out by the author'.



The large PDP10 computer which provides facilities for running interactive software and producing graphical displays was used for this purpose. A suite of analysis programs was developed which makes use of the graphics capabilities of this computer, to display information which has been processed from the lift system activity recordings. Graphical data is the most suitable presentation of the large quantities of information produced by the analysis programs as it allows trends to be clearly displayed. Absolute values, which would require tabulation, are not so easily interpreted but are available if closer investigation is required. The suite of analysis programs allows the display of the following parameters:-

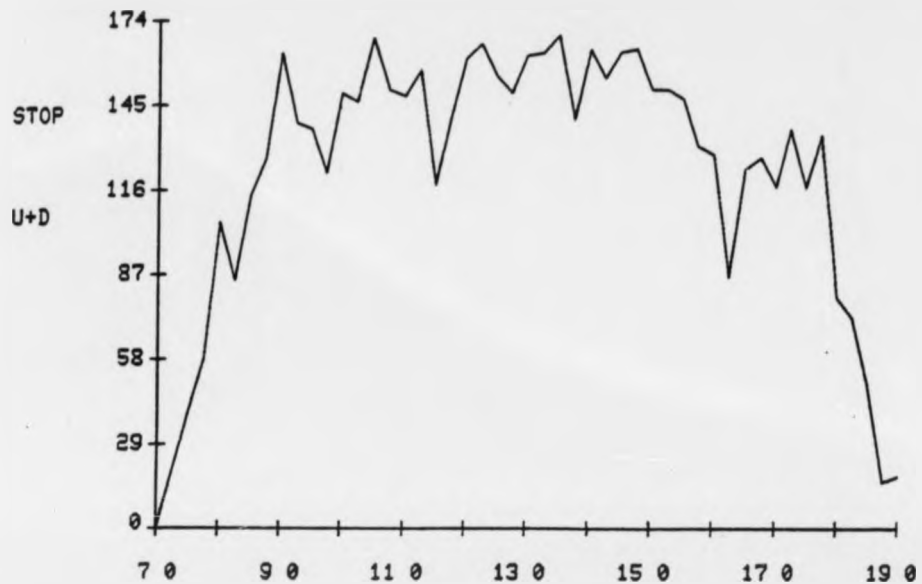
- i) Stops (figure 2.6)
- ii) Landing calls (figure 2.7)
- iii) System Response Time (max and mean in seconds) (figure 2.8)

Data can be displayed for either up or down directions or both directions summed. The interval over which sample values are taken and the start and end points of the analysis can be specified.

Additionally the movements of each car through the building may be plotted over an hour's activity, (figure 2.9).

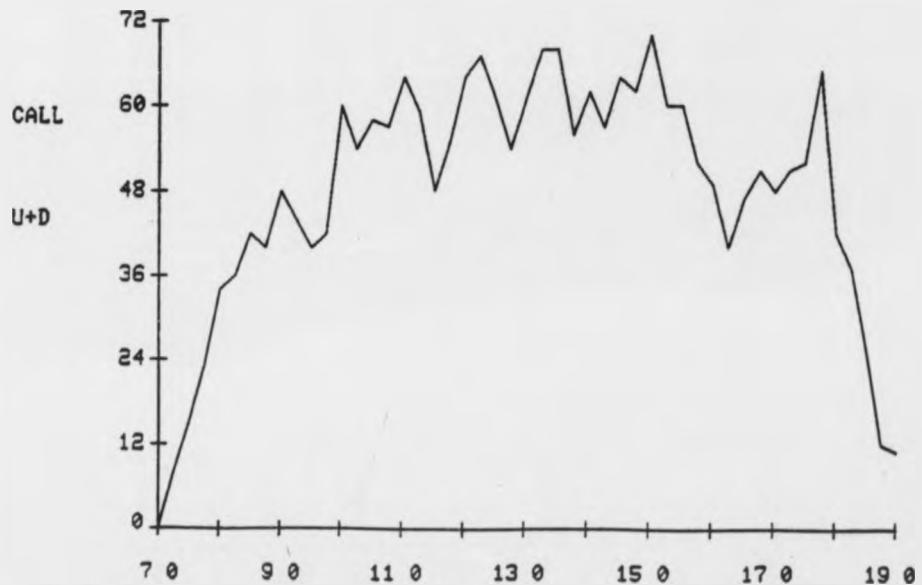
#### 2.4 Possibilities For Advancement

Using the minicomputer data logger, it was discovered that certain features of traffic flow could be identified and a global description could be assembled of the way in which a lift system is used. However,



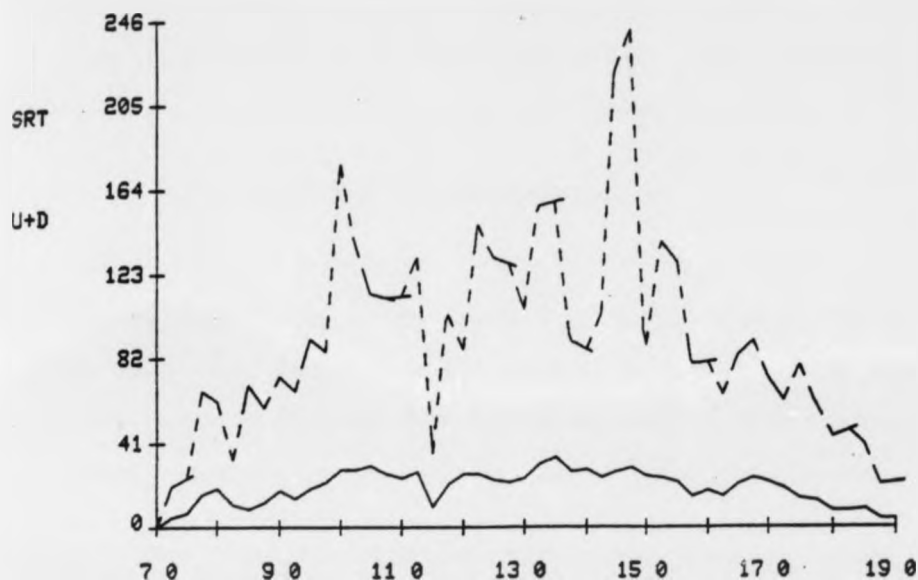
NEXT(R/C/N/E/H)?

FIGURE 2.6 Graph of Stopping Rate



NEXT(R/C/N/E/H)?

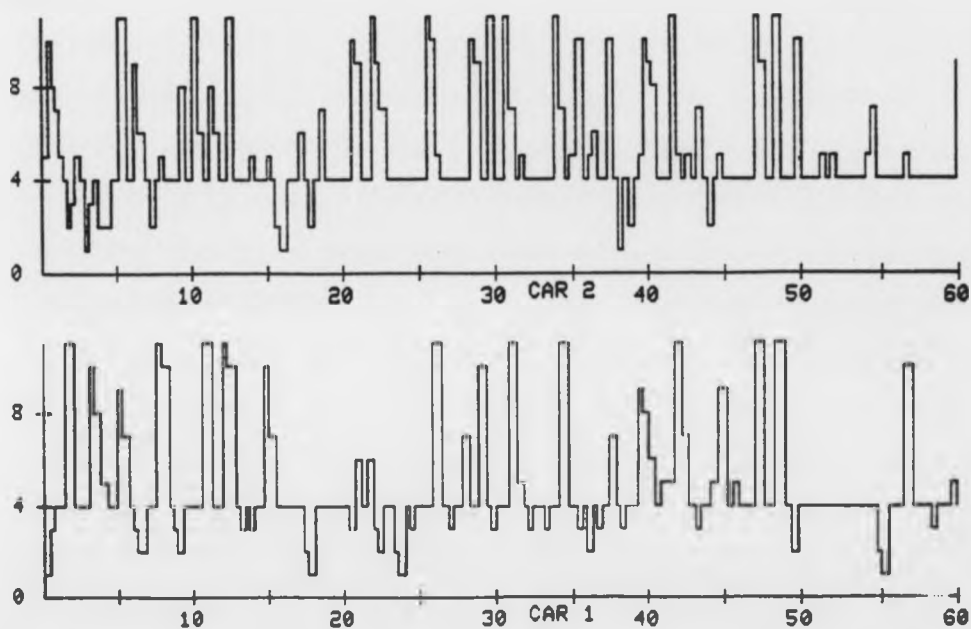
FIGURE 2.7 Graph of Call Registration Rate



NEXT(R/C/N/E/H)?

Figure 2.8 Graph of System Response Time (mean and max)

RUN NO: 1 DATE: 22. 3.79 TIME: 17. 0 BUILDING: BAR HQ  
 FLOOR



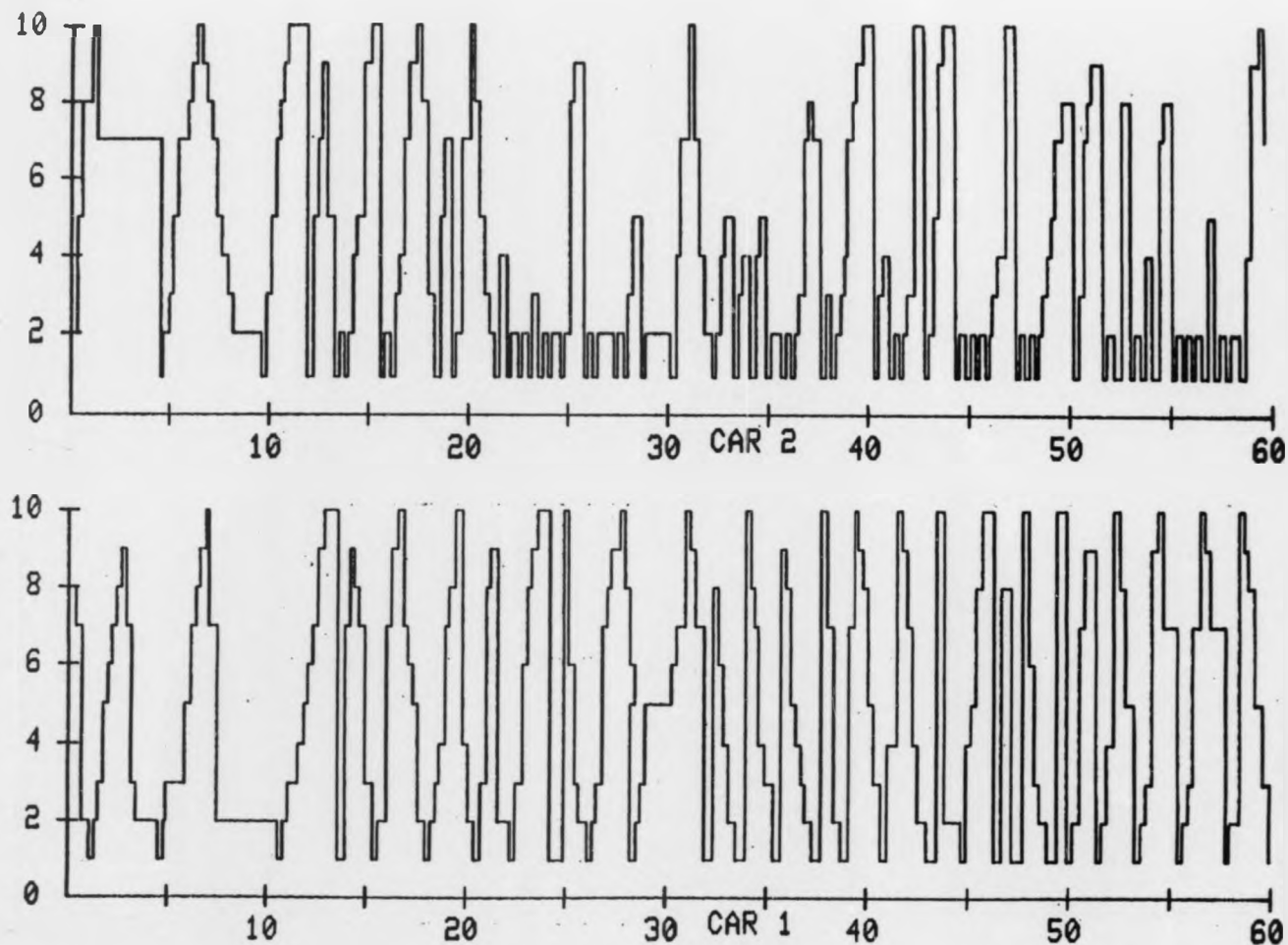
TYPE <CR> TO DRAW NEXT CAR TRIPS(M FOR NEW MODE),(HC FOR HARD COPY).  
 Figure 2.9 Graph of Car Movements

the logged data was found to be of limited use for the analysis of short term variations in traffic or lift system responses.

#### 2.4.1 Detection of Lift System Malfunctions

Much of the recorded data was discovered, upon analysis, to be of doubtful quality due to the presence of malfunctions in the lift system equipment. Such faults had remained unnoticed by lift users and maintenance technicians and only became apparent after analysis of logged data showed unexpected or aberrant behaviour. An example of the nature of a fault which was discovered during analysis is demonstrated by figure 2.10. This shows the spatial history of two lift cars in a group of four plotted over an hour. Car 1 is exhibiting the normal behaviour of a lift car controlled under a full collective algorithm, namely, clearing all calls ahead of it, then reversing and performing the same activity in the opposite direction. This is demonstrated by the successive peaks and troughs on the graph with multiple stationary points between each reversal. Car 2, however, does not behave in the same fashion and for much of the time is continually in motion between floors 1 and 2. The cause of this anomalous activity was located as a fault in the floor selector equipment of car 2. This malfunction unfortunately renders the logged data of little use for the purposes of analysis because of the large number of stops caused at floors 1 and 2 which bear no relationship to passenger movements. Another fault which also becomes apparent from figure 2.10 is that car 2 never stops at floor 6 though the frequency with which other cars do stop demonstrates that passengers are travelling to and from this floor. The presence of these malfunctions is not immediately obvious to users of the lift system since unexpected car arrivals or

PUN NO. 1 DATE 9. 1.76 TIME 11.50 BUILDING ELAND HOUSE  
FLOOR



TYPE <CR> TO DRAW NEXT CAR TRIPS(M FOR NEW MODE), (HC FOR HARD COPY).

FIGURE 2.10 Controller Malfunctions Displayed by Car 2

failures to stop at requested floors can easily be attributed to someone pressing the wrong call button. Thus faults of this nature could persist over a long period and degrade the performance of the lift system by effectively reducing the number of lift cars available to carry passengers.

The analysis procedure is by no means an exclusive search for lift system faults and similarly profound malfunctions may exist in addition to the ones discussed here and remain undetected. Thus if the data gathering process is to be effective, rigorous testing of the lift system must be conducted to purge it of any faults before data logging begins. The complexity of operation of a lift system and the availability of the mini computer used for data logging (which can be quickly reprogrammed) suggest that a very suitable maintenance and diagnostic tool might be provided by a computer. The ease of reprogramming the computer would allow it to operate both fault detection and data logging functions with little change to the hardware.

Diagnostic tests specified for current maintenance schedules fall into two distinct categories:-

- i) Dynamic
- ii) Algorithmic

Dynamic tests include measurements of timings of moving parts such as door opening and closing times and interfloor flight times. Algorithmic tests ensure that the processes by which the lift controller equipment dispatches lift cars in answer to passenger calls are functioning correctly. The latter task is a very complex activity because of the number of possible permutations of car positions and passenger call patterns. Lift controller manufacturers specify a

procedure, for testing a complete controller, which involves creating every possible permutation of conditions with a predicted response for each. A fault condition can be located if the actual response fails to match the predicted one. Algorithmic testing of large lift systems is very complex, time consuming and extremely tedious if conducted by a team of maintenance personnel. Because of the repetitiveness of the tests involved, computerisation of these procedures could be achieved relatively easily resulting in a powerful test facility.

#### 2.4.2 On-line Data Analysis

A second disadvantage of the minicomputer data logger scheme lies in the need to transport data from the building where the lift system is situated to a PDP 10 installation. Considerable time delays are incurred between the logging and analysis of data and it is thus difficult to observe the effects on performance of, for example, changes in the lift system control policy or door timings. In order to effect improvements to the lift system, it is important to obtain information rapidly relating the efficacy of any adjustments. In this way an iterative process of improvement may be employed whereby each adjustment may be evaluated before the next is made. This approach requires that data analysis be immediately available in the lift motor room. When this difficulty was realised, some analysis facilities were incorporated into the data logging minicomputer, these functions only being performed when the computer would otherwise have been idle. However, the analysis that can be performed is limited to tabulations of data which give only a restricted insight into the lift system operation. This was found to be inadequate for the purposes of the research being attempted.

On a longer time scale, it was found that the remoteness of the analysis equipment resulted in difficulties for the analyst in relating results to the features of the building and its traffic. It thus becomes obvious that the analysis and logging operations could become more efficient and useful if sophisticated data processing could be achieved on site to run concurrently with the logging activity.

#### 2.4.3 Implications for the Lift Industry

The development of data logging, diagnosis and analysis equipment which operates on site to process information from an active lift system arose out of a need to compare simulated data with data from the real world for research purposes. However, it was soon realised that these facilities could greatly improve the quality of lift system maintenance and long term management if they were made available, as general purpose accessories to standard lift systems. The timing of these developments is particularly fortuitous as the increasing height of buildings and consequent complexity of lift systems, and the decreasing cost of the necessary technology on which to implement these ideas, create a favourable environment for their realisation. The following chapter considers the requirements of lift system users and owners with regards to these facilities and discusses their implementation.



Chapter 3

Proposal For Lift Management

### 3.1 Introduction

The concept of lift management has developed as the next logical stage in a research program, spanning several years, at UMIST concerning many aspects of lift system technology. This work has been conducted in association with William Wadsworth and Sons, Bolton, and latterly with Lift Design Partnership, Bolton. Current objectives include relating the considerable weight of theoretical research and simulation studies to operational lift systems in real buildings. This involves the acquisition and subsequent analysis of comprehensive data concerning the activity within a lift system to provide an insight into lift usage.

Lift management describes the continued adjustment of a system of lifts in order to optimally "tailor" their lifting service to the requirements of the building in which they are situated. Without lift management, those involved in design and maintenance of the lifts in a building are not in possession of sufficient data concerning traffic, utilisation of resources, faults etc., to be able to improve upon a manufacturer's standard installation. Under such circumstances the building occupants must "tailor" their requirements to the service provided by the lifts.

#### 3.1.1 Working Environment - Commercial Buildings

In a large commercial building the maintenance of the lift system is generally under the supervision of a building manager who will also be responsible for other facilities provided for tenants such as heating, lighting, air conditioning etc. The building manager is thus no specialist in lift technology nor can he devote more than a small proportion

of his time to monitoring the performance provided by the lift system. His primary concern is that the lifts should be mechanically operational and capable of carrying passengers. This task could be greatly simplified if an alarm were raised automatically to warn the building manager whenever a lift car became out of service. However, in a busy commercial environment, it is also important that the more subtle features, affecting the efficiency with which passengers are carried to their destinations, are optimally adjusted. A building manager thus requires some method by which lift system performance may be measured. If it is discovered that improvements can be made, for example to the lift system controller policy, then it is necessary for access to be available in order to realise these changes. Ideally it should be made possible to continually adjust features of the controller to ensure optimal performance in spite of changing traffic demands. Obviously control of such a regime would have to be automatic or it would occupy all the building manager's time. Finally, it may be that loss in performance is the result of some small malfunction and it would be a considerable advantage if such faults could be diagnosed and automatically reported to the building manager as they occur. This facility would also simplify the task of fault location for maintenance staff.

From the above observations, it becomes apparent that the supervision of a lift system could be improved if lift system technology was capable of providing the following facilities:-

- i) Indication of the serviceability of individual cars.
- ii) Indication of the performance of the whole system.
- iii) Flexible control policies
- iv) Indication of current or impending faults within the system.

### 3.1.2 Working Environment - Residential Buildings

A different environment exists in residential buildings. In contrast with commercial buildings, the traffic in a residential block is usually less intense and passengers are prepared to tolerate longer waiting times (within reason!). However, the lifts in several residential buildings are usually under the supervision of one building manager, rather than those of a single block, so that the management task is just as imposing. The residential buildings manager must be aware of the status of lifts in buildings often distributed over several square miles. This is particularly difficult in local housing authority developments where vandalism is an added problem. It is quite possible that malfunctioning lifts attract vandalism from frustrated passengers so that it is important to ensure a rapid repair service. Again an individual is incapable of efficiently executing the management task without the assistance of monitoring facilities. Automatic fault location would also be a great advantage.

Thus the management of lift systems in residential buildings would become much more efficient if the following facilities were available.

- i) Indication of serviceability of individual cars.
- ii) Indication of current or impending faults within the system.

In this case management is primarily concerned with maintenance rather than the more subtle aspects of performance control which are necessary for the high traffic intensities of commercial buildings.

### 3.1.3 Proposal for Lift Management

In the above discussion of commercial and residential building

environments, suggestions are made as to how the task of lift management may be eased for the building manager. It now becomes possible to rationalise these suggestions to form objectives for an integrated and largely automatic lift management system. Such a system would have to be generally applicable in order to be compatible with the wide variety of lift installations and traffic conditions encountered in modern high rise buildings.

The functions of the rationalised management system can be organised in a logical fashion to provide the following unique facilities:-

i) Lift In-Service Indicator (LISI)

A simple test is required to assess whether an individual lift car is capable of executing its basic function of transporting passengers between floor levels in a building. To ensure that the car can perform this task, the ability to open and shut the car doors and to move from one floor level to another must be verified. If these criteria can be satisfied the car may then be declared "in-service". Failure to execute one or both of these functions implies that the car is "out of service".

ii) Lift Equipment Diagnosis and Status (LEDS)

To determine the full operational status of a lift it is essential to regularly check that the performance is in accordance with the lift manufacturer's specification. Such a specification includes two types of data; firstly information relating to dynamic qualities such as timings of car and door movements and secondly information defining the operation of the control policy which governs the assignment of cars for passenger transportation. To

ensure that lift system operation is not degraded because of worn or defective parts, a complete assessment must be made of the lifts, against the manufacturer's specification. Any anomalous responses must be reported with indications of possible causes and recommendations for full rectification.

iii) Lift Monitoring and Analysis (LMA)

While LISI and LEDS provide indication of the correct operation of the lift system no means are provided to assess how well the system is adjusted to meet the demands of passengers. The objective of LMA is thus to provide a definitive analysis of lift system responses to user demands during day to day operation. This involves monitoring and recording activity within the lift system such as registration of calls and movements of lift cars in response, to produce a quantification of the service provided or a performance index.

iv) Lift Optimising Control (LOC)

Present methods of lift system control allow very little flexibility to accommodate the peculiarities of building design and population movements. Building inhabitants are forced to adjust their travelling habits to the service provided by the lift system. The objective of LOC is to monitor passenger demands and automatically optimise the lift system response to satisfy these demands in the most efficient way. Optimisation could be achieved by changing parameters of a lift system control policy such as high demand detection criteria or distribution of free cars and would result in a "tailoring" of the lift system to the building in which it was installed. The lift system would also be able to

accommodate changes in building population or usage that were unforeseeable to the original designers.

At present, no lift manufacturer provides such lift management facilities as an integrated system to complement the lift systems being sold. Some manufacturers have experimented with techniques for gathering data from lift systems, but this work has not produced facilities to aid building owners and managers, who are no specialists in lift technology, in improving lift performance. There seems no prospect of manufacturers producing fully integrated lift management systems since the increased knowledge of the lift system which would be acquired by building managers would erode the position of commercial advantage which manufacturers currently enjoy. Thus if lift management is to become a reality, equipment must be designed which can be added to an existing lift system, or incorporated in a new one, that will provide the complementary lift management facilities described in this section.

Although the functions outlined in this section are described as constituting an integrated lift management system it is advantageous to treat each function as an independent modular activity. This approach allows a lift management system to be configured with just as many of the management functions as are required, excluding those which are not considered necessary for a particular application. For this reason, the management functions will be developed as independent activities and interfaces will be defined which carry information from one function to another. These interfaces will also demarcate the boundaries of functional responsibilities.

#### 3.1.4 Review of Current Lift System Technology

Before discussing in detail how facilities for lift management might be implemented, it is necessary to consider the environment in which they are to operate, in particular the nature of the equipment which performs the basic control functions of the lift cars, such as car and door movements.

A standard multicar lift system controller, typical of any to be found in buildings constructed over the last 20 years, is logically divided into several units. Figure 3.1 shows this typical division of the controller into individual single car controllers and one group supervisory controller. This separation of control functions is made for safety reasons in addition to simplifying manufacturing and maintenance. With this distribution of control, one car may be operated alone with the power to the others switched off. Thus maintenance personnel may test one car in the knowledge that no other cars can move.

All single car controllers in a group are identical and have the following responsibilities.

- i) To control door operations and ensure that door locks are secure before allowing the car to move.
- ii) Full simplex collective control (i.e. answering all calls encountered with the same direction as that in which the car is travelling, continuing to the farthest call ahead with the opposite direction, then reversing and picking up all calls with the new direction which it encounters).
- iii) Operation of all indicators (such as bells and position



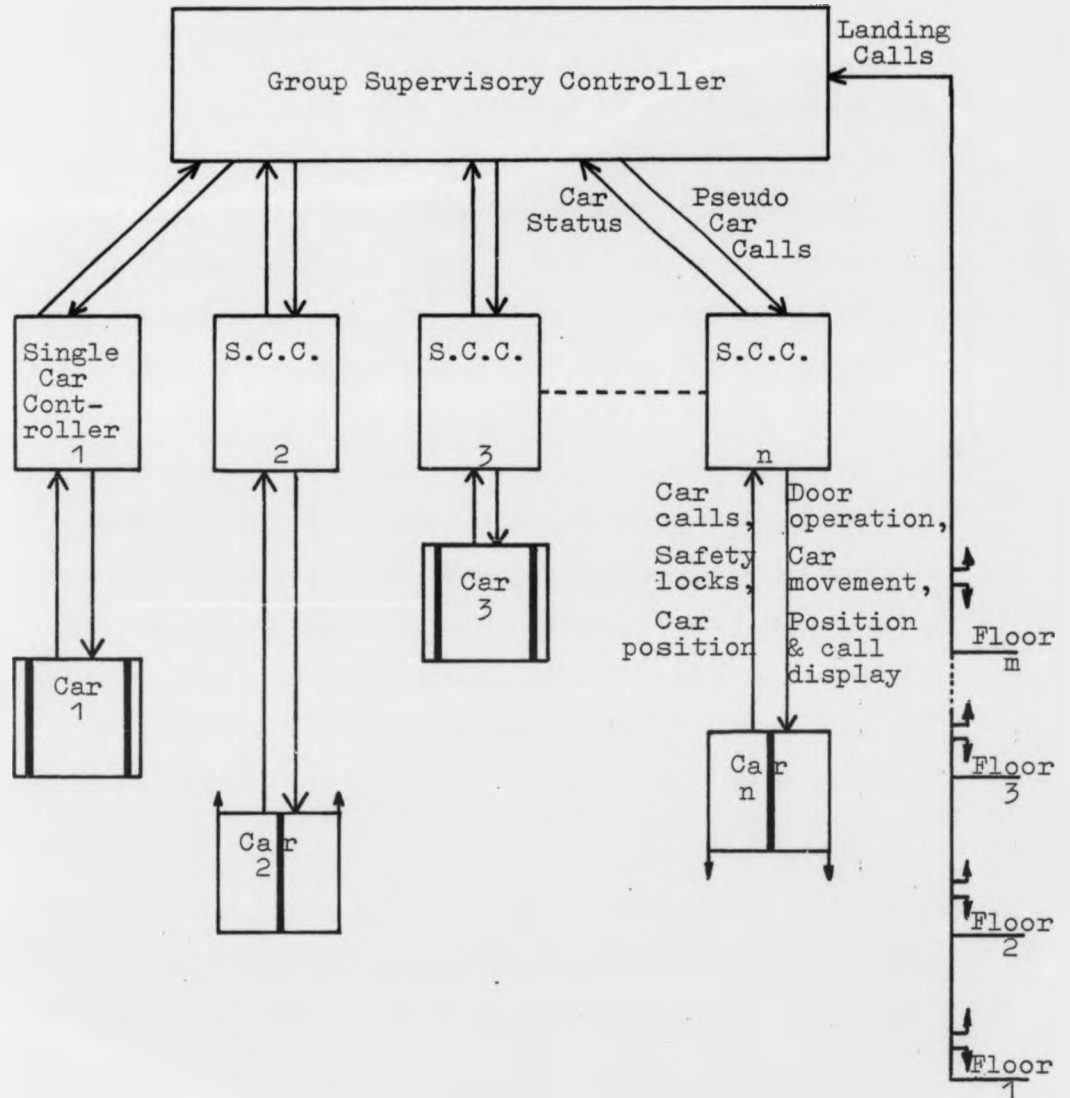


Figure 3.1 Multicar lift control

and direction signs) which relate to one car.

- iv) Other options are usually available to provide special services for firemen and maintenance crews.

As indicated in ii), when the single car controller is working under normal conditions, a lift car is made to stop for every call which requests a stop at a landing which the car is travelling towards. All such calls are serviced before the car is allowed to change direction and respond to calls in its new direction. This means that if the group supervisory controller fails, the single car controller can operate as an independent unit providing some lifting service although it is a poor one. Figure 3.1 shows that while car calls are monitored by the group controller, the group controller distributes landing calls to the most appropriately placed cars to answer them, in the form of pseudo car calls. Thus to operate a full collective algorithm, the single car controller need only ensure that the car moves in one direction while there is still a car call ahead of it and that it stops for all car calls for landings on the way.

The process of assigning landing calls can be very complex or can simply be to locate the nearest car to the call. The complexity of the group controller algorithm for assigning landing calls will vary from one manufacturer to another but it is usually limited by cost and maintenance factors.

Under normal conditions the group controller will continuously reset a timing device and by this mechanism indicate to the car controllers that it is functioning correctly. If the group controller fails, the timer will not be reset and the car controllers will then enter a failure mode of operation, thereby providing a reduced quality

backup service. In this mode car controllers will either answer all landing calls that are made or else answer pseudo landing calls at every landing thus providing a "bussing" service by stopping at every floor.

Although in the past lift system manufacturers have almost always used relay or hard-wired solid state logic in both single car and group controllers, many companies are now investigating the use of microprocessors for this purpose. The attendant advantages of flexibility, very fast reprogramability and compactness are very attractive when compared with relay based logic. However, manufacturers' reticence in adopting this new technology is understandable because of the considerably different skills that are required to work with microprocessors and the investment necessary to set up new manufacturing processes. Thus, in order to achieve compatibility with most lift installations, any equipment used to enhance the operation of a lift system must operate with both the established relay and the nascent microprocessor lift controller technologies. This fact will affect the basic design of any interface between a lift system controller and additional management equipment.

#### 3.1.5 Functional Hierarchy

The description of current lift system technology (in the previous section) demonstrates a hierarchical division of activity within the lift system controller. On the lower heirarchical level, car controllers are responsible for the operation of a single car, each car controller functioning independently of any other. On the higher level, the characteristic pyramid of influence within a hierarchy is displayed by one group supervisory controller which is responsible

for the co-ordinated operation of all the subordinate single car controllers. The group supervisor is thus freed from the task of controlling individual car activity and safety, commands being issued to the single car controllers in terms of car calls only.

A lift system incorporating lift management functions represents an endorsement and upward extension of the hierarchical structure. A single lift management system can be simultaneously monitoring the performance and diagnosing the faults of a number of separate lift systems. Here information is processed in global terms concerning long term activity rather than individual events in each lift system. Optimal control represents an enhancement of the mid level group control function. In-service indication operates at the lowest level by monitoring the activity of a single car.

Figure 3.2 shows a schematic representation of the hierarchical distribution of functions within the lift management system. This figure refers only to distribution of tasks and does not necessarily imply a distribution of hardware.

### 3.2 Components of Lift Management

The basic requirements of a lift management system and the environment in which it will operate were described in the previous section. A more detailed specification for each of the functional components of the system will now be developed. Only the lift in-service indicator has been actually implemented previously, as an operational device. Other lift management components are novel concepts and are thus developed from first principles.

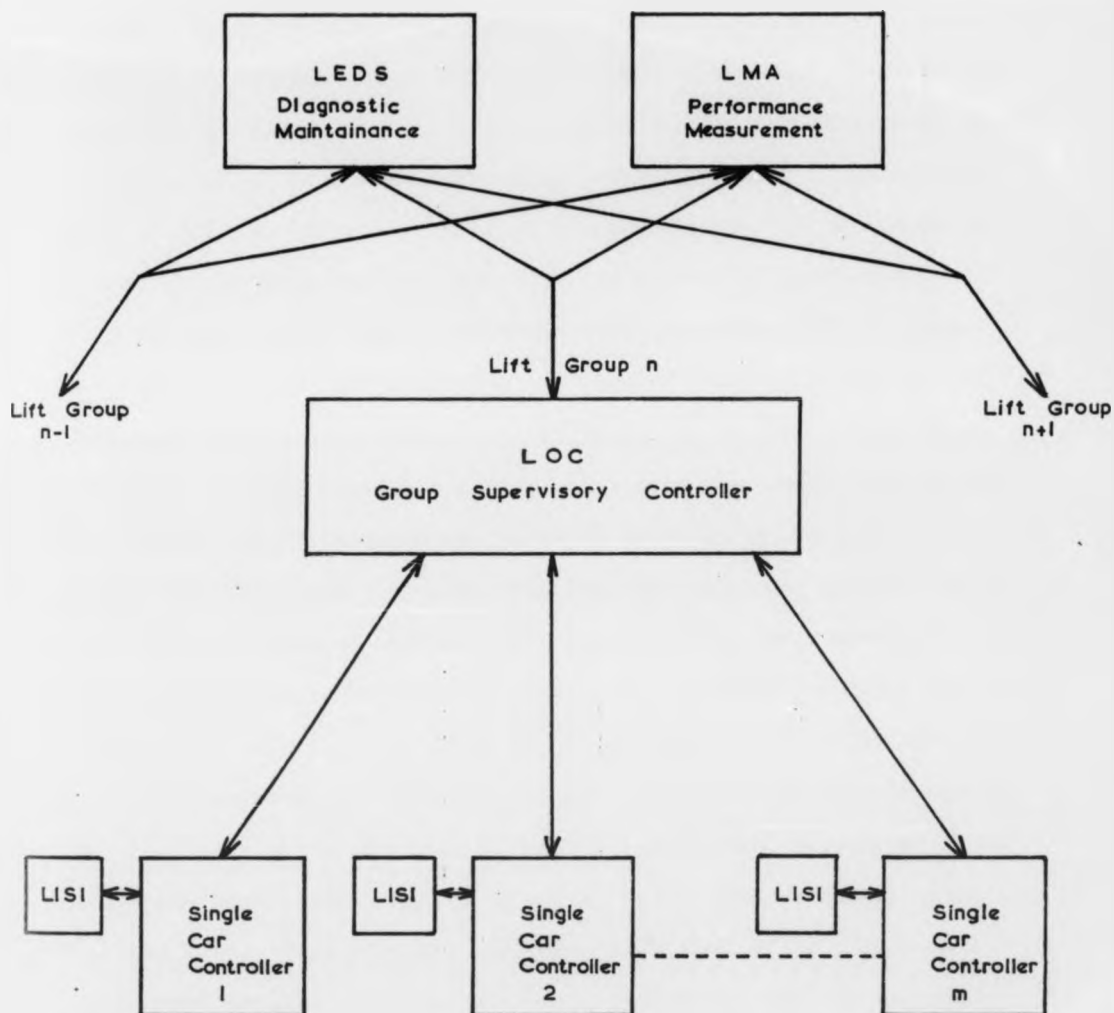


FIGURE 3.2 LIFT MANAGEMENT FUNCTIONAL HIERARCHY

### 3.2.1 Lift In Service Indicator (LISI)

This function, described by Clark (1978) is suitable for independent operation in residential environments (often single car installations) but could be incorporated in a more sophisticated lift management system to complement other status monitoring activities. The criteria upon which a lift car is judged to be in service are that it should be able to move up and down and open and shut its doors. This is considered to be the most basic indication that a lift is capable of carrying passengers to their destinations. If this sequence of events is not recognised within a specified elapsed time, the out-of-service alarm is raised. In the event of no passengers arriving during the elapse time period, the lift could not be expected to move, so before registering the alarm, car calls are injected into the lift by the LISI. If the required sequence of events is still not recognised, the lift is confirmed to be out of service. The building in which the LISI is to be installed must be observed during a prior period to determine a suitable interval for the elapse timer. This should be adjusted so that in the majority of cases (e.g. 99%) a passenger arrives and thus resets the elapse timer before it triggers the LISI to inject calls into the lift. This prevents excessive movements of the lift. A simple data logging device could be used to record the time at which each landing call is registered so that a suitable elapse time may be chosen. Alternatively a counter which records the number of demand calls generated by the LISI could be used to optimise the elapse timer setting after the LISI is installed. A balance must be achieved between extending the elapse time to minimise extra demand call generation, and reducing it to minimise the time during which the status of the lift is uncertain. During quiet periods (for example

at night) the LISI inhibits the call generation function by means of a photo-cell to detect loss of daylight. In an updated version of the LISI, demand generation is inhibited after detecting 3 consecutive periods when no passengers have arrived and car calls have therefore been introduced by the LISI to move the lift. These precautions prevent unnecessary wear on the lift machinery and avoid disturbing residents, living near to the lift motor room, during the night.

In addition to providing an out of service alarm to maintenance personnel, the LISI can also inform the building users that the lift is out of order. A flashing light is installed at the entrance to the lift on each landing and while the lift remains in service the light continues to flash. If the lift becomes out of service the light ceases to flash and intending passengers are thus informed that the lift will not answer their calls. This facility is more relevant to residential environments where lift users cannot easily obtain information about whether the lifts are operational.

Figure 3.3 shows a flow chart of the LISI activity. An individual LISI is required for each car in a lift system. The interface to the lift system is very simple and requires the following signals:-

#### INPUTS

- i) Lift motor ON/OFF
- ii) Doors opening
- iii) Lift operational (logical AND of Lift Power Supply ON  
and Lift Controller on Normal Service)

#### OUTPUTS

- i) 2 car call generation signals.





### 3.2.2 Lift Equipment Diagnosis and Status (LEDS)

The LEDS function replicates the numerous procedures that are stipulated as the approved method of ensuring correct operation of a complete lift system, by the manufacturers. Features which are being examined range from lift car dynamics, such as door and flight times, to complex group operations such as parking in empty sectors.

Measurement of dynamics can be made while the lift cars are in regular use, over a period of an hour or a day. Records of minimum, mean, maximum and number of occurrences should be made. These figures allow determination of not only the mean value but also the distribution of values about the mean to demonstrate consistency in the measured parameter. Typical parameters would be:-

- i) door opening times
- ii) door closing times
- iii) single floor flight time (going up)
- iv) single floor flight time (going down)

In the case of iii) and iv), a considerable variation in recorded values could be expected due to changes in passenger loads and also the weight of the trailing cable, related to the position of the lift car in the shaft.

Examination of the group control features is more complex and requires that the building be empty so that lift cars can be moved by registering test patterns of calls. The responses to such calls are predefined and a fully operational system will reproduce this defined sequence of events exactly. The tests examine the response of each lift car individually, while all other cars are taken out of

service, to ensure that it will respond to up and down landing calls and car calls for each landing level and that it cancels all car calls when it changes direction. These tests are then repeated for each combination of two cars, and additional tests of supervisory algorithms are also made. The number of operational cars is increased until all are in service and at this point the tests and responses become extremely complex. As the responses to the test patterns are observed, any malfunctions in the lift system group controller or simple car controllers can be isolated and diagnosed by associating them with the erroneous test response which they cause. Thus as the tests proceed, maintenance schedules can be compiled to direct the acquisition of spare parts and the replacement of faulty ones.

The comprehensive exchanges of data between the LEDS function and the lift controllers implies a sophisticated interface.

The LEDS function requires two types of input information:-

- i) data relating to timings of lift car dynamics
- ii) data defining each event within the lift system including all calls and car movements. (Although the LEDS function generates all calls, call data must be obtained from the controller to ensure that registration and cancellation of calls is conducted correctly).

No outputs are required by the LEDS function for the measurement of lift system dynamics, but signals must be output to the lift system controllers to generate car and landing calls during the controller status tests.

### 3.2.3 Lift Monitoring and Analysis (LMA)

Data can be obtained from a lift system, with relative ease, concerning registration of passenger calls and car movements in response to these calls. Although data of this nature can describe most of the activity within a lift system, in terms of timed events, it is neither a concise nor easily interpreted presentation of information relating to the system as a whole. Some form of information processing is required when examining data relating to long periods in order to compress it into a few significant parameters which immediately give an indication of the system status. This is the presentation of data which the manager of a large and busy building requires to ensure that the lifts under his supervision are providing a good service. Thus although detailed information is available for reference, the manager is liberated from the onerous task of extricating this information himself. The objective of the LMA function is to present, at an instant, the system status or performance over the last 5 minutes, hour or day in an easily comprehensible form. Because the data produced after analysis is in a very concise form it is important to create a means of presenting a great quantity of information with maximum clarity. For this reason tabulations of parameters are avoided. Graphical presentation of data conveys much more information, especially concerning trends. In this application it is more important for the user to be able to scan a large amount of data to observe trends than to cross-correlate absolute values as in a tabulation. The clarity of a complex data presentation may be further enhanced by graphical techniques such as Kiviat plots (Kiviat, 1973) or the use of colour.

The exact nature of the analysis performed and data which is

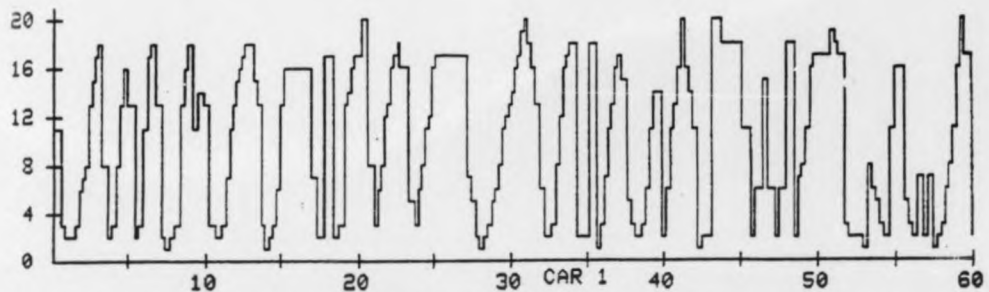
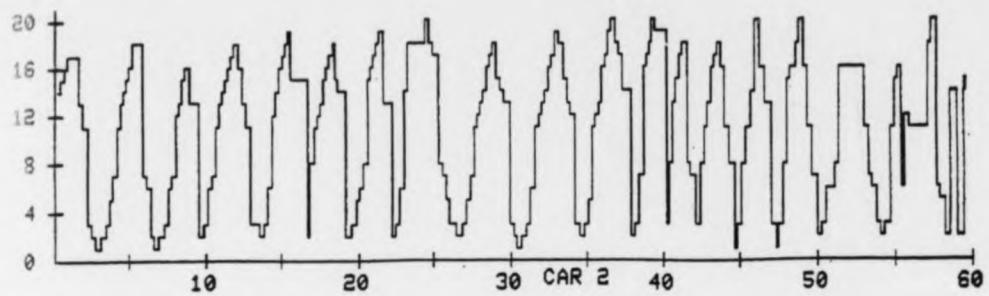
presented will depend to some extent upon the particular requirements of the building manager. Typically, analysis would yield graphical data on:-

- i) Lift car movements around the building (e.g. figure 3.4).
- ii) Variation in call registration rate with time of day  
(e.g. figure 3.5).
- iii) Variation in car stopping rate with time of day  
(e.g. figure 3.6).
- iv) Variation in system response time with time of day  
(e.g. figure 3.7)

(NB. System response time is the time between the first passenger on a landing registering a call and a car arriving in answer: defined by Barney (1977, p 273).

These displays demonstrate the changes in various parameters according to the traffic patterns at a particular time of day, or faults which subsequently change the operating characteristics of the system. A much more useful presentation would be a simple display which conveys a complete description of the lift system performance. This could be generated in the form of a Kiviat graph, where a pointed star with points on the North, East, South and West axes represents optimal performance (figure 3.8). A similar display is described by Hung (1979) for the performance analysis of computer systems. Four axes (N,E,S,W) of the graph represent parameters which are to be maximised to optimise performance while the other four axes (NE,SE,SW,NW) must be minimised.

As with computer performance control, lift management is a task

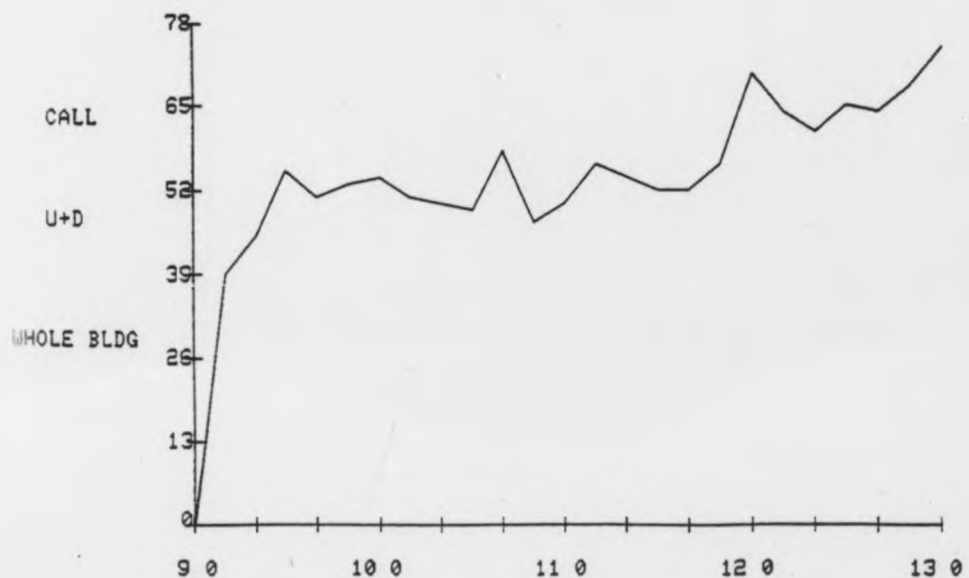


TYPE (CR) TO DRAW NEXT CAR TRIPS (M FOR NEW MODE), (HC FOR HARD COPY):

FIGURE 3.4 Graph of Lift Car Movements

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 9: 0



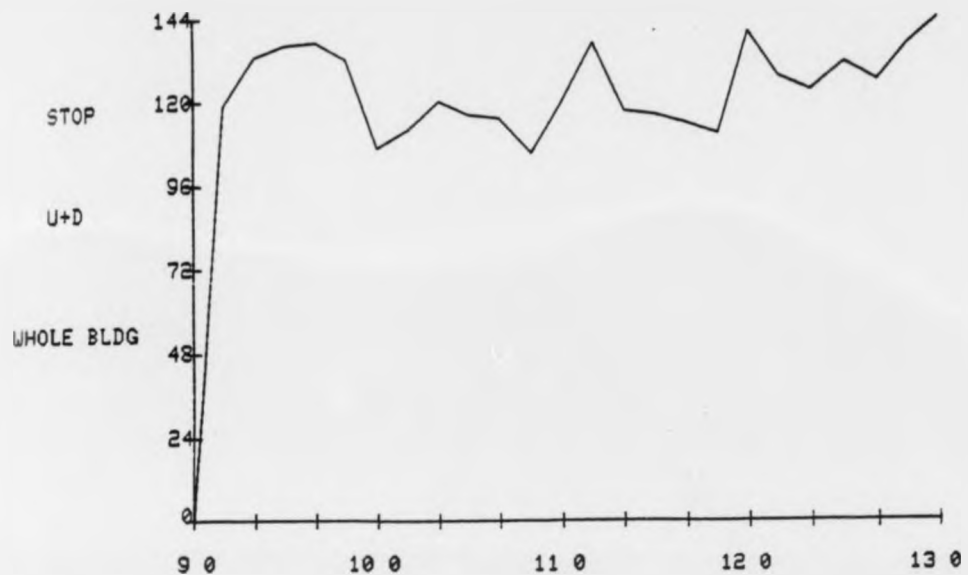
NEXT (R/C/N/E/H)?

FIGURE 3.5 Graph of Call Registration Rate

STO EX

SAMPLE TIME 10 DATE 14 10 77 START 9 0

51.

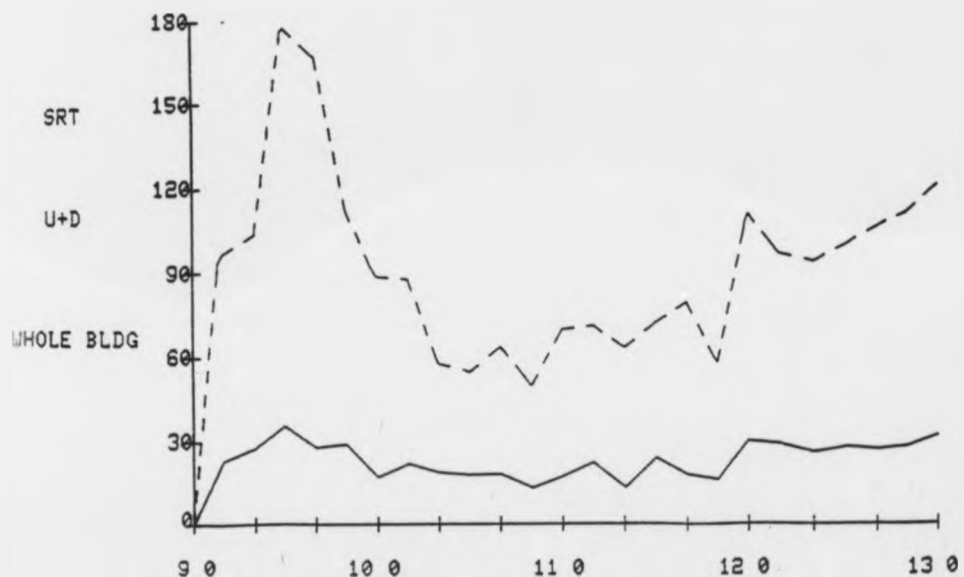


NEXT(R/C/N/E/H)?

FIGURE 3.6 Graph of Stopping Rate

STO EX

SAMPLE TIME 10 DATE 14 10 77 START 9 0



NEXT(R/C/N/E/H)?

FIGURE 3.7 Graph of System Response Time (mean and max)

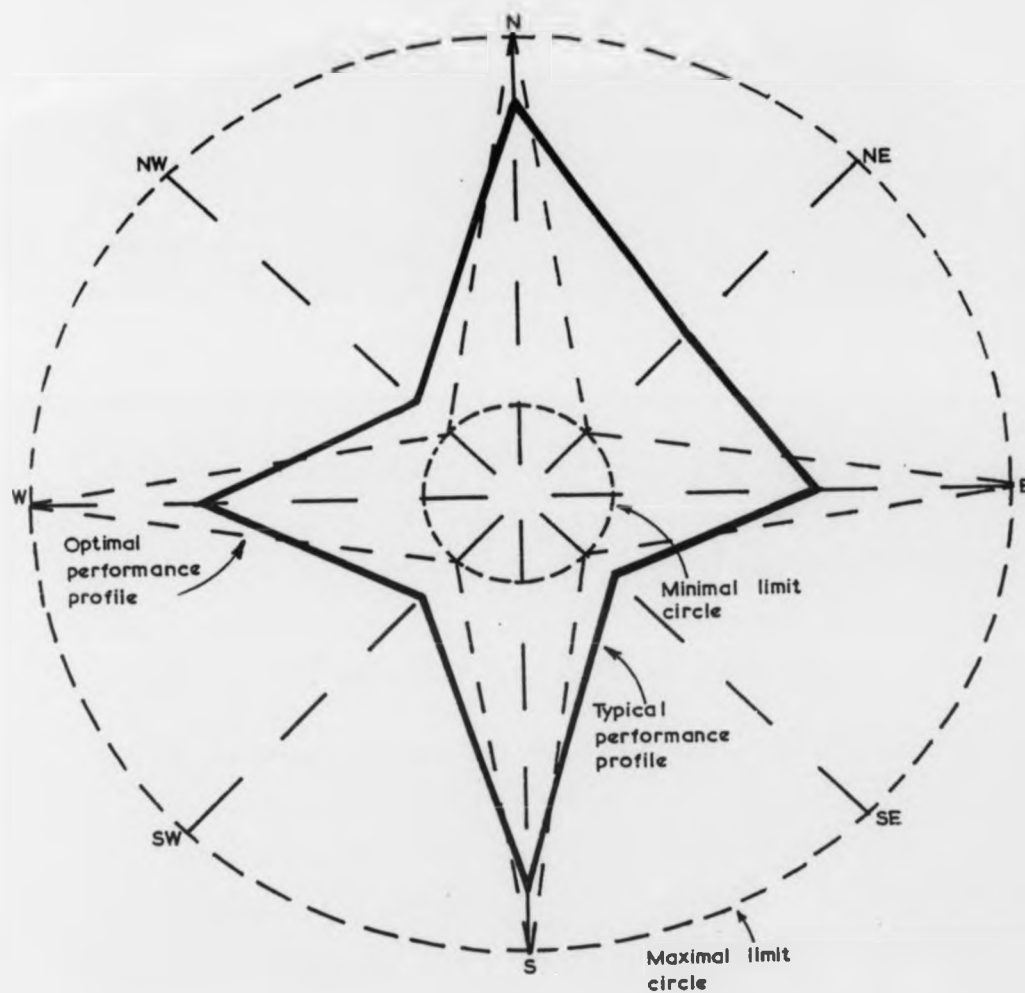


FIGURE 3.8 Kiviat Graph

of balancing a number of mutually opposing parameters. For example, while system response time should be minimised, handling capacity should be maximised, though improvement in one is not necessarily achieved without degradation of the other.

By monitoring all parameters which affect performance, as in the Kiviat graph, optimality may be approached. The variations in performance during the day may be demonstrated by displaying in quick succession the performance graph for each consecutive five minute period of the day.

In order to be able to conduct analysis of lift system performance over extended periods the LMA function must have access to historical records of the lift activities during that time. These records should be composed of enough information to describe the status of the system at any instant. Thus input data requirements for LMA are:-

- i) Registration and cancellation of all calls to be defined by source, position and direction.
- ii) All arrivals and departures of cars at landings, to be defined by car and position.
- iii) Door openings and door closings, to be defined by car.

Thus data relates to events within the lift system and each event is related to the time at which it occurred. The LMA function is a monitoring activity and therefore produces no output to the lift system. However, a sophisticated man/machine interface must be created in order to present graphical data to a building manager.



#### 3.2.4 Lift Optimising Control (LOC)

The patterns of traffic within a building are unlikely to be static over long periods, since staff distributions and tenants will inevitably change. Furthermore, during the course of a single day, traffic demands are probably subject to continual change for reasons such as coffee breaks, meetings, lunch hours etc. Thus to provide efficient traffic handling and follow the precept of lift management, namely to "tailor" the lift system to the needs of the building, it is important that the lift system controller should be capable of dynamically adjusting its control policy.

Unfortunately most controllers, manufactured to date, have been implemented in hard wired logic (usually relay logic) which implies that they are not easily reconfigured to produce a variation on the original algorithm. It is even less practicable to consider a dynamically self adjusting control policy for such controllers since this would involve unacceptable complexity and cost in equipment. The more sophisticated controllers may be equipped with primitive load weighing facilities or time switches which bring into operation special up and down peak traffic handling algorithms but do not measure the improvements gained from such strategies.

Although truly dynamic optimising algorithms are not available commercially, research has been conducted (Closs 1970) into the use of computer based controllers which dynamically allocate a call to the lift car most suitably placed to service it. This decision is based upon which car can answer the call in the shortest time or, if the passenger's intended destination is known, which car can take the

passenger to his destination in the shortest time. However, for the passenger's reassurance, the following restrictions are made:-

- i) A car may not pass a floor at which a passenger wishes to alight.
- ii) A car may not reverse its direction whilst carrying passengers.
- iii) A passenger may not enter a car travelling in the reverse direction to that requested.
- iv) A car may not stop at a floor at which no passenger enters or leaves the car (while passengers are still being carried).

Additionally long term control decisions may be made by monitoring performance parameters such as those generated by LMA in order to optimise performance. In this mode the controller could adapt to the peculiarities of a building by "learning" which control policies yielded the best performance under particular traffic conditions and the most efficient parking distributions. Also, peak demand periods could be anticipated and special policies implemented to handle them.

The LOC function must obtain status information from the single car controllers of the lift system and must also be able to instigate car calls within the car controllers. Thus a sophisticated interface must be developed to transfer this information. At a higher level, the LOC function will receive performance information from the LMA activity. This information is in a highly refined form and bears little relation to individual car movements.

### 3.2.5 System Communications

The functions of lift management all have requirements for transfer of information which is derived from or destined for the lift system. To prevent duplication of the information transfer

task a common process will be designed that can provide communications to any lift management function from a single interface to the lift system. The information requirements of each lift management function have been described in the previous sections and are summarised in figure (3.9).

It has already been mentioned in section 3.1.3 that all lift management functions should be modular and independent. It should therefore be possible to include in a management system only those functions which are required for the particular application. The following examples demonstrate how different configurations of lift management systems might arise and more importantly, illustrate the need for a flexible interface between the management system and the lift system.

- i) It may be required to operate LMA and LEDS without LOC to monitor performance and provide status information for an existing lift system without disturbing the original relay logic controller.
- ii) In a new building it may be desired to implement a complete management system incorporating all lift management functions. LOC is only practicable if a computer based lift controller is installed because of the dynamic flexibility of control algorithm which is required.
- iii) Though undesirable because of the extra complexity involved, a configuration might arise where a computerised lift controller supporting LOC is installed alongside a backup relay based controller. The relay controller would thus only become active if the computer controller failed. Such a system

FIGURE 3.9 I/O Requirements for Each Lift Management Function

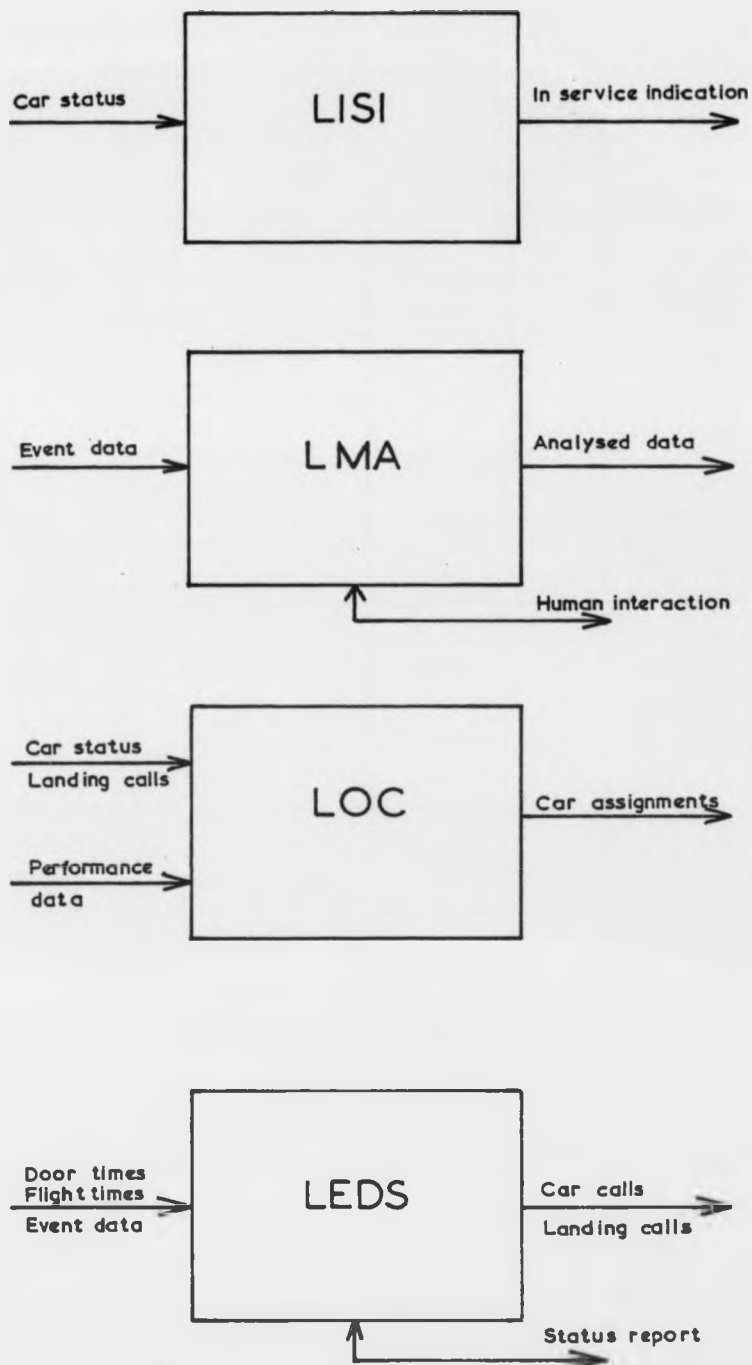


Table 3.1Possible Controller Hardware Configurations

GROUP CONTROL	CAR CONTROL	PRACTICABILITY	COMMENTS
Computerised	Computerised	Desirable	Simplest to implement and most suitable for lift management
Computerised	Conventional	Not practical	Not feasible because of ill-defined interface to most conventional car controller units
Conventional	Computerised	Undesirable	Possible, if management insist on backup relay for computerised group supervisor
Conventional	Conventional	Possible	Could be used to monitor performance of conventional controller in existing system

might be installed if the building management were unsure of the reliability of the new technology and demanded a backup controller with which they were familiar.

Thus the interface between the lift management system and the lift system may vary considerably depending on the type of lift system controller used. Table 3.1 lists the various combinations of controller technologies which might be encountered. The controller is divided between single car and group supervisory control since in the case of the system using relay backup (example iii), when the backup is operational a relay group controller will be operating computerised car controllers.

In order to maintain a unified approach to data transfers between lift systems using diverse technologies and the lift management system, it was decided to design an adaptable interface. This acts as a front end processor to the lift management system and is implemented in some form in every application. By virtue of this front end, the lift management system obtains data in the same form, irrespective of the nature of the information source. When a lift controller employing conventional technology is used, data is obtained directly from high voltage sources within the lift system. These signals are interpreted and messages conveying status information are composed and passed to the lift management system. When a computerised lift controller has been installed, status messages are compiled from data transfers within the controller computer. Thus duplication of high voltage interfacing circuitry is avoided. The front end processor and lift system controller can be considered as a functional unit. In instances where computerised lift control

is not required, the controller activity is merely removed so that the front end processor acts as a translator of information between lower hierarchical levels and the analysis and diagnostical level of the lift management system.

The basis of the data gathering process is described by YIP (1979). In addition to data gathering, the front end processor must be capable of sending data into the lift system according to commands from the LEDS activity.

The proposed system will require communication over long distances (e.g. between two lift motor room installations). For this reason a high speed and secure communications link will be employed which is described in more detail in the following chapter.

#### 3.2.6 Summary

Four independent activities have now been identified as being important functions of a general purpose lift management system. The designs for these functions have been formulated with the various needs of building managers of both commercial and residential buildings in mind. The proposed management functions will relieve building managers of what has become a complex and exacting task due to the increasing complexity of the lift systems under their supervision.

## Chapter 4

### Functional Specification For A Lift Management System

In the previous chapter, the idea of a lift management system, to simplify the work of a building manager, was developed. The operation of each management function was given in broad outline. In this chapter, the design of each function is considered.



#### 4.1 Hardware for Lift Management

The use of computers to perform lift management functions has been discussed briefly in a previous section. In the following section, hardware requirements for lift management will be described in detail.

##### 4.1.1 Suitable Technologies

The complexity of operation and the flexibility required of the lift management functions preclude the use of any technology other than digital computers for all processing except the LISI activity. Computers offer the following unique attractions:-

- i) Fast programming/reprogramming allowing modifications to be made with a minimum disturbance to users.
- ii) Different tasks may operate on the same hardware, thus cost and complexity of hardware is not directly related to the complexity of function.
- iii) Sophisticated maintenance and self diagnosis can be programmed into the equipment itself.
- iv) Long life and reliability because of a minimum of moving or heat-producing parts.

These features compare favourably with the conventional technologies used by lift manufacturers, which is important, because a certain amount of mistrust might be engendered by the introduction of new techniques.

The LISI function, in contrast, is simple enough to be implemented in solid state TTL logic.

##### 4.1.2 Communications Hardware

Reasons have already been given for adopting a modular structure

for the lift system controller. Most importantly this gives the lift system the ability to continue to operate, though at a reduced efficiency, when faults have occurred. Advantages also accrue from implementing lift management functions on distributed and modular hardware. In particular, this allows presentation of data to a building manager in his office, thus obviating the need to visit the lift motor room to investigate the status of the lifts. Furthermore, by virtue of the hierarchical nature of the lift management system, the building manager could monitor and supervise several lift systems which are distributed throughout a building, via a single analysis and diagnostics level computer system.

However, in order to realise a distributed computing system of this nature, a sophisticated, fast and secure communications network is required. Transmission should be possible over distances of hundreds of metres and the communication channel must therefore be restricted to a two wire connection as a multiwire system would prove prohibitively expensive. Additionally, there may be restrictions on the installation of new wiring within buildings which are already cluttered with other environmental and communications services.

Freitas (1979) describes a communication system for distributed data acquisition and control (D-DAC) which requires only a single pair of wires to which any number of communicating stations can be connected. Any station can initiate communications with any other station via a defined protocol. This system will be used to provide all necessary long distance communications requirements of the distributed lift management system.

#### 4.1.3 Requirements for Lift Management Hardware

This section contains firstly, generalised hardware requirements followed by details of each individual lift management function.

##### 4.1.3.1 General Hardware Requirements

Consideration of the working environment and financial limitations must be made before any details of functional hardware may be discussed. The following general points should govern the choice of hardware.

i) Noise immunity.

The lift motor room is an electrically noisy environment because of the continual switching of high currents to the lift motors. Thus signal paths should be shielded against electromagnetic radiation and power supplies should employ filters to minimise the effects of transients.

ii) Dirt protection and robustness

The lift motor room can often be dirty so computer systems should be insulated from their environment by a suitable casing and cooling air should be filtered. The casing should also be capable of withstanding reasonable physical maltreatment.

iii) High voltage isolation

Computers should be completely isolated from the hazardous voltages employed in the lift system. High voltage circuitry should be housed in a separate enclosure from computer equipment to prevent damage from accidental short circuits of high voltages into the computer.

iv) Printed circuit boards

All circuitry should be mounted on printed circuit boards which are interfaced to a standard bus structure by edge connectors and supported in a rigid card cage.

v) Separation of power supplies

Each computer should be powered from an independent low voltage supply to ensure that failures in external equipment do not hamper internal operation. This is also required by maintenance personnel who need assurance that circuitry they are working on is completely isolated.

vi) Separation of bus structures

Different computer systems should not share the same bus structures to ensure that a failure of one system does not halt the other. Communications should take place via electrically buffered input/output ports.

vii) Fail safe design

Hardware must always "fail safe" so that no failure, however unlikely, can endanger users of the lift system.

viii) Minimal system

Because of the large number of individual computers incorporated in a lift management system, care must be taken to minimise both the cost and size of all components so that the overall system is acceptable to owners and management of the building. For this reason, large scale integrated technology, such as microprocessors will be used throughout even for the more sophisticated applications requiring a man/machine interface.

ix) Standardised hardware units

Compatible computer hardware should be used throughout the

system. This allows the same program to be run on several different hardware units and reduces the quantity of spare parts necessary to maintain the system.

The discussion will now consider hardware requirements for a complete lift management system, commencing with the lowest heirarchical level, the simple car controller, and concluding with the analysis and diagnostics level.

#### 4.1.3.2 Single Car Controller

Although the single car controller has been previously defined as being part of the lift system, rather than being a lift management function, design details are included which will provide a suitable interface for a microprocessor based group controller, supporting LOC.

A single car controller does not require much processing power and does not utilise sophisticated peripheral devices, such as disks and terminal equipment. Thus, a simple computer will suffice for this application, probably comprising two or three printed circuit boards carrying about 1Kbyte of data memory, 8Kbytes of program memory and a number of I/O ports. Experience gained in the U.S.A. shows that a system of this size based on a Z80 microprocessor, is capable of driving two lift cars. Circuit boards should be housed in a rugged enclosure which will protect them from electrical noise, dirt and physical damage, with their own internal power supply. High voltage circuitry should be housed in a separate unit. Communications with the group supervisory controller should be conducted via an electrically buffered bidirectional port with handshake control. Figure 4.1 shows the single car controller hardware in block diagram form.

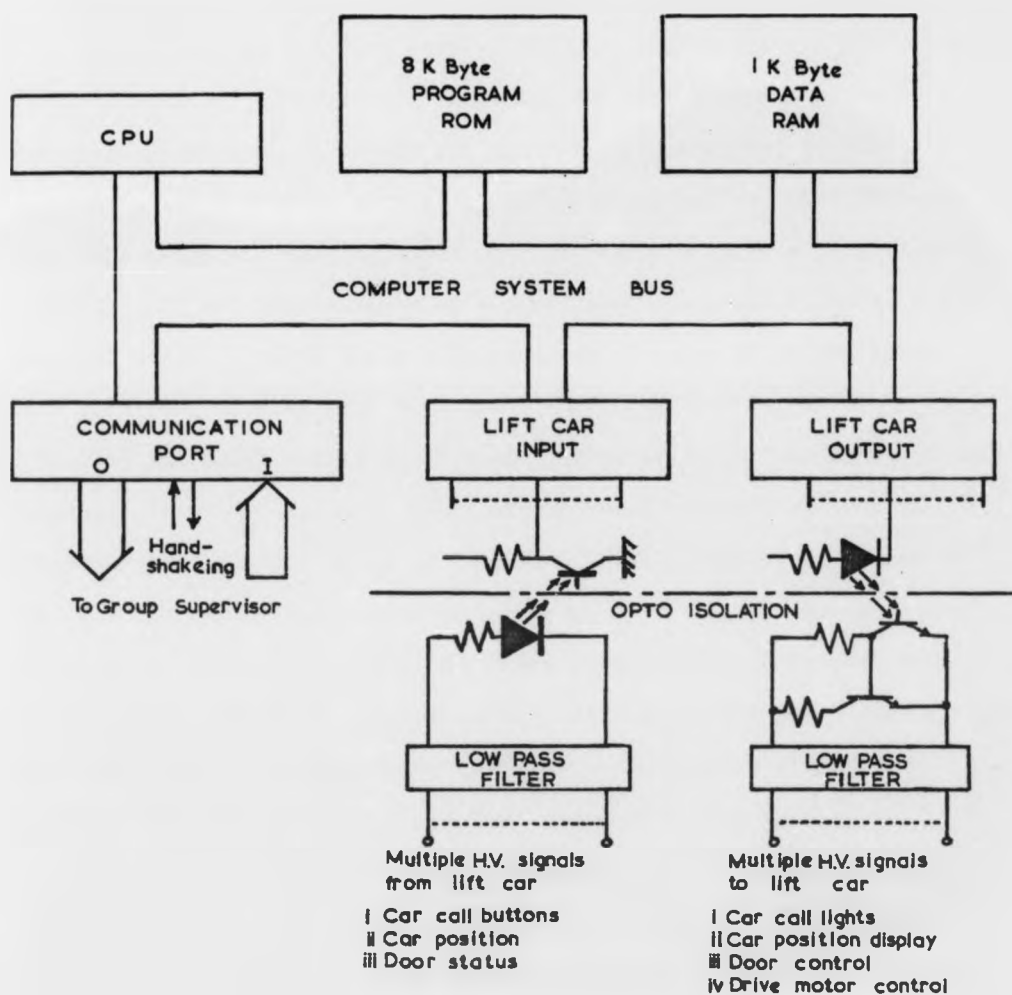


FIGURE 4.1 Single Car Controller Hardware

#### 4.1.3.3 Group Supervisory Controller (Supporting LOC)

A number of lift systems with microprocessor control are now commercially available, eg see Miller and Wareing (1980).

(Barney, 1977, p.121) suggests that four separate groups of six, twenty-four person cars serving all floors of a twenty four storey building could be controlled by a single PDP11/10 minicomputer with 16K bytes of memory. Although the control algorithm used in this estimation was a dynamic sectoring process which may be quite different from that which will be run under LOC, the above example does give some indication of the requirements of a supervisory controller for a single group of lifts. Thus a 4 MHz microprocessor (nearly twice the speed of a PDP11/10) working with 8bit bytes (half the word length of a PDP11/10) and complemented by at least 16K bytes of on line memory should provide a suitable system on which to implement supervisory control for more than a single group of lift cars. The hierarchical nature of the lift system ensures that only one group of lifts will be supervised by one group controller, therefore spare capacity should be available with which an additional communications task can be handled. Communications with high level lift management functions are conducted via a D-DAC network. The DDAC interface consists of a complete microcomputer subsystem with internal bus structure, mounted on a printed circuit board, but which interfaces to the main system as a peripheral device. Landing call information is collected from the lift system via standard high voltage isolation circuits as used elsewhere in the system. Figure 4.2 shows the hardware of the microprocessor based group supervisory controller in block diagram form.

In certain cases, it may be desirable to interface a lift management system to a group of lifts with a conventional controller. Under such

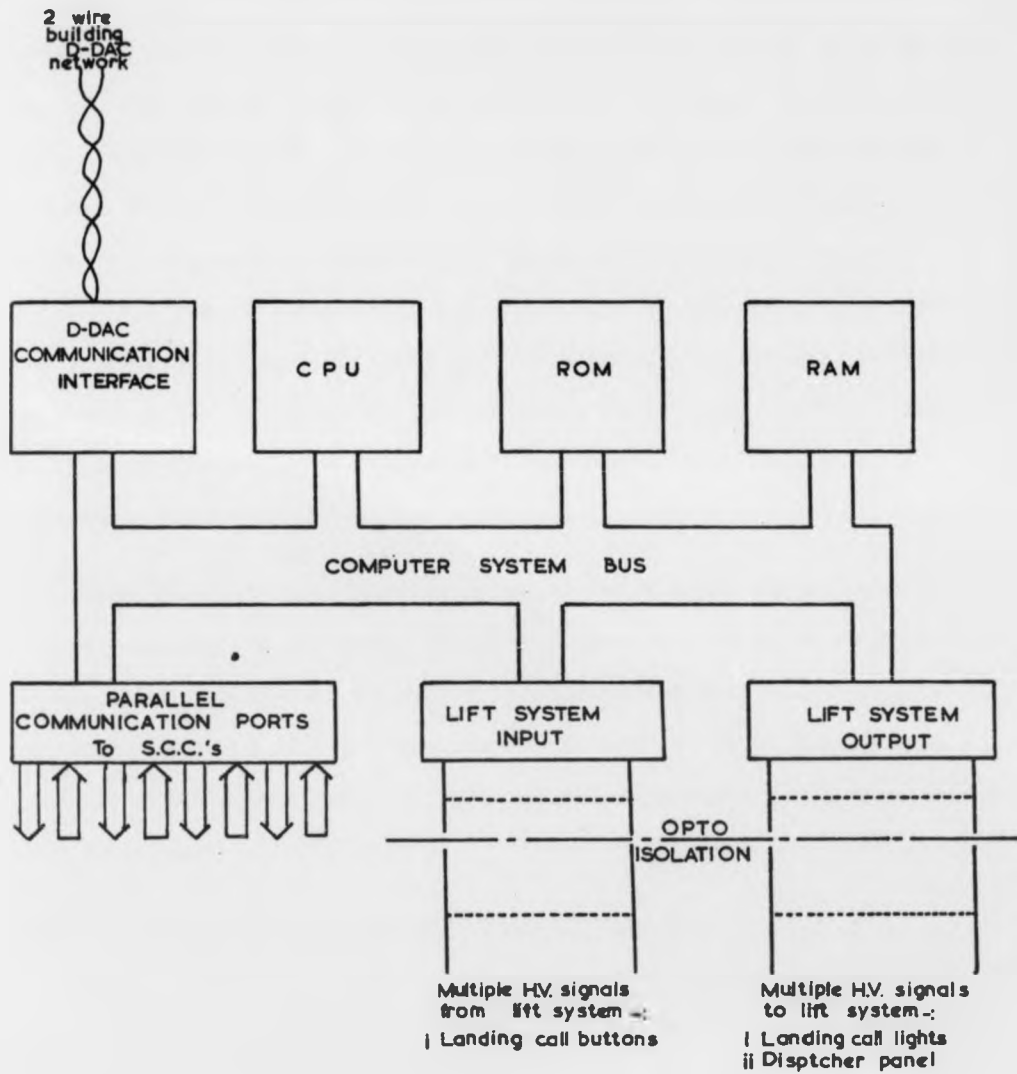


FIGURE 4.2 Group Supervisory Controller Hardware



circumstances the control aspect of the proposed group supervisor becomes redundant but the communications task is still required to transfer data between the lift management system and the lift system. Additionally, data gathering hardware is required to interface to the high voltage signals within the conventional lift controller via extra isolation circuits. However, the essential computer system remains the same except that memory demands are much smaller. By employing this approach, the interface to the high level lift management functions is unaffected by whatever low level controller configuration is implemented. Figure 4.3 shows hardware block diagram for the conventional controller interface.

Finally, facilities must be provided for a mechanic to connect simple equipment to the group controller equipment so as to be able to instigate manual control over lift cars during maintenance. This equipment could be simply a replica of the control panel inside each lift car which communicates to the controller hardware via a parallel port interface.

#### 4.1.3.4 Diagnostic and Analysis Computer System

Both the LMA and LEDS lift management functions provide an interface to a human operator. Thus, in addition to being, themselves, complex computing tasks, they require the support of a sophisticated operating system to provide a suitable working environment for an inexperienced user. Additionally both tasks are required to operate from the same location, the building manager's office, and are never both fully active at any one time. It is thus advantageous to execute both tasks on one generalised computing system in order to avoid duplicating equipment costs and to simplify the man/machine interface.

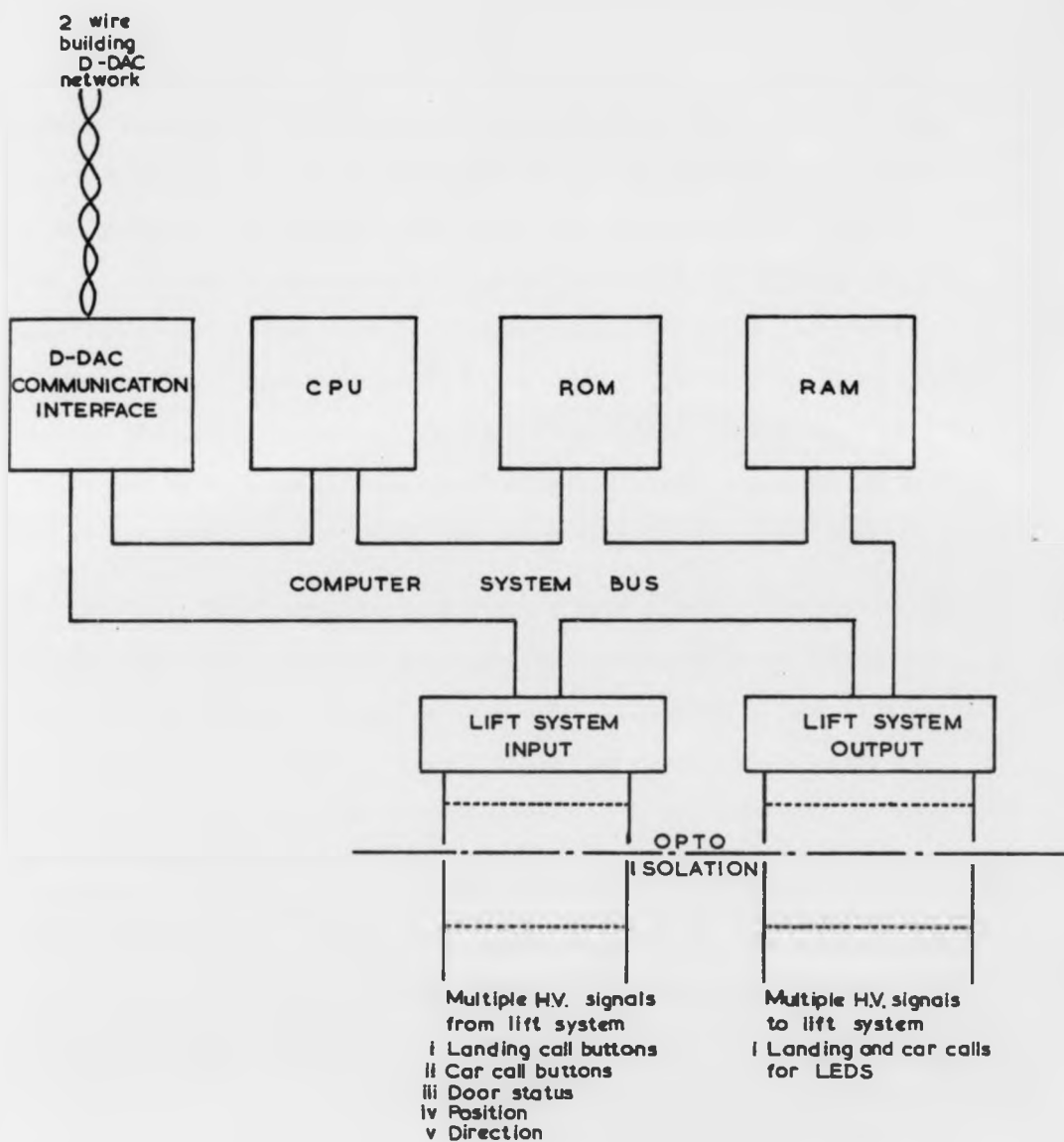


FIGURE 4.3 Interface to Lift Systems not Incorporating Computer Control

The programs to be run are complex and large and will require a computing system with at least the full complement of random access memory, addressable by a standard microprocessor with 16 bit address bus (64K bytes). To store the large amounts of data associated with these programs, and perhaps additional programs too, a backing store will be required to supplement the main memory of the system. A moderately fast access time is necessary but cost is an important consideration. Paper or magnetic tape is not suitable for this purpose because the serial nature of the recording process incurs unacceptable delays during data retrieval. Hard magnetic disks, while offering fast access are expensive and bulky and are therefore also unsuitable.

The most cost effective solution is thus floppy disks or perhaps a combination of floppy and the recently introduced "mini winchester" hard disk technology. These devices offer between 0.25 and 11 M bytes of storage. Floppy disks are well suited to data storage since they are easily loaded and removed from drive units and can thus be archived in a substantial library of disks containing records of lift system activity over long periods.

There will be a requirement for graphics in this application, to display information to the user. In this case, colour graphics, would be particularly desirable, since a single display can contain more information and will be more attractive to view. High resolution is unnecessary since displays are only to indicate trends. Drivers for colour raster scan display devices, such as televisions, are now widely available. These drivers are configured as banks of memory which interface directly to computer system busses, so that connecting a colour display to the proposed computer system becomes a trivial task.

The user will be equipped with an ASCII keyboard which, in conjunction with the colour display, will provide an interactive interface. A printer will be used to generate hard copy for status reports and maintenance requirements. Figure 4.4 shows the hardware for this system in block diagram form.

In certain instances, it may be desirable for a management agent, responsible for a large number of commercial buildings, to obtain data or automatic warnings of failures or potential failures within the lift system. For such cases, a second D-DAC interface is provided which is linked by ordinary telephone lines. Thus lift system information can be transmitted across towns and cities to the exact point at which it is required. The remote site would be equipped in a similar fashion to that described for the building manager's office.

For the residential buildings manager's office, similar equipment could be used but requirements will vary considerably. In the simplest case the only equipment at the lift motor room is a LISI unit for each lift car. The status of these devices, multiplexed onto a pair of wires or a telephone line, could be scanned at regular intervals by a very small computer system with just a VDU for a user interface.

#### 4.1.3.5 LISI Hardware

The original prototype LISI device, (Clark, 1978), was constructed using a combination of relay and solid state logic. An update of the circuit has now been reduced to solid state only. It should be noted that dedicated hardware for the LISI function is only necessary when other lift management functions are not implemented, and "in service" information is not available from computer based interfaces.

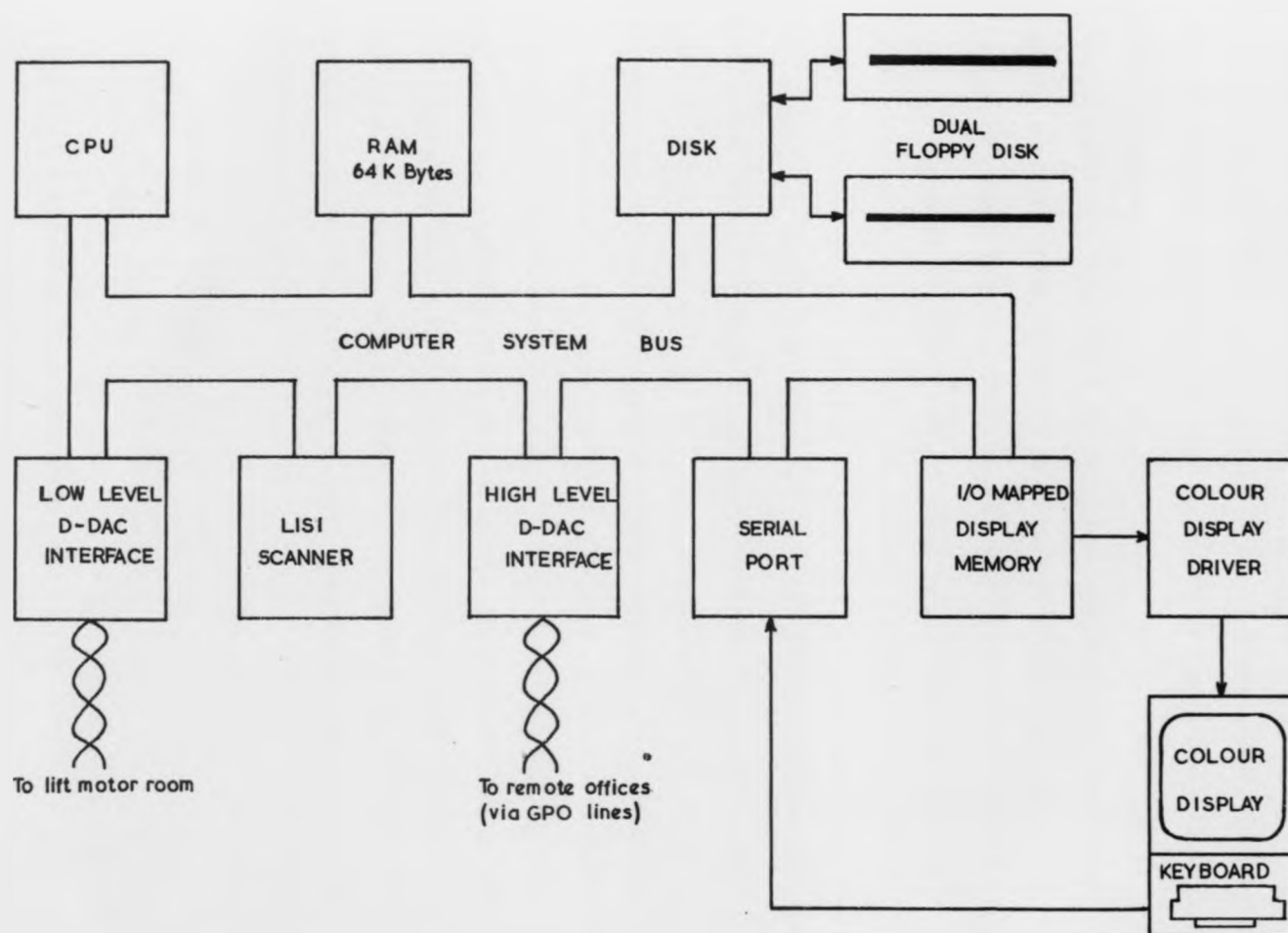


FIGURE 4.4 Analysis and Diagnostic Hardware

Signals to the LISI are received via isolation and voltage reduction circuits. Analogue timers are used for interval timers. LISI incorporates an independent high voltage (50V) supply, which is controlled via relays to energise two extra relays in the car control logic. This high voltage is thus isolated from both the LISI equipment and the lift controller for complete safety. Two car calls must be introduced into the car controller to ensure that the lift car moves at least once, since a car call for a landing at which the car is stationary would result in no movement. The extra relays in the car control logic are thus simply wired in parallel with the circuits for two car call buttons. When the lift is identified as being "in service" the LISI causes a number of high power light emitting diodes to flash with approximately a two second period. A single flashing light emitting diode, encapsulated in a vandal-proof protection, is installed on each landing in the building above each entrance to the lift shaft to inform users of the serviceability of the lifts. A continuous "in service" signal from each LISI is multiplexed onto a pair of wires (or telephone line) which carries the status information to a control monitoring station. A DIGICABLE multiplexing device, as used by Chung (1973), could be used for this application. Figure 4.5 shows the circuit diagram for the solid state version of the LISI device.

#### 4.1.4 Sources of Hardware

##### 4.1.4.1 Standard Hardware

Standard hardware such as processing and memory components for computer systems were chosen from the range of a single manufacturer to ensure hardware compatibility throughout the lift management system. However, the manufacturer, Cromemco Inc. of California, USA., also

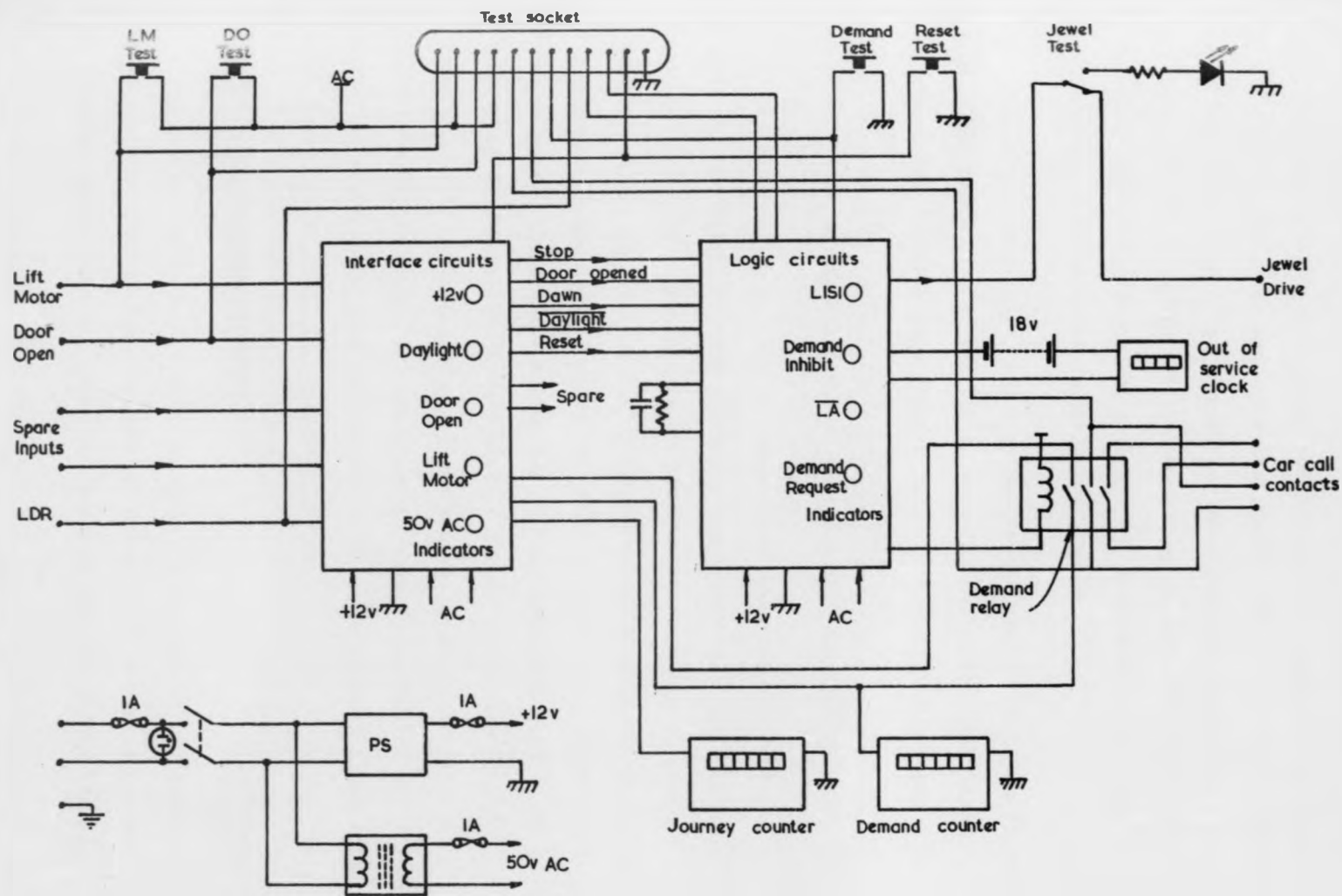


FIGURE 4.5

LISI Circuitry

maintains compatibility with other similar product ranges by adhering to the S100 standardised bus structure (IEEE, 1979). Cromemco products range from small single board computers (suitable for controller applications) to a comprehensive multitasking system with disk store and colour graphics driver (for analysis and diagnostic level work). All items are well made and ruggedly constructed.

Figure 4.6 shows the Cromemco single card computer in block diagram form. The combination of processor, volatile and non-volatile memory, and serial and parallel input/output facilities which are mounted on this single printed circuit card, ensure that it is widely applicable to all the lift management tasks requiring simple processing power.

For more complex processing, there is a comprehensive range of memory and peripheral drivers which are compatible with the S100 bus. These printed circuit boards can be selected to configure a powerful computer system, tailored to the requirements of a specific application. The Cromemco system 2 and 3 computers provide ventilated cabinets with power supplies, floppy disk drives and an S100 backplane capable of carrying up to 21 printed circuit cards. A list of the facilities offered, each on a single printed circuit card, is given in Table 4.1. The ability of the system 2/3 computers to support sophisticated processing tasks makes them well suited to the analysis and diagnostic level functions of the lift management system.

#### 4.1.4 Non Standard Hardware

Customised hardware for lift management will have to be produced under contract (if warranted by demand) where items are not supplied by standard manufacturers. Items in this category are listed below.



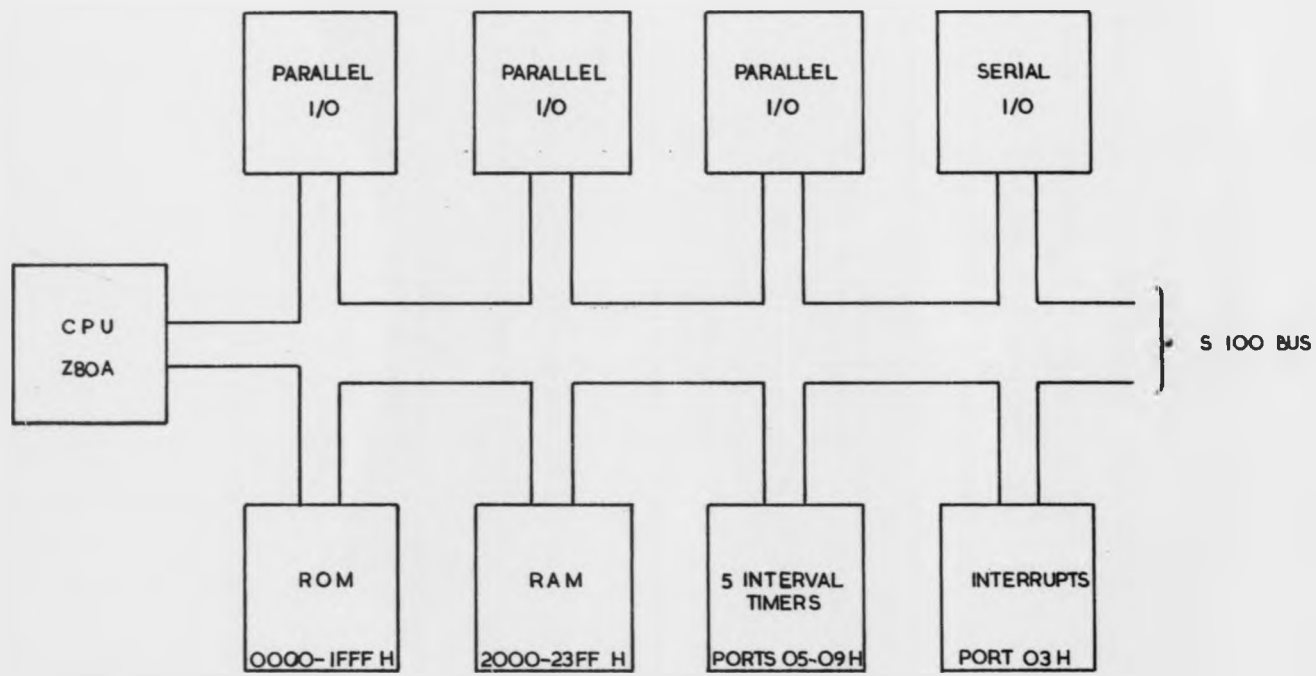


FIGURE 4.6 Cromemco Single Card Computer System

TABLE 4.1SUPPORT HARDWARE FOR CROMEMCO S100 BUS SYSTEM

Floppy disk drive (for up to 4 8" or 5" disk drives).

Hard disk drive (for "mini winchester" disk, uses DMA).

Printer interface (for serial and parallel connections).

Analogue interface (7 channels of input and output).

PROM programming (for 2708 and 2716 devices).

Parallel interface (8 bi-directional 8 bit ports + hand shaking).

Isolated Parallel interface (24 opto isolated input channels,  
16 opto isolated output channels,  
8 relay isolated output channels,  
11 opto isolated strobe/handshake lines).

Colour Graphics interface (incorporates integral bus)

756 x 484 point resolution

16 colours or grey levels

4096 Colour palette

Output for RGB monitor or PAL/NTSC TV monitor

and graphics memory

16k byte memory appears to CPU as 2 I/O ports

Communications interface (2 serial ports RS-232 or 20m A loop,  
100-9600 Baud rate

2 parallel ports - 8 bits each

10 interrupt lines with priority control

10 interval timers).

i) D-DAC communications interface

Details of circuits and components are described by Freitas (1979). For this application, a specialised S100 bus interface must be developed so that the computer system may address the D-DAC controller as a peripheral. The hardware for this particular D-DAC application is shown in Figure 4.7 and complete details of both hardware and software of a D-DAC system are contained in the report series of Freitas (1979).

ii) High Voltage Isolation boards

Although manufacturers produce S100 bus compatible high voltage isolation boards, these are not suitable for the lift management application. This is because high voltage circuitry must be housed in a separate rack from the computer system to ensure absolute security from accidental damage which could prove very costly. Instead, all high voltage isolation boards will be housed in a separate rack. Each board is divided into groups of eight input or output lines which can be selected according to an address which defines a single board and a further address defining a group of lines on that board. Both addresses are stored in an 8 bit latching buffer which is set by an output instruction from the central processor of the computer system and which is part of that system. A further input or output instruction transfers data between the processor and high voltage lines. Such a system requires one parallel input and two parallel output ports to address up to 4096 high voltage lines and will interface to a Cromemco single board computer unit without alteration.

High voltage isolation of input and output signals to the computer will be effected by the use of opto-isolator circuits which are small

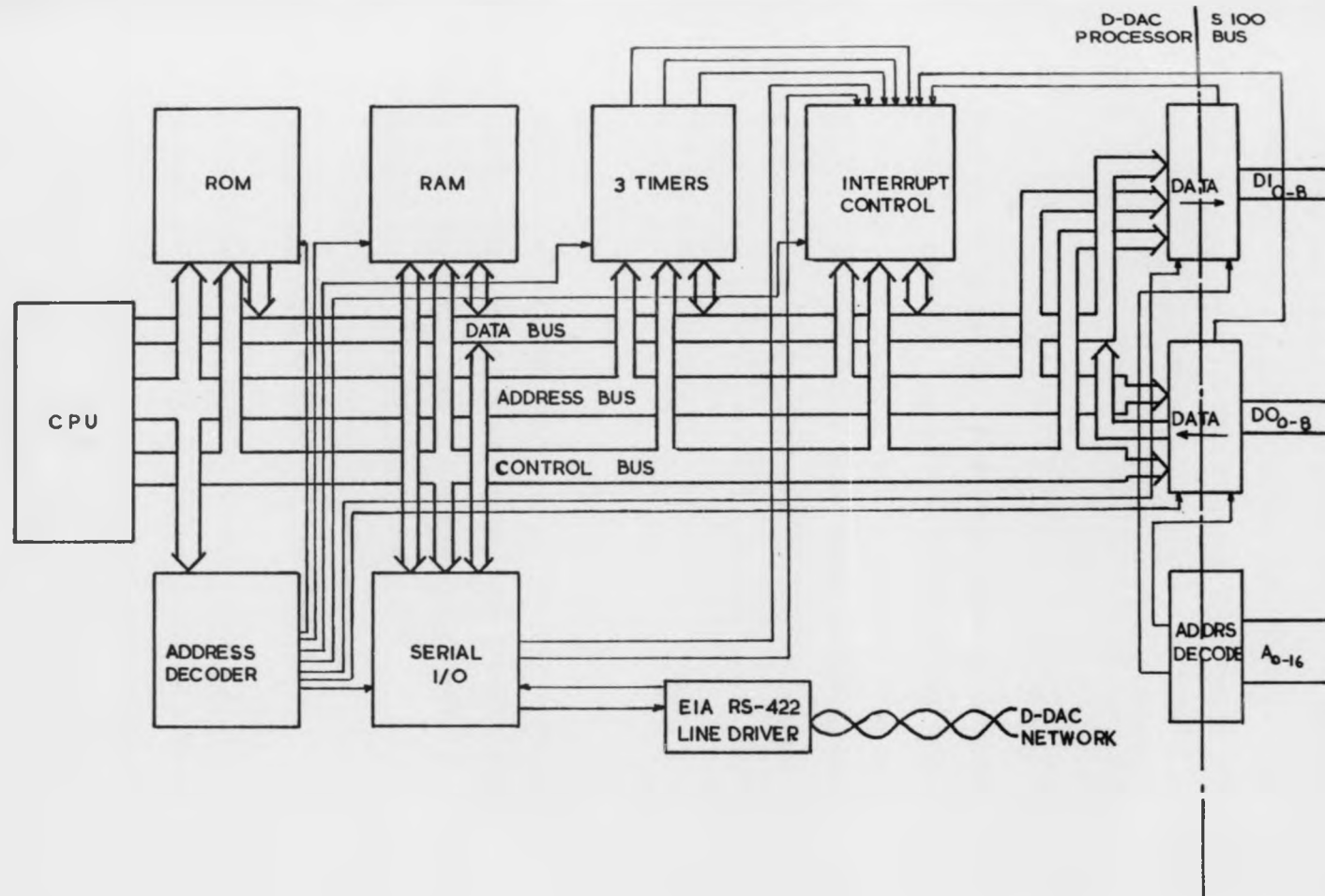


FIGURE 4.7 Circuit Diagram for D-DAC Interface to S100 System

and robust and can withstand potential differences far in excess of those which will be encountered in this application. The circuit diagrams of a high voltage isolation board for input and output are shown in Figures 4.8 a) and b). These boards will be employed wherever a high voltage interface is required.

### iii) Parallel communications port

Each of the single car controllers requires a single parallel bi-directional communications port with handshaking, while the group controller must have a similar port to interface with each of the car controllers. Thus an interprocessor communications boards is required (Figure 4.9) which can support a variable number of parallel ports. Up to 8 ports can be driven from one board which should easily cover the needs of any group controller.

#### 4.1.4.3 Costs

Table 4.2 gives some indication of the cost of implementing the complete lift management system, shown in the circuit diagram of Figure 3.2. The cost of the simple residential buildings system is given in Table 4.3.

## 4.2 Software for Lift Management

All lift management functions, with the exception of LISI are heavily software orientated. In the discussion of hardware, the advantages of standardised components have been mentioned. This means that different functions will be implemented on virtually identical hardware. It is therefore the software of the lift management operations that creates the uniqueness of each function.

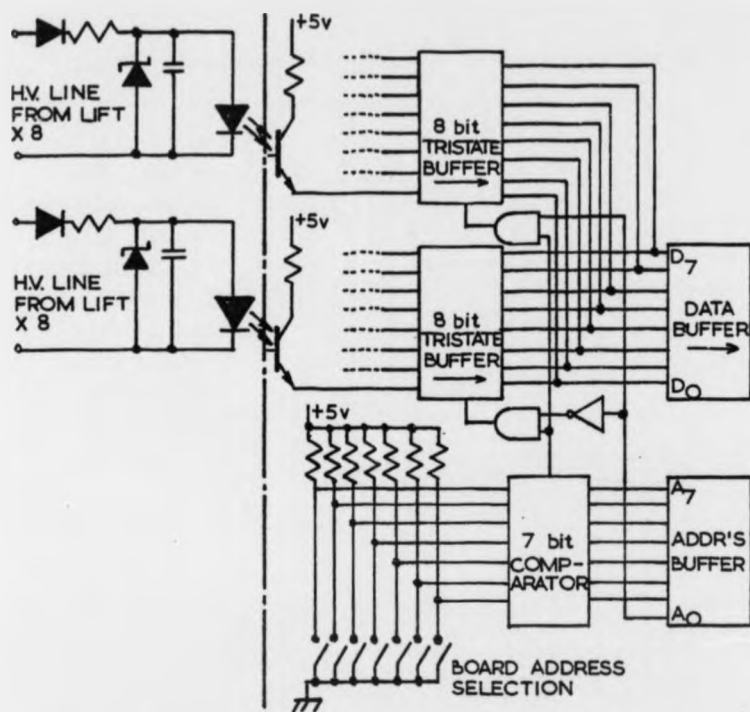


FIGURE 4.8a High Voltage Input Interface

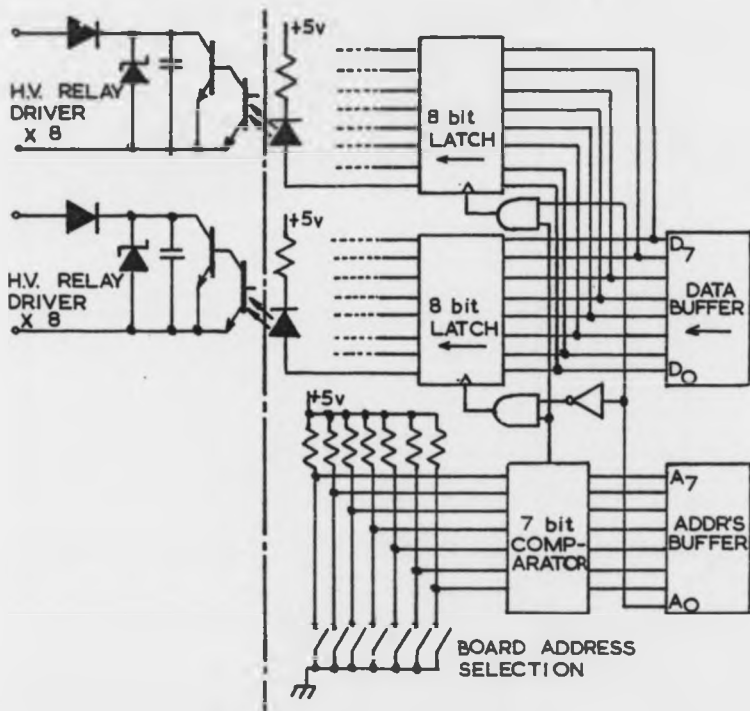


FIGURE 4.8b High Voltage Output Interface

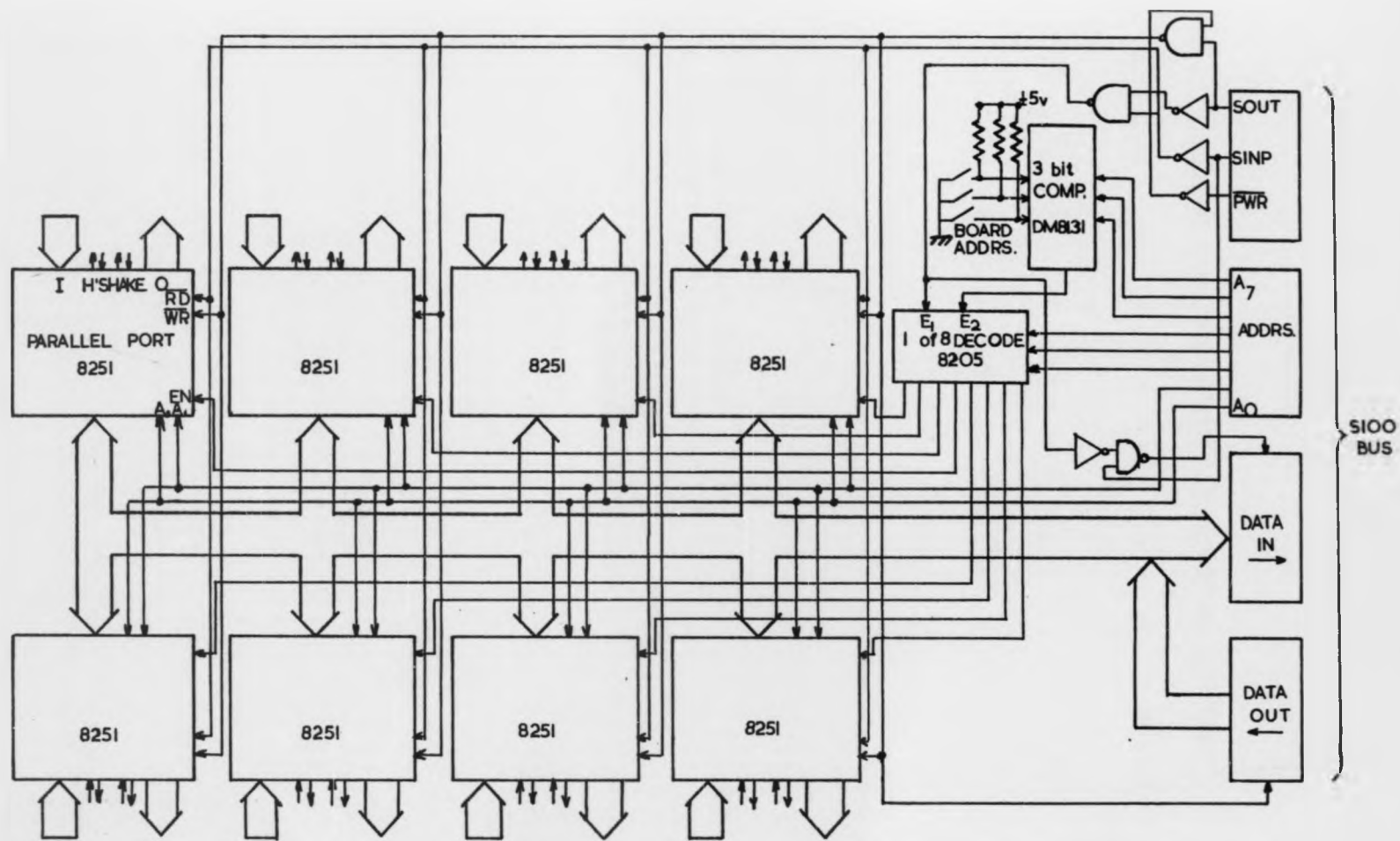


FIGURE 4.9

Parallel Communications Board

TABLE 4.2aEstimate Costs of Lift Management System for Commercial Building

<u>Lift Motor Room</u>	Approximate Cost
S.C.C. (for one lift car)	£
Cromemco System Ø computer including Single board computer Power Supply S100 bus + card cage + cabinet	1,000
Parallel Communications Port	100
Isolations Circuits	<u>500</u>
	1,600 per lift
 G.S.C.	
Cromemco Systsm 1 computer (as System Ø but extra memory)	1,500
Isolation Circuits	500
Parallel Communications Ports	150
D-DAC interface	<u>200</u>
	2,350 per group
 <u>Building Manager's Office</u>	
Cromemco System 3 computer including 11M Byte hard disk 2M Byte floppy disk storage 64K Byte RAM Serial 110 Printer interface	6,000
Printer	2,000
Colour Graphics subsystem	2,500
D-DAC interface	<u>200</u>
	11,000



TABLE 4.2bEstimated Costs of Lift Management System for Residential BuildingLift Motor Room

	£
LISI	500
Signalling Hardware	<u>200</u>
	700 per lift

Building Manager's Office

Cromemco System 3 including 2M Byte floppy disk storage 64K Byte RAM Serial I/O Printer interface	4,000
VDU	500
Printer	<u>1,000</u>
	5,500

#### 4.2.1 Software Support

At the lower levels of the lift management hierarchy, each section of hardware is dedicated to the execution of a particular type of program. For example, the group supervisory controller, while being able to run different algorithms, has only one main function which is to assign landing calls to individual lift cars. For this type of activity a programming language is required which follows closely the instruction set of the central processor (i.e. assembly code) to keep program size to a minimum. Additionally, this language should encourage structured programming techniques and support activities such as real time control. Languages which satisfy these requirements are PL/M and FOURTH.

At the top hierarchical level, a more generalised computing environment is required. Here, user-interactive software is run, data files are created and stored and a sophisticated communications protocol is supported. Thus for the analysis and diagnostics level, a significant requirement exists for advanced software which is general purpose, in addition to the programs which actually conduct lift management functions. In the development stages of the system even more user support will be necessary in the form of compilers, assemblers and debugging aids. The various software support requirements of the analysis and diagnostic functions are listed below.

##### i) Disk Operating System

The operation of bulk storage devices such as disks must be transparent to both the user and his programs. The user should be able to transfer data between memory and peripheral devices using logical file and device names or channel numbers. Facilities for creating, deleting, altering and listing a directory of files should also be provided.

ii) Data Base Management

The LMA and LEDS functions process large quantities of data generated by the lift system controller. This data must be stored on disk for fast access when required by the processing tasks. To facilitate efficient control of data storage, a data base manager is required which sorts data according to the type of information that it contains.

iii) Multi Tasking

Data gathering must be concurrent with any processing activity so that information concerning lift system activity is not lost. To effectively control separate processing of jobs, a multitasking operating system is required. The data gathering job can be activated by interrupt so that other processing is only suspended when data is to be stored.

iv) High Level Language Programming

LMA and LEDS are complex programming tasks and therefore high level languages are required to express these functions succinctly. This is important to facilitate program writing and maintenance. Structured languages such as PASCAL, which also has sophisticated data handling facilities, are to be preferred in this application area. Also a compiling language is essential if processing speed is to be maintained at a realistic level. The slowness of an interpreter precludes the use of languages such as BASIC.

v) Software Libraries

Software libraries are necessary to drive sophisticated peripherals such as the graphics display and the D-DAC controller. It should be possible to search these libraries in order to load only those routines

into memory which are called by the user program before program execution begins. The graphics library should include facilities for:-

- i) display initialisation
- ii) erasure of display
- iii) cursor addressing
- iv) pixel illumination
- v) pixel attribute control (colour/brightness, resolution etc.)
- vi) line drawing
- vii) alpha numeric character display

The D-DAC network drivers should be an extension of the standard input/output process of the high level language, with network locations addressed in the same way as disk data files.

#### vi) Program Testing and Development Facilities

During development and installation stages of implementing a lift management system, facilities will be required which are not needed under normal operation. It is desirable to be able to use the analysis and diagnostic level computer system to provide many of these extra facilities and thus remove the need for additional software development equipment to be brought on site. These facilities include:-

- i) Assembler and compilers
- ii) Debugging software
- iii) Program down loading (by utilising the D-DAC network)

#### 4.2.2 Functional Software

The discussion will now consider the software for a complete lift management system, commencing with the lowest hierarchical level, the single car controller and concluding with the analysis and diagnostics level.

#### 4.2.2.1 Single Car Controller

Programming of the single car controller is a matter of ensuring that the basic rules of safety and the simplex collective algorithm are adhered to. As discussed in section 4.1.3.2., such a program has already been written, using macro assembler code, for a Z80 microprocessor. A list of the functions performed by the controller software is given in Table 4.3. The program is loaded into non-volatile read only memory for secure storage and fast access and occupies about 8K bytes.

The demands made on the car controller processor are light, thus sufficient time is available to conduct additional tasks of calculating average, minimum and maximum values for door and flight times of the car being controlled. These details are communicated every hour, on demand to the group supervisory controller which then passes the data up to the high level activities via the D-DAC network. Additional communications describe changes in status of the lift car, as and when they occur. This information is also passed to the high level lift management functions though it is used as well in the decision making processes of the group supervisory controller.

#### 4.2.2.2 Group Supervisory Controller

In essence, the task of the group controller is to monitor landing calls and assign them to the most appropriate cars to answer the calls. The algorithm which is utilized to make the assignment may simulate one of the several proprietary systems which are used by the major manufacturers. Alternatively, a completely new technique may be implemented to provide a particular form of optimisation. The basic operation of any algorithm should be:-

TABLE 4.3Functions of Single Car Controller Software

a) Independent service (for authorized personnel, via car stations only)	Control Algorithm
b) Firemens' control (emergency manual control)	
c) Car-top control (for maintenance personnel)	
d) Access control	
e) Directional collective (depending on nature of landing call station)	
i) Full collective	
ii) Simple collective	Door Operations
iii) Down collective	
iv) Modified landing call cancelling	
f) Cancellation of car calls and landing calls at terminal floors	
g) Door motor control	
h) Limited door reversals	Passenger Signalling
i) Long/short door timing	
j) Differential door timing	
k) Nudging (in cases of resistant door obstruction)	
l) Load detection	Activity Monitoring
m) Hall lanterns and gongs	
n) Call acceptance and position indication	
o) "Next" car indication	
p) Car direction arrows	
q) LISI (if required)	
r) Anti nuisance control (cancels car calls if car is empty)	

- i) Scan landing calls
- ii) Scan car status information
- iii) Make algorithmic decisions
- iv) Assign calls in accordance with iii)

These operations are performed cyclically at regular intervals which are timed by a hardware clock generating an interrupt.

A background communications task is activated in the intervals between control operations. This handles all the data transfer between the group controller and the single car controllers and the D-DAC network. All communications are initiated by interrupts so that the group controller process is never halted, for example, because a data transmission buffer is full. Different communications activities are assigned relative priority levels. Thus only an activity of higher priority than the current activity can interrupt the continuity of processing. The group controller task has precedence over all others, being initiated by a timed interrupt. Priority control of interrupts is managed by a hardware device.

A model of the lift system status is kept in the group controller memory and it is this model that is scanned upon initiation of a control cycle. The lift system status can thus be examined very rapidly. The status model is updated asynchronously by the car controllers whenever the status of a car changes. Status communications are therefore initiated by the car controllers. The time taken by one control cycle will depend considerably upon the type of control algorithm used. In the case of a dynamic optimising algorithm (Barney, 1977, p 135) this could represent a significant proportion of available processor time.

The communications tasks of the group controller are listed below.

- i) transmission of landing call data to the high level management functions.
- ii) transmission of activity signal to each car controller at regular intervals
- iii) transmission of data from single car controllers to high level management functions
- iv) monitoring activity signals from each car controller
- v) additional communications with the lift management system concerning group controller status and the updating of control parameters for optimisation.

The activity signals are a simple semaphore, transmitted by every controller to signify that it is operational. If an activity signal fails to appear from a particular controller within a predefined time limit, that controller is assumed to have failed and appropriate action is taken by the remaining controllers. Typically, if two consecutive group controller activity signals are not transmitted, each car controller will monitor landing call hardware so that all landing calls will be registered by all car controllers. While this mode of operation yields far from satisfactory lifting performance, some service is maintained until the group controller can be restored to working order.

Information generated by the lift controller comprises two types of data. Event data defines individual events within the lift system whereas trend data describes long term features, for example, the average door opening time of a lift car over an hour. The record format of the BRE data logger - see McKay (1980a) and Barney and Dos Santos (1977) p.288 gives elapsed times between events in a predefined cycle, bounded by successive door closures.



In contrast, the proposed format will describe events individually, as they occur. This approach was chosen to simplify the processing burden of the group controller which would have been responsible for formatting event data strings if the old format was used. Although the new event data format conveys essentially the same information as that used <sup>in the</sup> BRE logger, it is more easily comprehended in this form and allows increased flexibility in the type of events represented. Also non standard occurrences such as double door operations and downward travelling passengers entering cars which were assigned to an up landing call are more easily described if a strict cycle of events is not already defined. Two reasons for the choice of event data format used by Barney were:-

- i) To limit the data rate on a printout device to within the device capabilities.
- ii) To enhance the readability of printed data.

The argument for (i) is now irrelevant since event data is not intended primarily for printout, and the carrying capacity of the communications channel is now much greater. Secondly, it is arguable that the proposed data format is just as meaningful when read as "raw" data, since the time of occurrence of each event is contained in each event data string. Using the old data format it was necessary to calculate this for each event. McKay (1980) also argues in favour of an event based format.

The proposed data format is described by YIP (1979) and is summarised below.

- i) \* HH:MM - time in hours and minutes generated every minute
- ii) ESSFFC - for arrivals and departures of cars with the following representation
  - E - A = arrival
  - L = departure (leaving)
  - P = parking
  - SS - time of event in seconds
  - FF - floor level
  - C - car number
- iii) ESSFFD - for landing calls with the following representation
  - E - C = call
  - E = erasure of call
  - SS - time of event in seconds
  - FF - floor level
  - D - direction (U/D)

Further categories may be required to define car calls, algorithmic calls and perhaps door cycles.

If computer control is not implemented then the data gathering task becomes that described by YIP (1979). Additionally there is a requirement to introduce signals into the lift system. This means only that control messages must be translated, and appropriate output lines to the lift controller be set or reset. A flow diagram of the complete task which shows the original structure proposed by YIP plus the additional output module is shown in Figure 4.10.

A suitable programming language for both the controller task and the communications/data gathering task is PL/M which is a structured

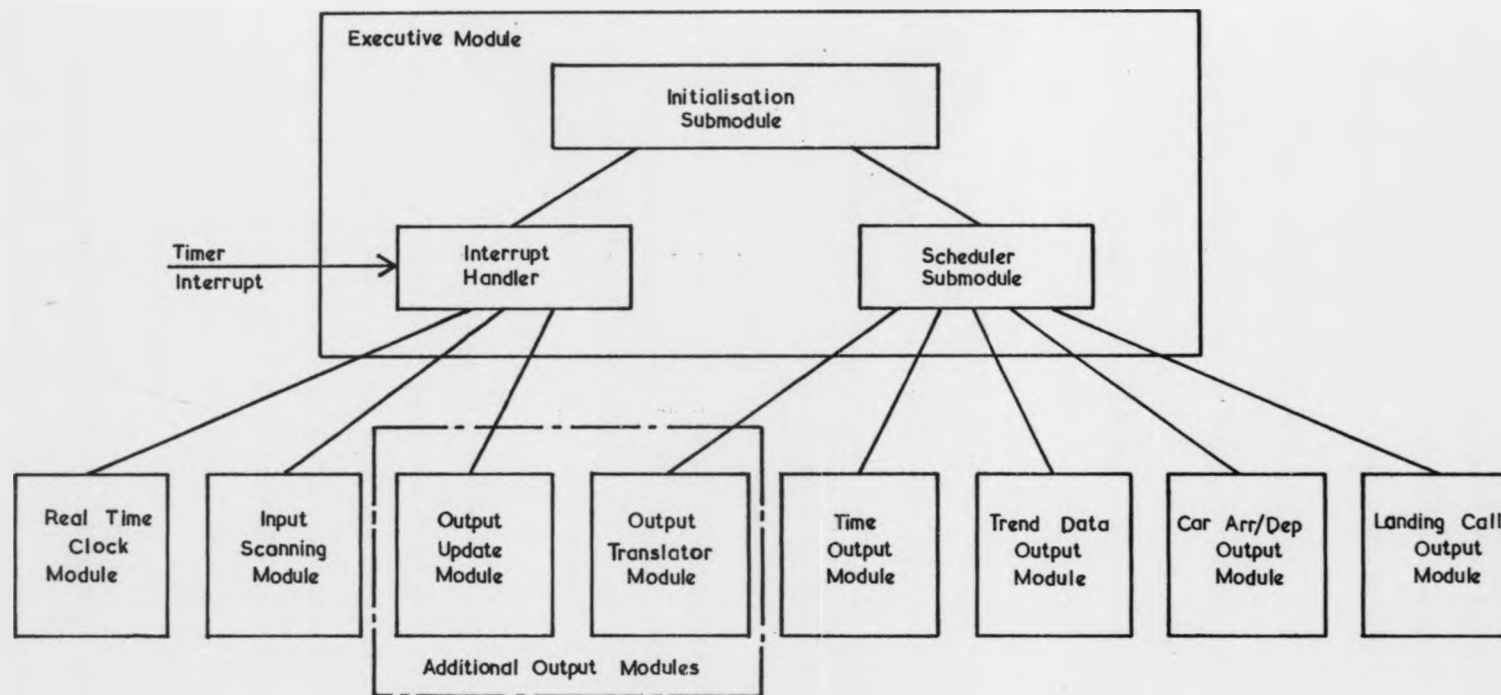


FIGURE 4.10 Structure of Front End Processor Software

language. PL/M is a language designed for use on microprocessor (8080/Z80) based computers which follows closely the instruction set of the CPU and allows interrupt and real time operation.

#### 4.2.2.3 Lift Monitoring and Analysis

The LMA task performs any type of analysis (to be specified by the user) on the large amounts of data obtained from the lift system controller equipment. The generation of this data is synchronised with the occurrence of events within the lift system. Thus data may be presented at any time and, if more than one group of lifts is being monitored, from any one of a number of sources. For this reason, a subtask of LMA which is active at all times is the archiving of data from lift controllers. A data-base is thus generated and data is defined by source, time and event type for later access. For completeness of records, the archiving of data should be a continuous task which is available as long as power is supplied to the computer on which it runs. This task should be activated by interrupt on receipt of data.

The processing undertaken at the command of the user consists of data retrieval, sorting and extraction of relevant information, required for example, to plot graphs as described in Section 3.2.3. Additionally, performance data concerning each monitored lift system must be produced by the LMA task for use in the LOC function to determine parameter settings or alterations within the group controller. In a similar fashion to the data archiving job, performance analysis runs constantly whenever the computer is operational, even if graphical data is not being displayed for the user.

During the periods when LEDS is being used to test lift controller

equipment it is desirable to remove as much of the load as as possible from the central, shared processor which executes LEDS, LOC and LMA, since when LEDS is fully active, the LOC and LMA tasks are redundant and all but the LMA event data archiving processes are deactivated.

The LMA function requires complicated data file handling in transactions with the disk units, a number of floating point mathematical operations and a simple interface to a graphics subroutine library. For all these reasons a high level language is desirable. Fortran could be used for this application but a language such as Pascal which has sophisticated data manipulation facilities and which encourages modular and well structured programming is to be preferred.

#### 4.2.2.4 Lift equipment Diagnosis and Status

In addition to event data, the input data stream, supplied by the front end processors of a lift management system, contains trend information concerning door and flight times. This information is archived separately from the event data and is used by LEDS to identify mechanical faults or maladjustments. The trend data is scanned every hour. Additionally any LISI units which are connected to the lift system are scanned to detect any cars which become out of service. If any anomolous behaviour is recognised either from a LISI or the trend data, an error report is generated and passed to the building manager or maintenance contractor. This monitoring activity is maintained as long as the computer is running.

During quiet periods of the night or in the case of a complete lift system failure, the LEDS function will become fully active,

(triggered by a clock or an operator respectively). In this mode, calls are injected into the lift system via the front end processor interface, and the LEDS task then monitors incoming event data to ensure that the lift system is responding correctly to the stimuli. Thus the controller testing program utilised two large tables of data:-

- i) A table of call patterns to be input to the lift system.
- ii) A table of lift car movements data which should match data being received from the lift system.

Landing call and car call buttons in the lift system should be disabled and passengers prevented from entering the cars so that no extraneous stimuli and responses can be generated.

If an unexpected response is received a diagnostic subprogram is entered which identifies the nature of the malfunction causing the response (possibly using further stimulus/resonse tests), informs the operator and decides whether it is possible to continue testing the remainder of the control system. Unexpected responses include no activity at all from the lift system within a specified period.

The complexity of this task requires a high level programming language such as Pascal or Fortran.

Figure 4.11 shows a flow diagram of the LEDS function.

While LEDS is fully active, other tasks such as performance analysis and performance parameter generation for LOC are deactivated. This reduces the central processor load to a minimum so that stimuli and resulting responses can be handled in real time.

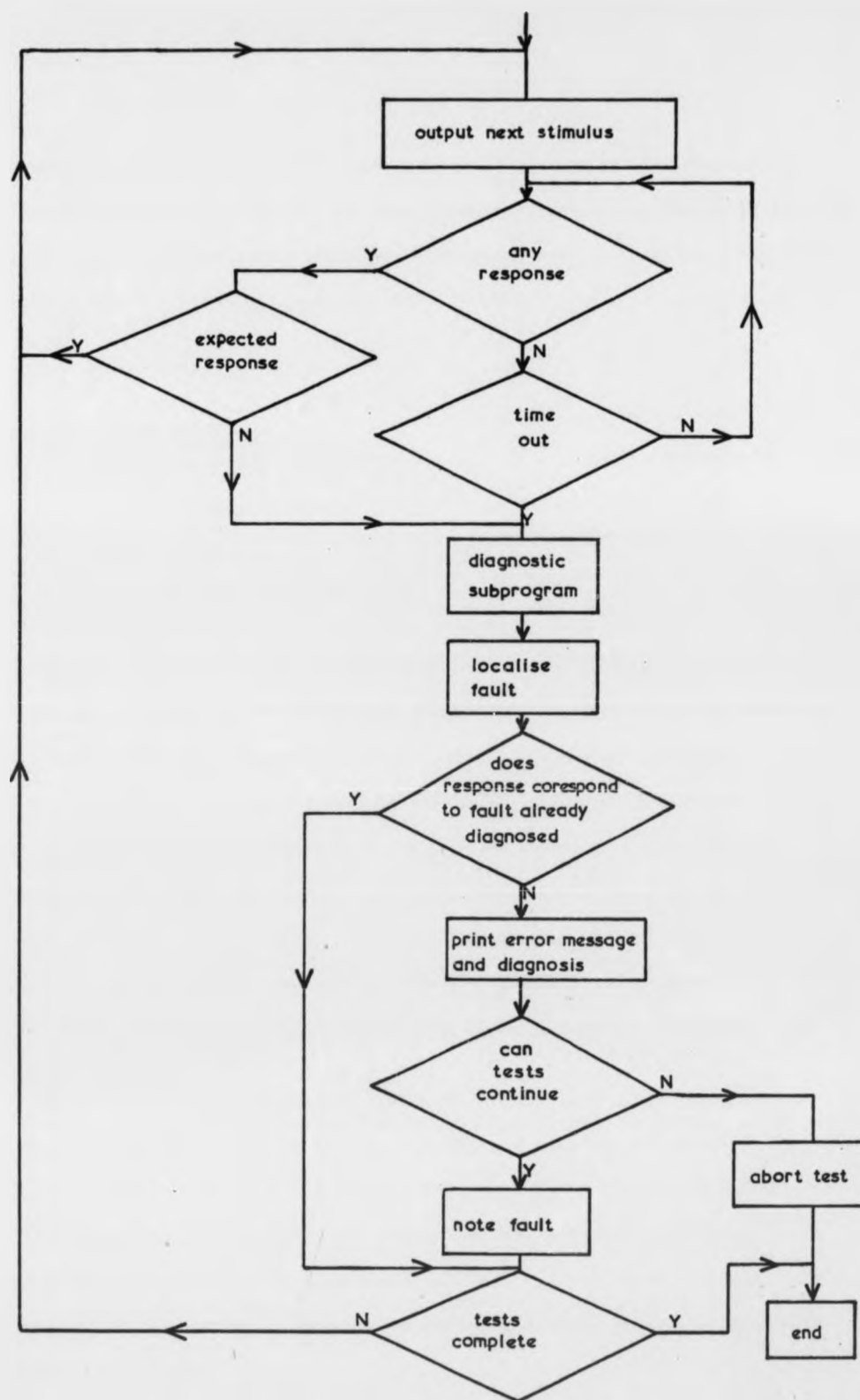


FIGURE 4.11 Flow Diagram of LED Tests

#### 4.2.2.5 LOC

The LOC function monitors the performance data produced by LMA and issues commands to the group supervisory controller, which instigates changes in parameters which define features of the controller algorithm. Typically these features would relate to

- 1) recognition of high traffic situations (load weighing)
- 2) " " " " floors (call/stop counting)
- 3) Floors receiving priority service (VIP service/restaurant floors)
- 4) Sector boundaries
- 5) Parking floors
- 6) Long response time detection

Primarily the LOC operates according to predefined rules for optimising performance by balancing the various interrelated parameters which affect the efficiency with which the lift system operates. However a more sophisticated system might allow these predefined rules to be supplemented by information, processed from data recorded on a previous occasion when conditions were similar, in a form of "learning" process. Strict control must be exercised in the use of such techniques since certain parameter changes could lead to instability in the lift system or in the actual parameter changing function itself.

The LOC should be completely disabled while the LEDS test patterns are applied to the lift system so that the controller parameters remain constant. In fact the diagnostics process is simplified if the LEDS program initialises the group controller with standard parameters before the test sequences begin. With this arrangement the responses to test stimuli should always be the same if the lift system is fully functional.



#### 4.2.2.6 Operating Environment for LMA, LEDS and LOC

To co-ordinate the multiple activities that are to be conducted on the analysis and diagnostics level computer, a supportive operating environment is required. The initiation of each processing task must be co-ordinated under the supervision of a multi-tasking operating system. Each processing task is activated by an interrupt which is generated by a hardware device. Interrupts are monitored by the operating system which assigns them to various priority levels, allowing only an interrupt of higher priority than that of the current processing task to take control of the computer's resources. An operating system of this nature is currently under development by the Cromemco company which will run on the Cromemco hardware used in this application. A flow diagram showing the organisation of the various tasks under the control of the multitasking operating system is shown in Figure 4.12.

One of the multiple tasks which will always be available on this system is an input data handling program. This program will be responsible for accepting input data from the low level lift management functions and archiving it for use by all the high level management functions. Data must be archived in two categories:-

- i) Event data - describing specific events within the lift system.
- ii) Dynamics data - values samples over an hour of the dynamic qualities of car and door movements.

The integration of this program into the multitasking environment is shown in Figure 4.12.



#### 4.3 Implementation of a Lift Management System

The concept of lift management arose out of a need to obtain large quantities of reliable data from a variety of lift systems for the purposes of research. Experience has shown that data logging alone is inadequate for this task because of the need to ensure that the lift system is operating correctly and because on-line data processing is required to facilitate a rapid production of results. However, it was realised that requirements for similar facilities exist in the commercial environment and that managers and owners of large buildings could benefit greatly from advances in this field. Thus the design details of this chapter describe an integrated commercial system for use by building managers. The system, which is computer based, provides an optimising control scheme, diagnostic status testing and performance data. However, the design remains incomplete in certain aspects. Omissions in the description arise because the necessary research for their consolidation cannot be undertaken until the basic features of the system have been realised in a prototype form. This will enable the original requirements for a data gathering environment to be achieved. Design omissions relate to the specification of a performance index to be produced by the LMA function and its use by the LOC function. Thus the implementation of a complete lift management system is a two stage process. Primary development involves the production of a complete interface with a lift system, enabling information to be fed into, and derived from the lifts. The second development stage covers the development of data processing techniques with which to manipulate the data flows generated by the primary stage. Thus from the research point of view it is now necessary to examine the various forms of information that can be derived from a lift system to suggest information processing

activities that may be conducted by the lift management system.

Chapter 5

Lift Data Analysis

The discussion of Chapter 2 places the development of design and analysis facilities for lift systems in a historical perspective. Chapter 3 continued from this foundation, to develop a proposal for a new and sophisticated range of facilities designed to interface with a working lift system for the purpose of allowing status and activity data to be manipulated. It can easily be imagined that the advanced capabilities of a system using a distributed network of computers would provide a powerful analysis tool. However, the potential of this system can only be realised if analysis procedures are also accessible, which will extract important information and present it in a clear and comprehensible form. It is necessary to consider exactly how the information obtained from a lift system may be optimally used. Thus it was decided to conduct a general investigation to ascertain what information can be derived from recordings of lift system activity, concerning traffic and lift usage. This chapter therefore continues with a discussion of the analysis of data obtained from some working lift systems.

### 5.1 Sources of Data

The mini computer based logger described in chapter 2 has been used over the period of 1977 to 1979 to record lift system activity in a number of buildings in London. At the beginning of this project logged data was available which had been collected in three office buildings and three residential buildings. It was decided to concentrate investigations on the data from the office blocks since the lighter traffic and smaller sizes of lift systems in the residential environments were found to generate too little activity to enable trends and patterns to be observed. Also it was expected that the more formal timetable of

arrivals and departures and the common occupations of building users in office blocks might create more consistent traffic patterns.

A library of some 50 days of logged data was available as the total recorded output for the data logger. Unfortunately the quality of this data proved to be of a doubtful nature and in the final analysis most of it had to be discounted. There are several reasons for this which can mostly be attributed to the novelty of the work. Thus as experience was gained the quality and reliability of the logged data improved.

Initially no facilities were available for analysis purposes so that many malfunctions in the monitored lift systems remained unobserved though they create a considerable disturbance in the recorded data. Examples of such malfunctions are given in chapter 2. The original policy of recording a lift system exactly in the condition it is found, was abandoned in favour of attempting to restore it to full working order before commencing to record data. Even with current analysis facilities it is still not possible to ascertain that faults have been completely removed from the lift system. Only using the LEDS function of the proposed lift management system can this be achieved.

A second factor contributing to the unreliability of data recordings is the algorithm used in the data logger to record lift system activity. It was discovered that many of the signals, derived from the lift system controller equipment, are liable to show temporary changes in state which are inconsistent with the condition which they represent. It was thus necessary to implement enhanced versions of the data logger software which perform strict checking of the sequence in which signal status changes.

Finally ambiguities were found to exist in the method of recording data. For example, assigning a time to the duration of a landing call as a car arrives at the same landing, since at that instant the direction which that car will proceed to travel is unknown. If both an up and a down call are registered as a car arrives at a landing it is impossible to know which timer represents the system response time.

All these factors severely limit the usefulness of the recorded data and it was therefore decided to concentrate analysis on data from the two buildings most recently studied. The data from these buildings incorporates the amendments instigated in the logging procedure as a result of the experiences discussed above. The chosen buildings each have only one or two complete days of reliable recorded data. This amount of data is obviously not sufficient to enable an exhaustive study to be attempted but allows some conclusions to be drawn. In particular, it should be possible to identify the features of traffic flow which are peculiar to the time of day.

## 5.2 Analysis Tools

A suite of programs which conduct validation and analysis of logged data had been written for BRE and was available for use at the start of this project. These programs, the work of a contract programmer (S. Braende), though undocumented, provide a useful insight into the data being produced by the logging equipment. The facilities offered by this package of programs are discussed in chapter 2 and appendix C. It was discovered that in processing the logged data, the analysis programs sorted information more fully than was apparent to the user. To utilise this information an additional program was written which allows the



activity of any floor (in particular the main terminal), or the whole building minus the activity at the main terminal to be plotted on a graphics display. This is in addition to the original facility, which only displays the activity of the whole building. Any of the following functions may be plotted for the up or down directions or for both directions summed:-

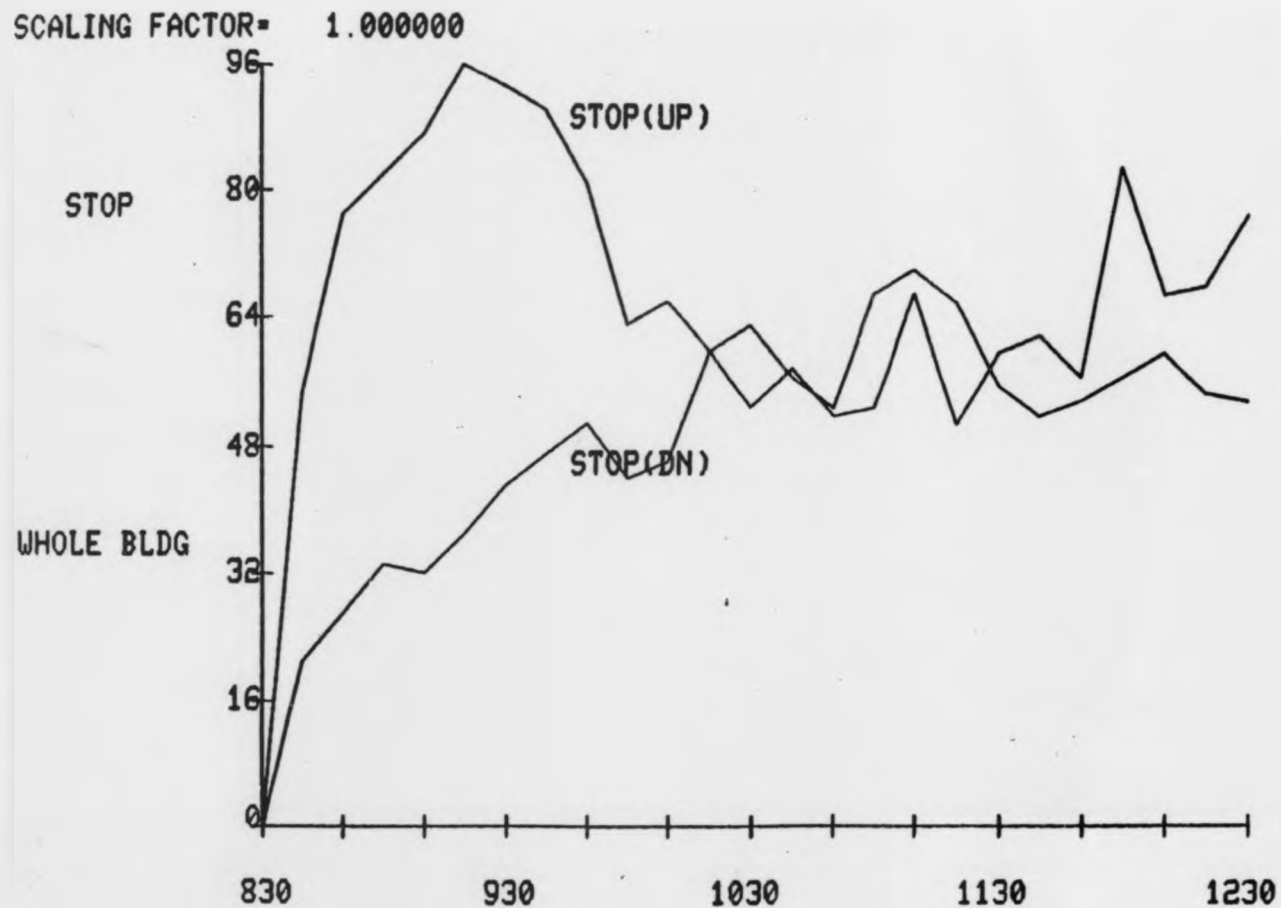
- i) lift car stops
- ii) landing calls
- iii) system response times (max and mean)
- iv) door opened times

Another program which was used to enhance the display facilities was written to fulfil the commonly occurring need to compare the variations of two parameters. This program allows any two parameters to be superimposed on the same graphical axes, with the choice of multiplying one parameter by a scaling factor (figure 5.1). Additionally an option exists to plot the variations of one parameter divided by the other (figure 5.2).

These enhancements were made simply by adapting the original display generator program which plots stops, calls, system response times and door times against the time of day at which they were sampled. The analysis suite of programs was left unchanged by these additions, on a library area of the computer disk space. The enhancement programs are loaded onto the user's own disk area under the same name as the program module which they replace. Since the computer will search the user area before the library area for each program module prior to running it, the enhanced program is automatically used in preference to the library module (see figure 5.3). Program modules run sequentially,

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30

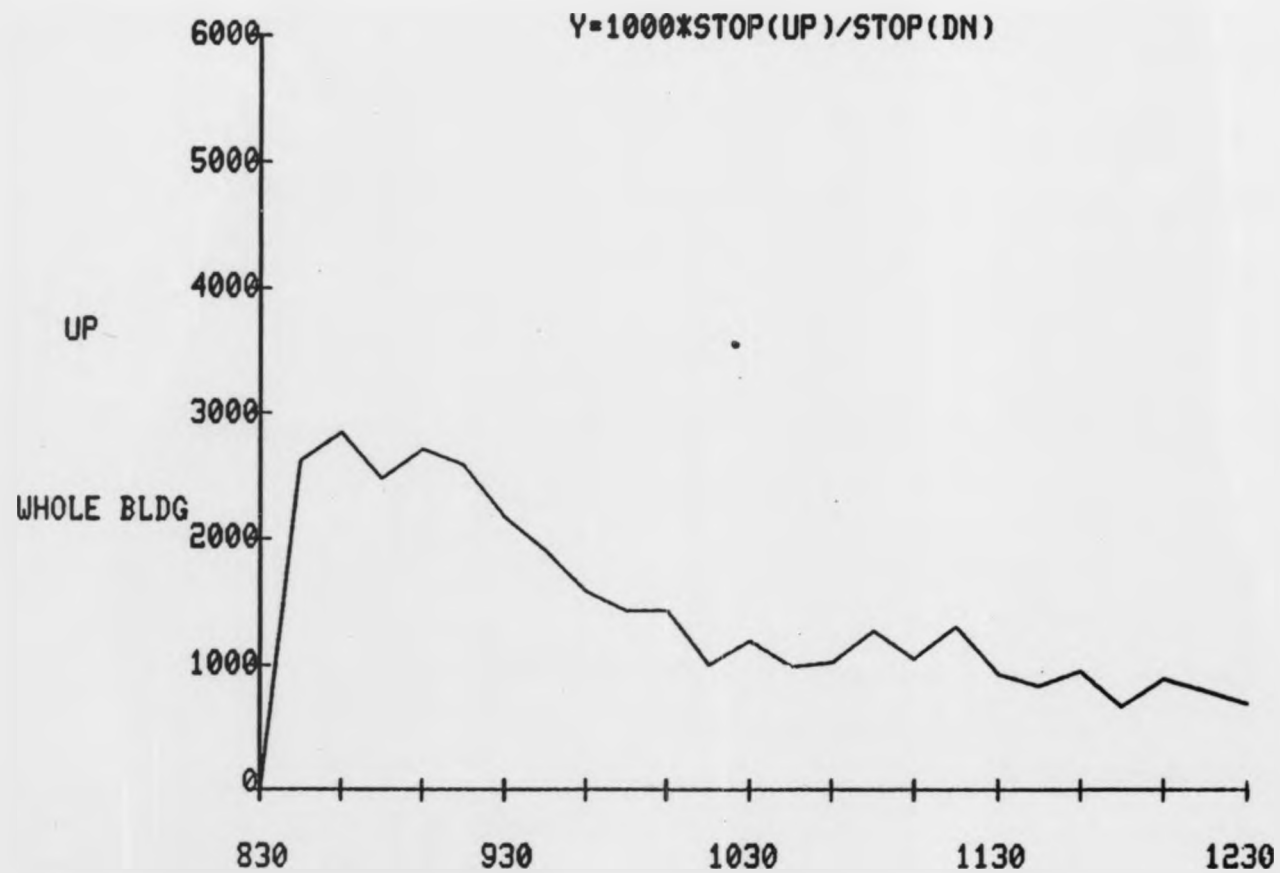


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.1 Graphs of Stops (Up) and Stops (Down) Plotted on the Same Axes

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30



NEXT(R/C/S/P/N/E/H)?

FIGURE 5.2 Graph of Stops (Up) Divided by Stops (Down)

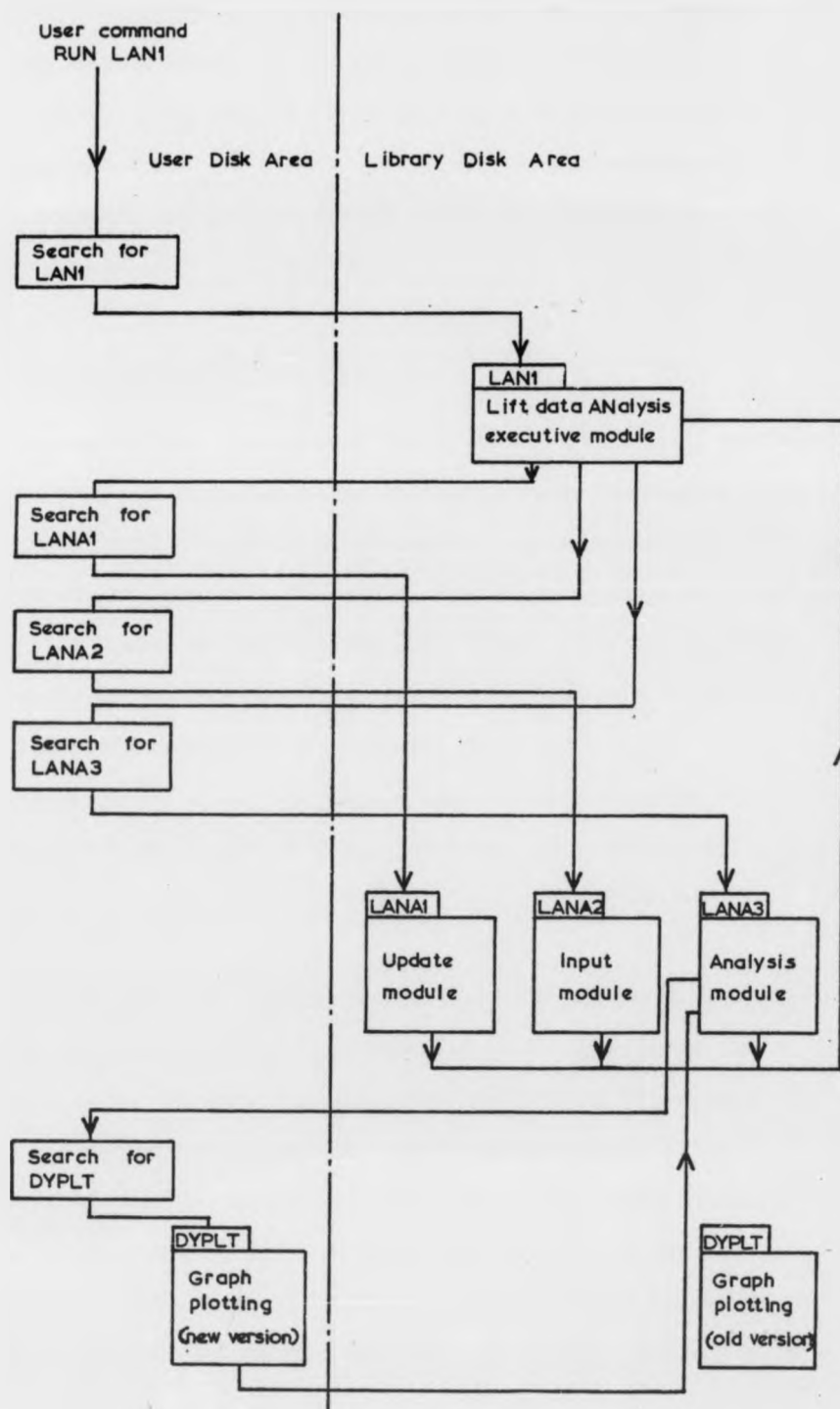


FIGURE 5.3 Library Search Process

using the "CHAIN" facility of the PDP10 computer. Thus this whole process is transparent to the user. The advantage of this mode of use is that the enhanced programs may be quickly altered and recompiled without having to change the library programs. The above program enhancements allow an easier analysis of traffic trends from the logged data.

### 5.3 Data Analysis for Traffic Studies

Before examining some examples of logged lift system data, the traffic patterns which might be expected to be manifested and the methods by which they may be identified will be discussed. In a simplified building environment one might expect to be able to identify one of three traffic flows in the lift system at any time of day. These are up peak, down peak and balanced interfloor which are defined in chapter 2. The above conditions could be detected in the following ways. (NB. The directionality of stops, i.e. "Up Stops", used in the following discussion refers to the direction of travel when the car is next in motion).

#### 5.3.1 Up Peak Traffic

During the up peak, all traffic enters the lift system at the main terminal floor with destinations distributed equally throughout the building. Thus, since in most buildings the destination floors are above the main terminal level, up peak traffic should cause a large number of stops for upward travelling cars. Down going stops will be minimal since little or no traffic is entering the lift system above the main terminal. Also there should be few landing calls except at the main terminal. Thus a graph of up stops divided by down stops, plotted

against time of day should show a marked peak during the up peak period. The ratio of up stops to up landing calls at this time should yield the value of the number of stops per round trip (S) used in the up peak traffic design calculation. However, under realistic conditions, building occupants who arrive early will already be travelling around the building, creating a more random traffic flow which will be superimposed upon the continuing up traffic created by later arrivals.

#### 5.3.2 Down Peak Traffic

Although representing the opposite of the up peak (i.e. emptying the building from all floors to the main terminal level) the down peak must be identified by completely different characteristics to the up peak. Because passengers are entering the lift system at every floor, desiring to travel down to the main terminal, the number of down landing calls is very high. The number of up landing calls is small and should further diminish as the building empties. Thus a graph of down stops divided by up stops, plotted against time of day, should show a dramatic rise during the period. Furthermore, all stops divided by all landing calls should tend towards the unity value as the condition continues, since the majority have a common destination stopping floor. This latter function should be more stable since down stops divided by up stops will vary considerably as the number of up stops becomes very small.

#### 5.3.3 Balanced Interfloor Traffic

The term balanced interfloor traffic is an attempt to describe traffic flow which is not characterised by any particular trend of population movement. This would represent the traffic, for example, between the end of the mid morning coffee break and the start of the

lunch period. Passengers are arriving at all floors at equal rates with destinations equally distributed throughout the building. Under very light traffic conditions each arriving passenger might create a landing call to summon a lift car and subsequently one car call to stop at his destination. In this case, the ratio of stops to landing calls in both direction is 2:1. As the system becomes more heavily loaded, it is more likely that there will be a coincidence between the landing call of one passenger and the car call of another. Thus the ratio of stops to landing calls tends to unity as the system becomes more heavily used. The average of this ratio will never fall below unity, as this would mean that landing calls are not being answered. However a temporary drop followed by an equivalent rise above unity in consecutive sampling periods is possible due to the delay between call registration and a car stopping.

#### 5.4 Two Examples

To demonstrate the techniques of data analysis that have been developed and the information that can be thus derived from logged data, this section discusses two examples of buildings which have been studied. Figure 5.4 shows the layout of one of the buildings studied, which is a single tenancy medium rise (7 levels above ground) building with a single ground level main entry. Three levels exist below ground for building service equipment, storage and a staff canteen. The canteen attracts considerable activity during mid morning, lunch and mid afternoon breaks. A sports and leisure complex on the level below the ground floor is very busy particularly at the end of the working day when employees of the company which owns the building arrive from all

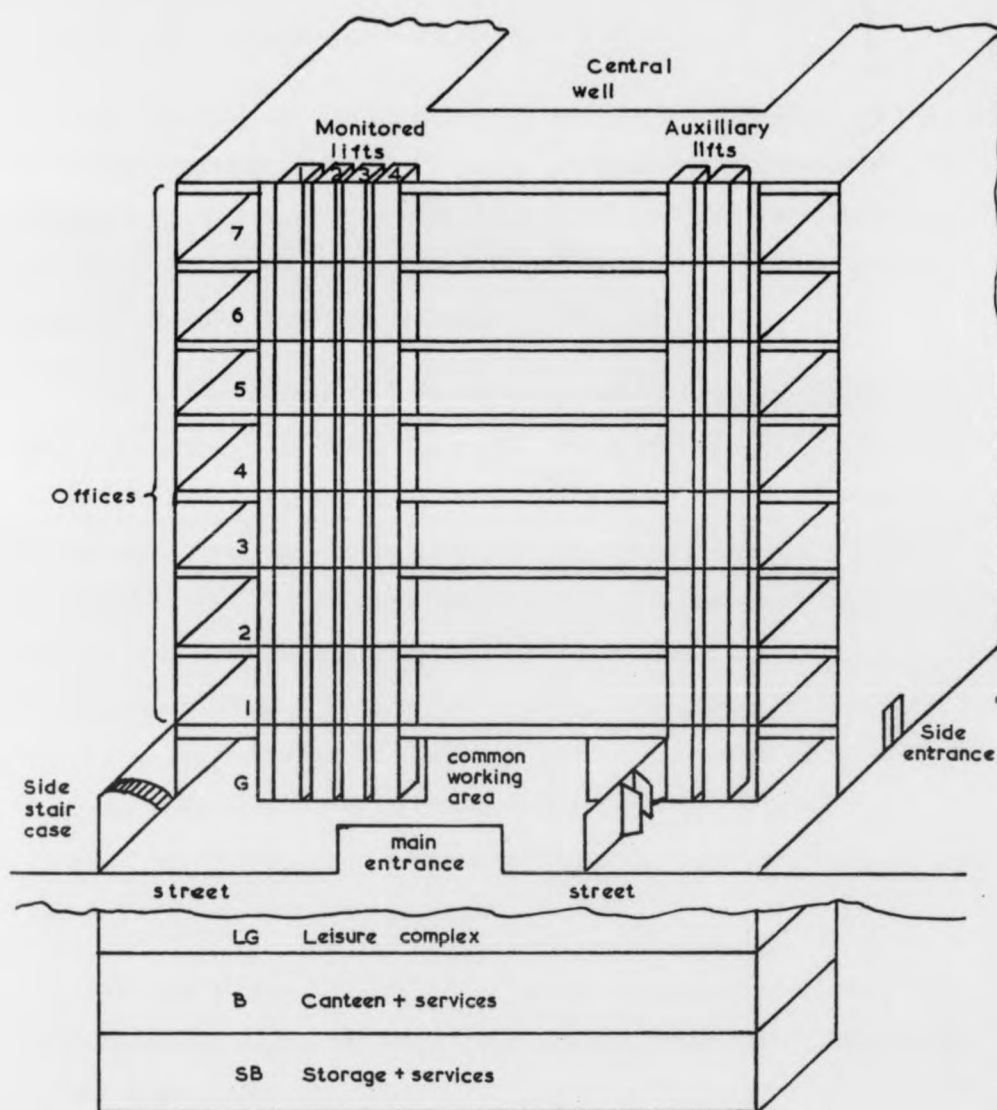


FIGURE 5.4 Layout of Building 1



over the city to take advantage of these facilities.

The supervisory control algorithm of the lift system is rudimentary, employing a policy of dispatching cars at regular intervals with the objective of maintaining an even distribution of lift cars in the building. The main terminal is given preferential service and cars are parked there if traffic (landing call registration) is light.

In contrast with this, the building shown in figure 5.5 is a multiple tenancy 26 level building. There are several entry points and access from outside the building may be made at two different floor levels which are served by a group of escalators in addition to the lift installation. The lower ground floor is an extremely busy communal working area carrying heavy traffic in a horizontal direction as well as attracting much vertically moving traffic. Two groups of four lift cars operate in the building, one serving the basement level up to floor 19 (low rise group) and the other serving the basement to floor 6 and floors 18 to 24 (the high rise group). Data for this building was only obtained from the low rise group.

The supervisory control algorithm of this system utilizes a fixed sectoring policy and cars are therefore distributed amongst the sectors when traffic is light.

#### 5.4.1 Building 1

The activity of the lift system is presented in figures 5.6 to 5.8 for a complete day in terms of stops, calls and system response time for each direction separately and for both directions summed. The analysis suite of programs allows the user to define a sampling period

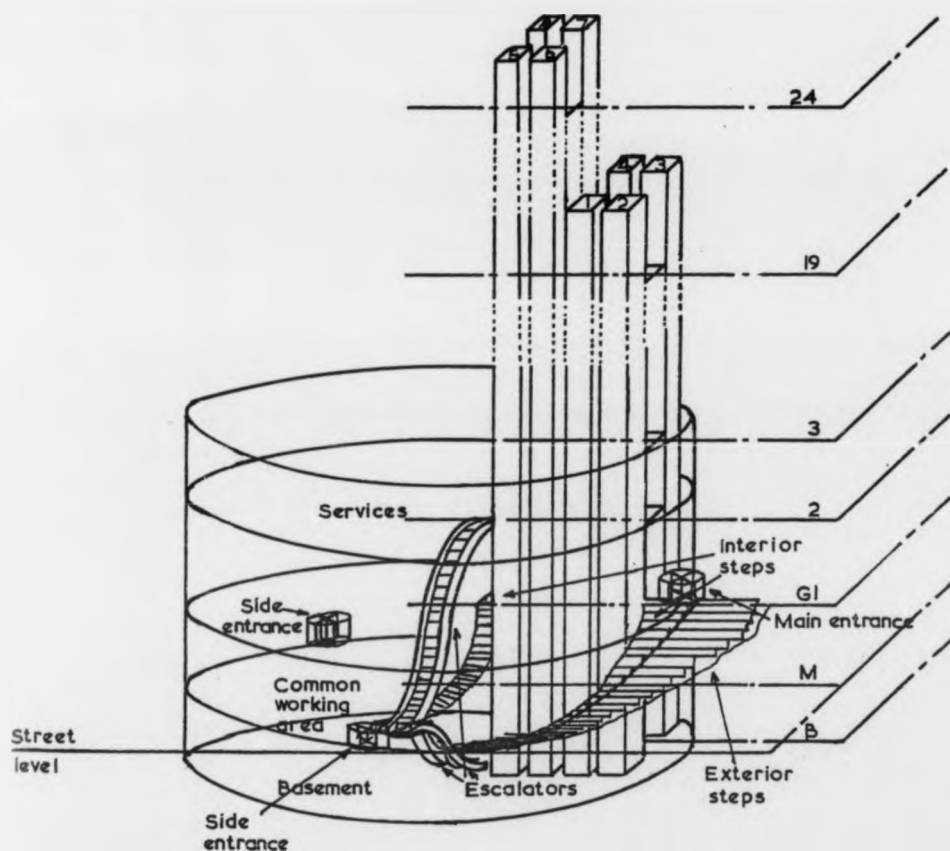


FIGURE 5.5 Layout of Building 2

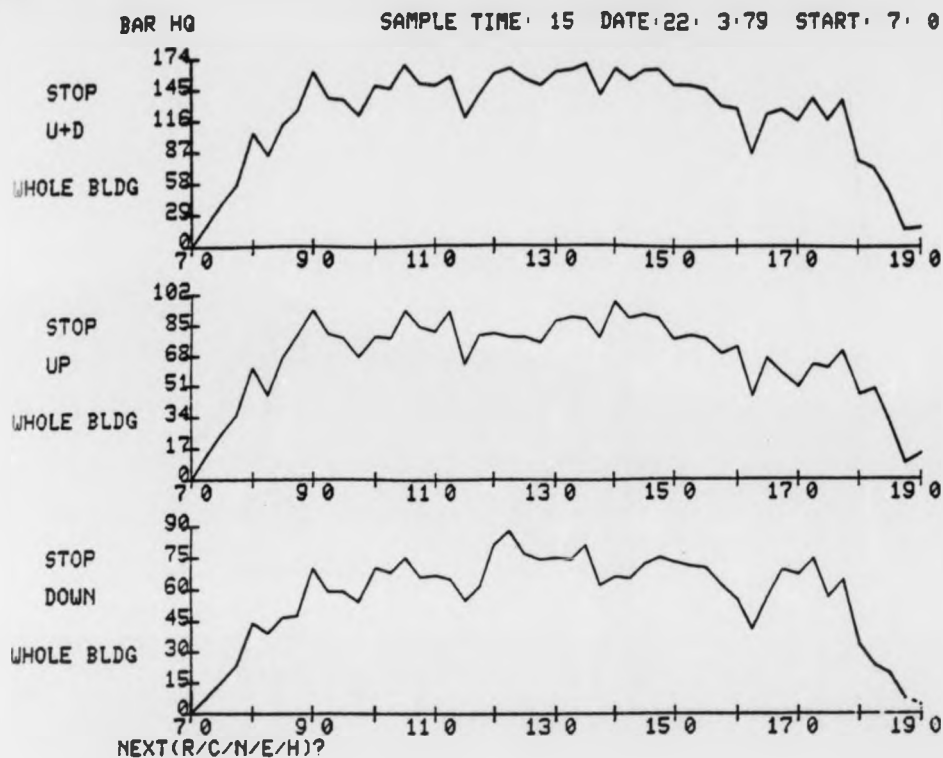


FIGURE 5.6 Stopping Rates of Complete Working Day

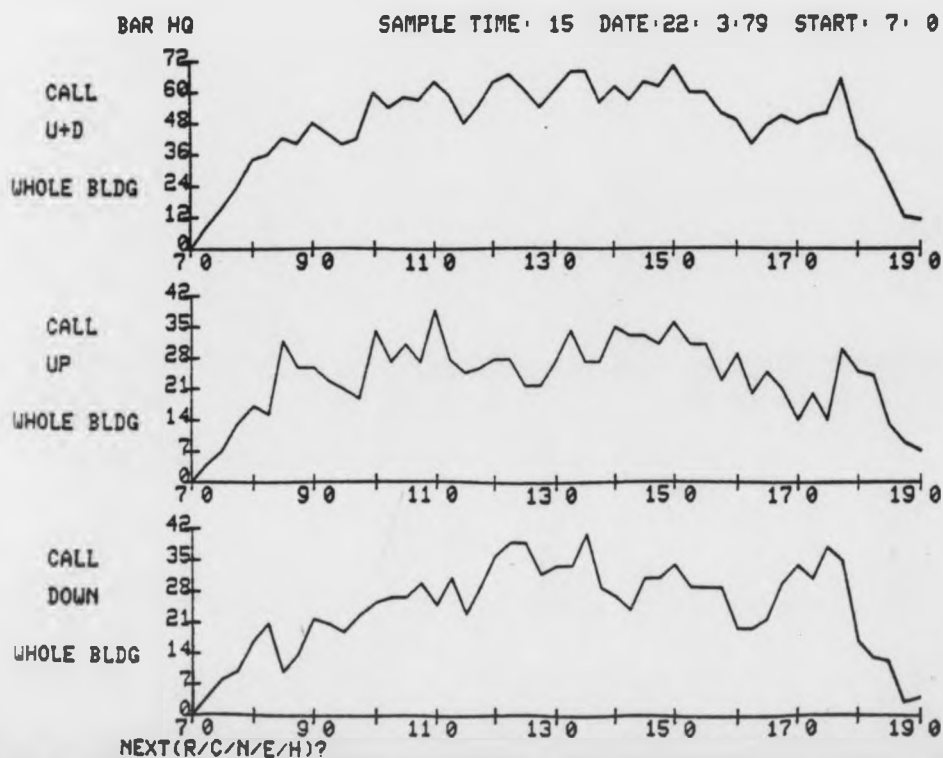


FIGURE 5.7 Call Registration Rates for Complete Working Day

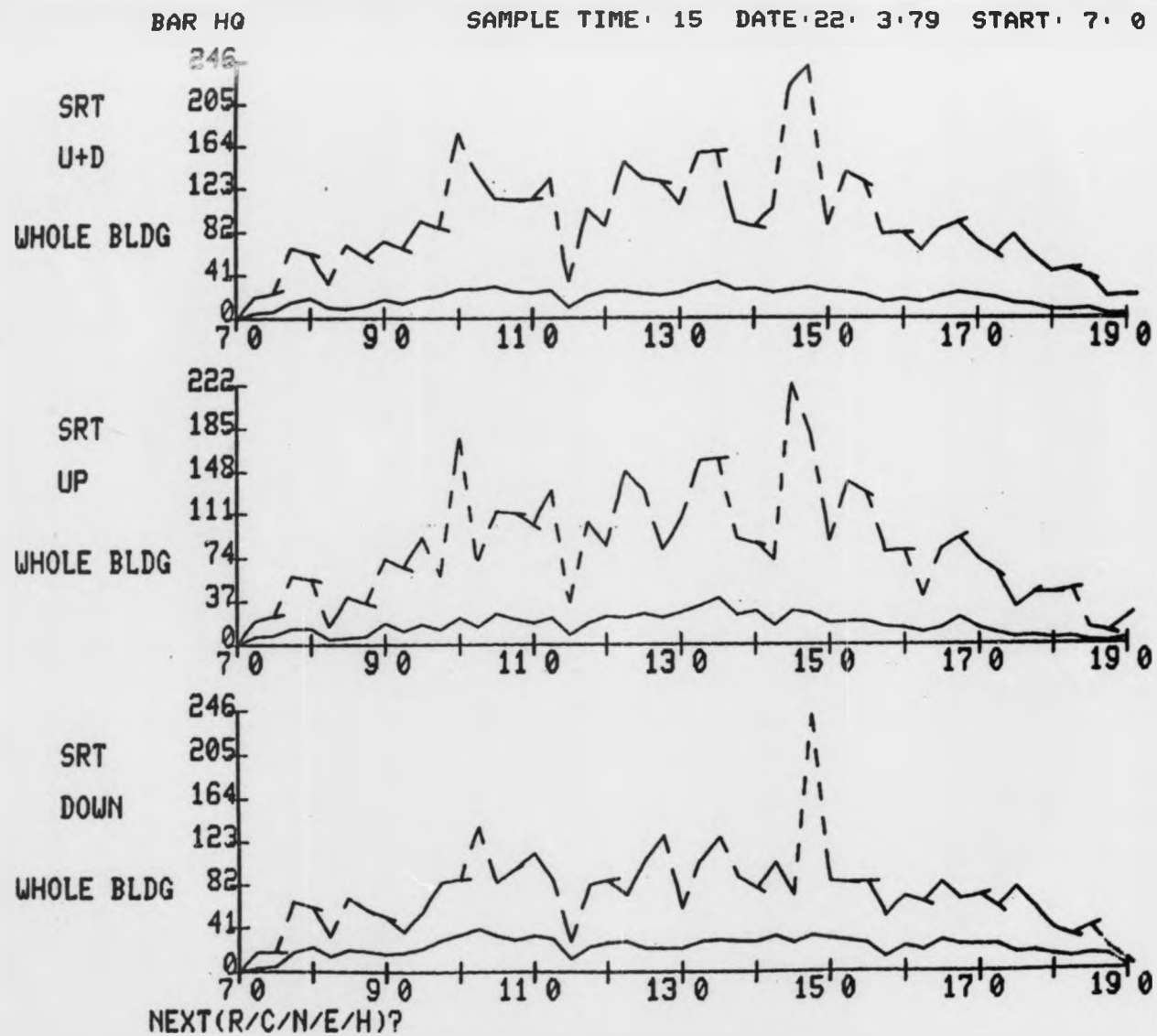


Figure 5.8 System Response Time for Complete Working Day

to be used in the processing of logged data. For this particular building a sample period of 15 minutes was chosen by trial and error. This duration was found to smooth out 'jitter' or 'noise' in the graphical data being produced, which is caused by too short a sampling period and thus insufficient data in each sample. If the sampling period is too long, trends in the data due to changes in traffic flow will be smoothed out in addition to the unwanted 'jitter'. Thus a compromise must be sought which appears to demonstrate features of traffic flow clearly while reducing the effects of background noise. The value chosen for the sampling period will depend on the height and business of the building, the number of lifts and other factors which affect the rate at which events occur within the lift system. Figure 5.9 demonstrates the effect of varying the sampling period from 5 minutes to 30 minutes.

#### 5.4.1.1 Up Peak

The data does not show any identifiable signs of an up peak. A graph (figure 5.10) of up stops and down stops plotted on the same axes for the building minus the activity at the main terminal demonstrates that the number of stops increases at approximately the same rate in both directions as traffic in the lift system builds up. This is partly due to traffic moving to the floors below the main terminal and is also caused by traffic entering at other floors; the result of early arrivals. However, if the morning arrival of building occupants is considered as an influx of passengers at the main terminal regardless of their subsequent direction of travel, a peak period may be identified. Figure 5.11 shows the number of stops in both directions divided by the number of calls in both directions for the building minus the main terminal. When traffic is entering the building at the main terminal and dispersing

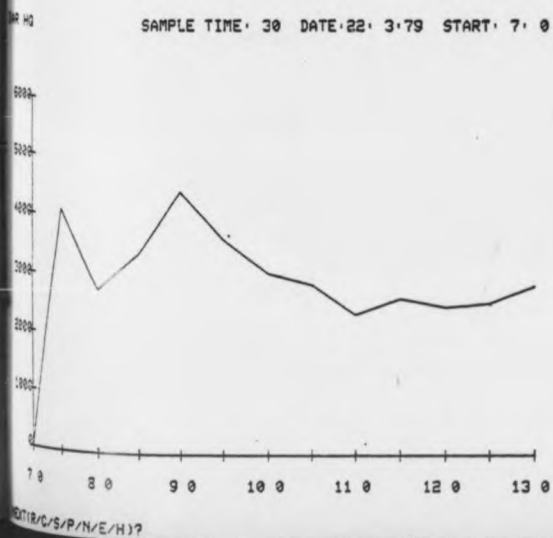
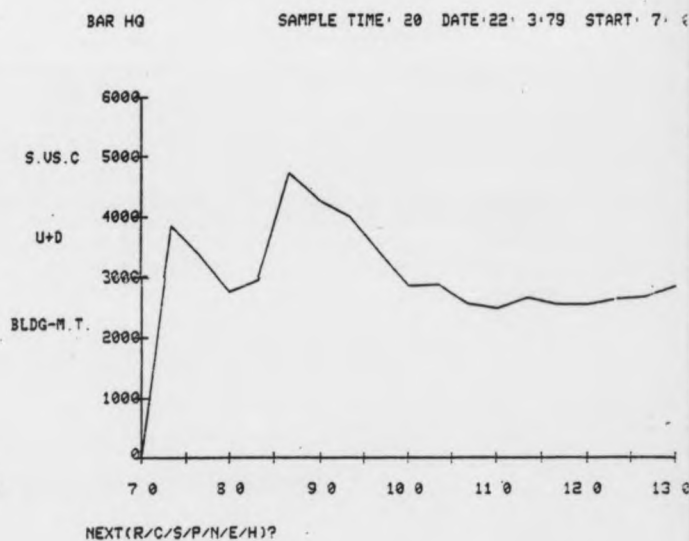
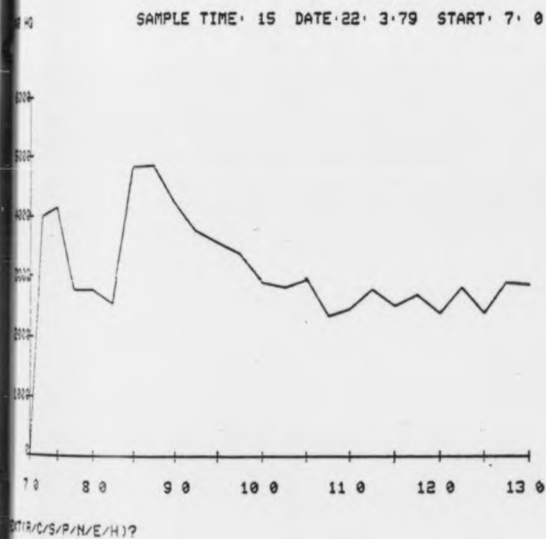
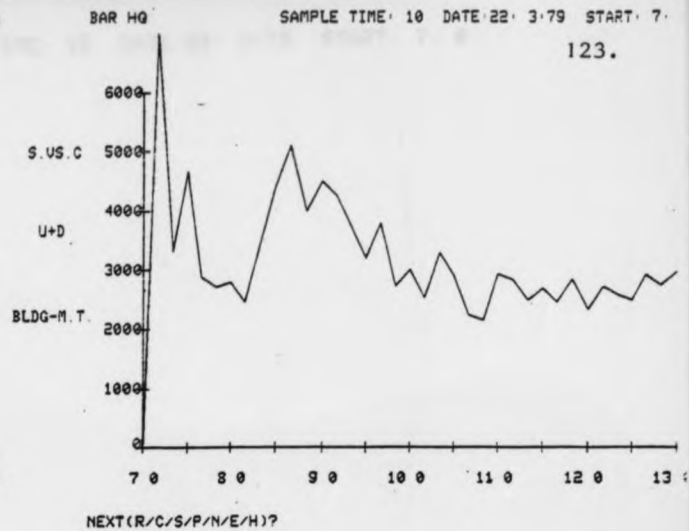
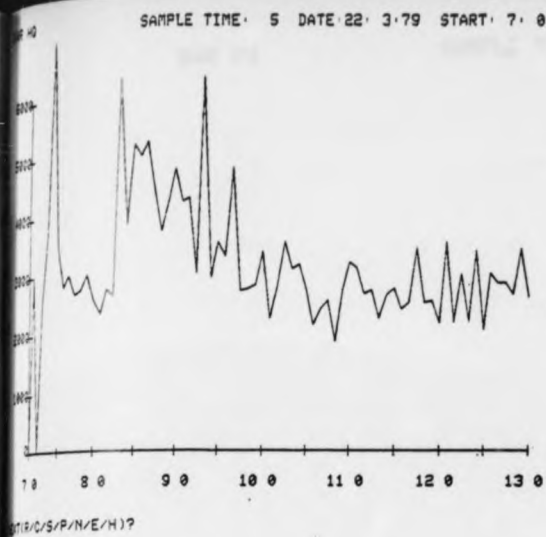


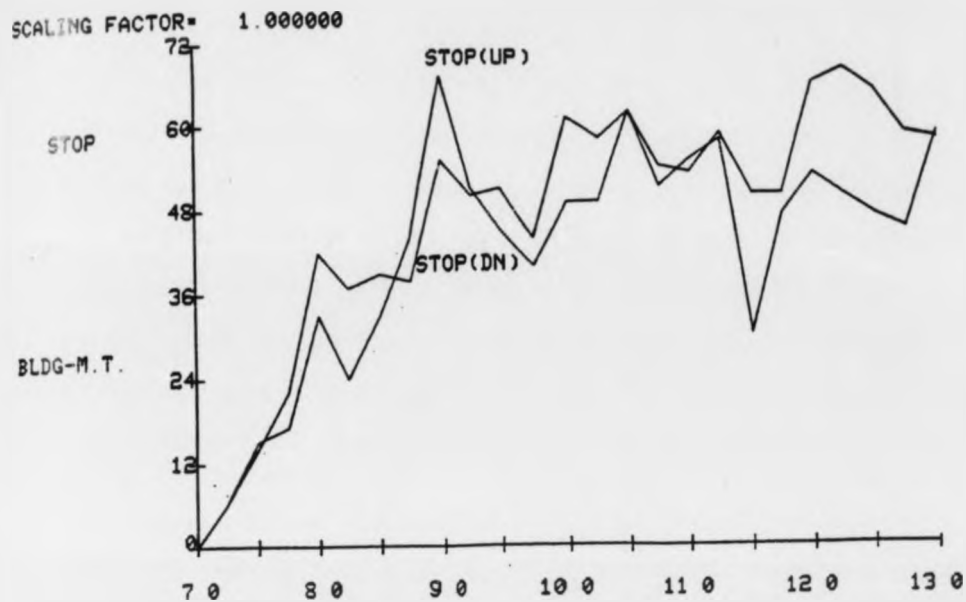
FIGURE 5.9

Effect of Varying Sample Interval  
Between 5 and 30 Minutes

BAR HQ

SAMPLE TIME: 15 DATE: 22: 3: 79 START: 7: 0

124.

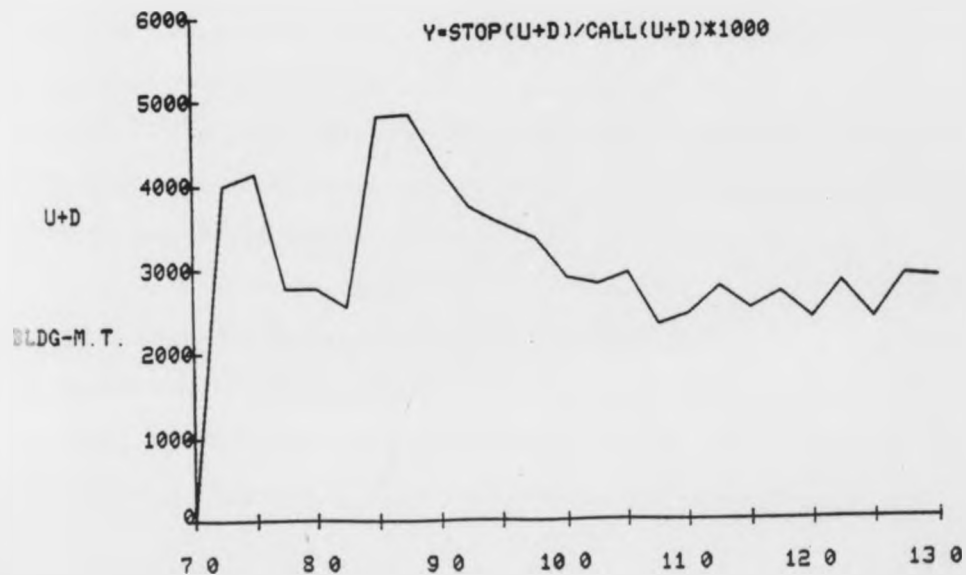


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.10 Up Stops and Down Stops for Building minus Main Terminal

BAR HQ

SAMPLE TIME: 15 DATE: 22: 3: 79 START: 7: 0



NEXT(R/C/S/P/N/E/H)?

FIGURE 5.11 Stops Divided by Calls for Building Minus Main Terminal

On all other floors, the ratio of stops to calls for the building minus the activity at the main terminal will be high. Thus two peak influx periods can be identified from figure 5.11, the main one being from 8:30 to 9:30. This peak is likely to be of greater intensity with respect to the first peak (7:15 to 7:45) than is apparent in figure 5.11. because of the background of interfloor traffic that will exist due to the first influx of population. The highest level of the traffic influx is maintained for at least fifteen minutes, between 8:30 and 8:45.

A change in the supervisory control of the lift cars can be observed during the 8:30 to 9:30 peak period (figure 5.12). Before 8:30 and after 9:30 cars are returned to the main terminal where they remain until a suitable level of demand is created to warrant their use. This mode of operation can be observed, particularly for cars 3 and 4, until approximately 8:30 in figure 5.12 by the proportion of the graphs which are parallel to the x axis at level 4. (NB. due to an inconsistency in the plotting software the floor numbers in these graphs are incremented by one with respect to the numbers used for stops, calls and system response time graphs). However, during the influx traffic period, the group supervisory controller detects the heavier traffic condition (though not up peak) and therefore instigates a new control policy. This policy is designed to handle heavy interfloor traffic by distributing cars at regular intervals throughout the building by a scheduling process. This process takes a lift car to either the highest or lowest floor to which it has been requested to travel and, after a short delay it is allowed to move in the reverse direction. The time delay is intended to synchronise the movements of all cars and to prevent "bunching". Figure 5.12 shows that between 8:30 and 9:30 cars are



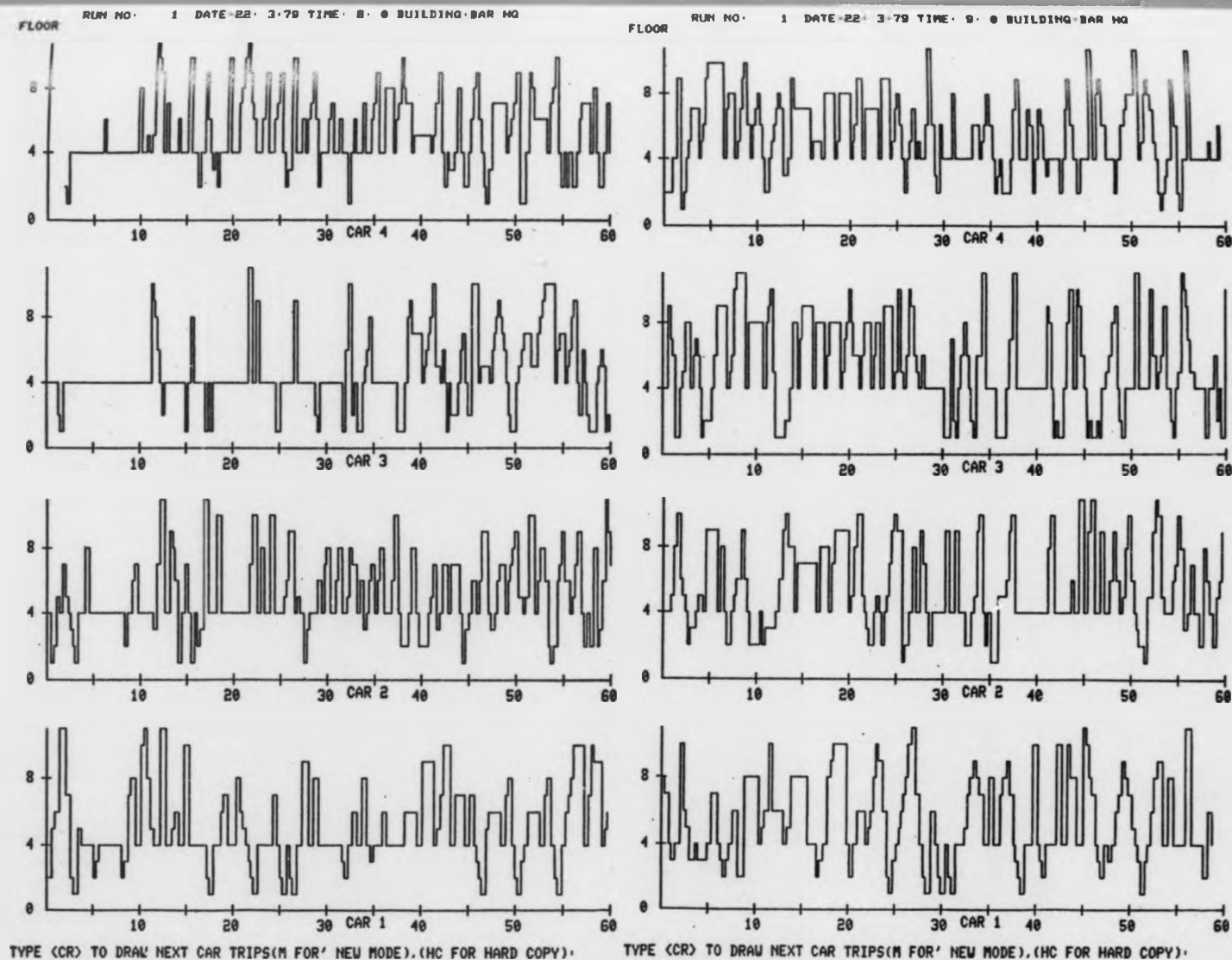


FIGURE 5.12 Car Movements Demonstrate Change in Control Algorithm Between 8.30 and 9.30

delayed excessively and remain at floors throughout the building for periods often in excess of 2 minutes. This is because of a fault which was discovered in the supervisory controller. However, this does provide further evidence of a heavy traffic flow from 8:30 to 9:30 which has caused the group supervisory controller to invoke a new mode of operation. During this period, service at the main terminal, where passenger demand is highest, is severely degraded.

The group supervisory controller incorporates devices to detect an up peak traffic condition and a control policy specifically designed to return lift cars speedily to the main terminal. However, this analysis has shown that an up peak condition does not exist as such and therefore the detection devices will not instigate the special algorithm. Instead, another traffic condition is detected but the algorithm which is invoked is not suitable to the obtaining traffic conditions.

#### 5.4.1.2 Down Peak

A down peak traffic condition occurs in this building due to the occupants of floors above ground level leaving at the end of the day. Figure 5.13 shows down stops divided by up stops for the building minus the activity at the main terminal. A sharp increase in the ratio of down stops to up stops can be seen, starting at approximately 16:30. This is due to the large number of stops made by downward travelling cars to pick up passengers destined for the main terminal floor. Concurrently, other traffic in the building rapidly declines causing a reduction in up stops. The down peak type traffic condition exists for about one hour, reaching a maximum at 17:00. The rapidity with which the peak traffic appears to fall is exaggerated by a sudden increase in traffic to floor 2 (figure 5.14). This traffic enters

BAR HQ

SAMPLE TIME: 15 DATE: 22 3:79 START: 13 0

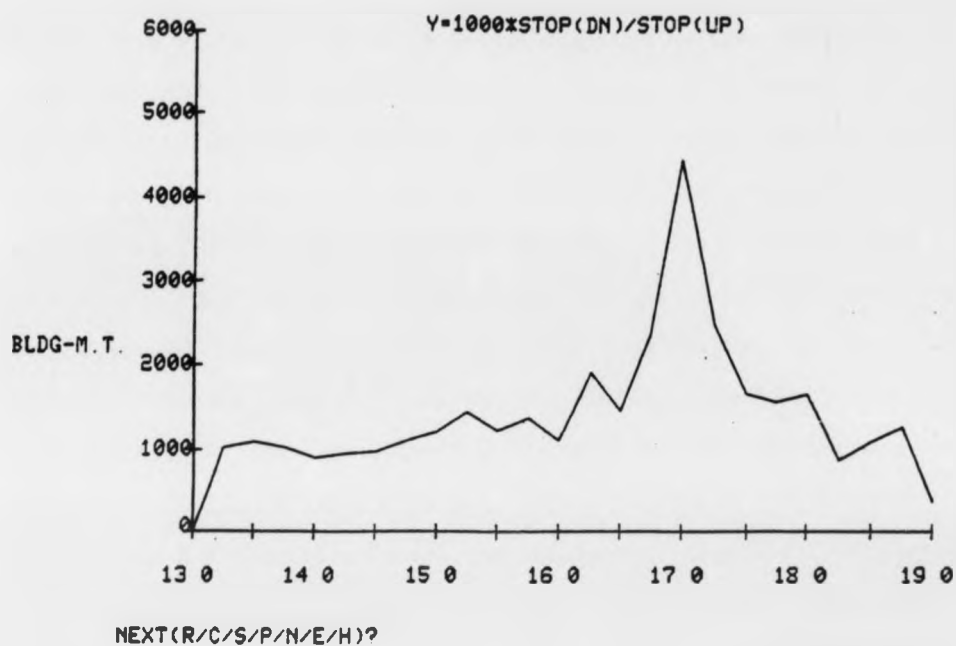


FIGURE 5.13 Up Stops Divided by Down Stops for Building Minus Main Terminal

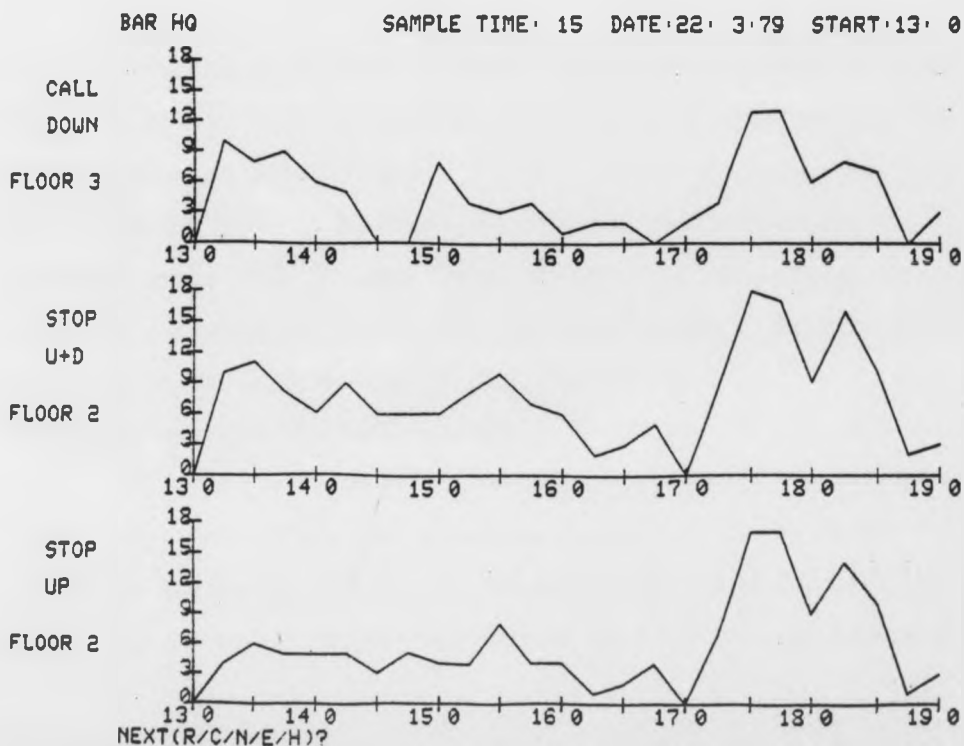


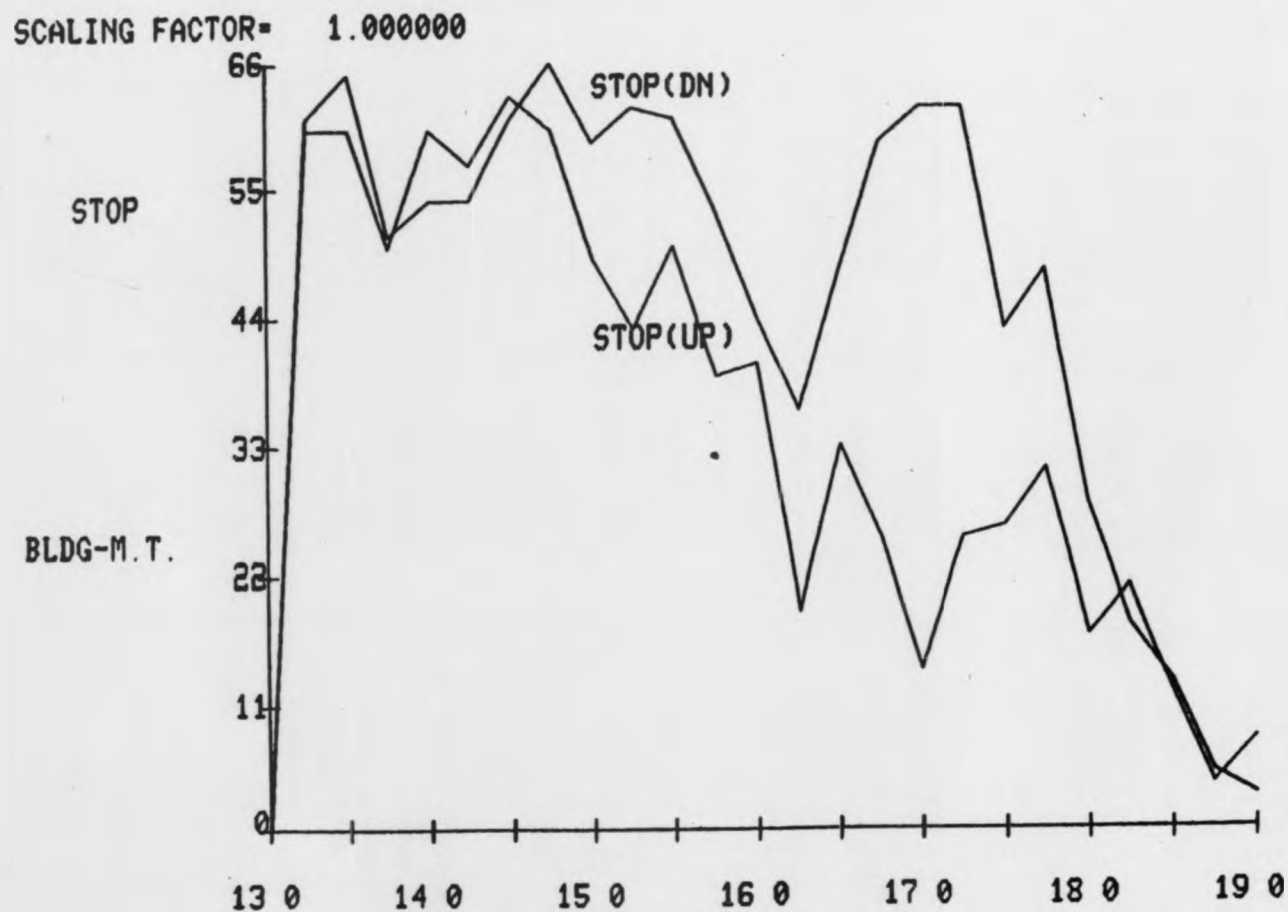
FIGURE 5.14 Floor 2 Attracts A Traffic Peak at 17.30

the building at floor 3 and uses the lift system to gain access to the sports and leisure facilities on floor 2. Figure 5.14, which shows the down call registration rate at floor 3 to be at the highest level for the whole day between 17:00 and 18:00, and a similar peak in stops in both directions at floor 2 during the same period, confirms this proposition. Cars travelling down to floor 2 will nearly always reverse and restart moving in an upward direction because of the low levels of activity at floors 1 and 0. Thus the traffic to floor 2 will appear as an increase in up stops at floor 2 as is shown by the bottom graph of figure 5.14. This increase will also affect the number of up stops in the building and therefore reduce the duration of the peak in figure 5.13. Figure 5.15 shows up stops and down stops during the down peak type traffic condition plotted on the same axes. It can be seen that the level of up stops between 17:00 and 18:00 in the whole building minus the main terminal (28-32 per 15 minutes) is only about twice that at floor 2 (15-17 per 15 minutes).

The supervisory control algorithm includes an algorithm to handle down peak traffic which is initiated by a device which detects a high ratio of down calls to up calls. However, during the period that the data being analysed was recorded, it is known that the down peak detection device was not functioning correctly and was working the down peak algorithm at intermittent periods throughout the day, though obtaining traffic did not require it. The down peak algorithm takes free lift cars from the main terminal to the highest floor, with the purpose of collecting downward travelling passengers on its return to the main terminal. This can be seen in figure 5.16 by the number of trips made to the top floor. The ineffectiveness of this policy can be seen by the number of journeys made to the top floor and back with

BAR HQ

SAMPLE TIME: 15 DATE: 22: 3:79 START: 13: 0



NEXT(R/C/S/P/N/E/H)?

FIGURE 5-15 Up Stops and Down Stops at End of Day

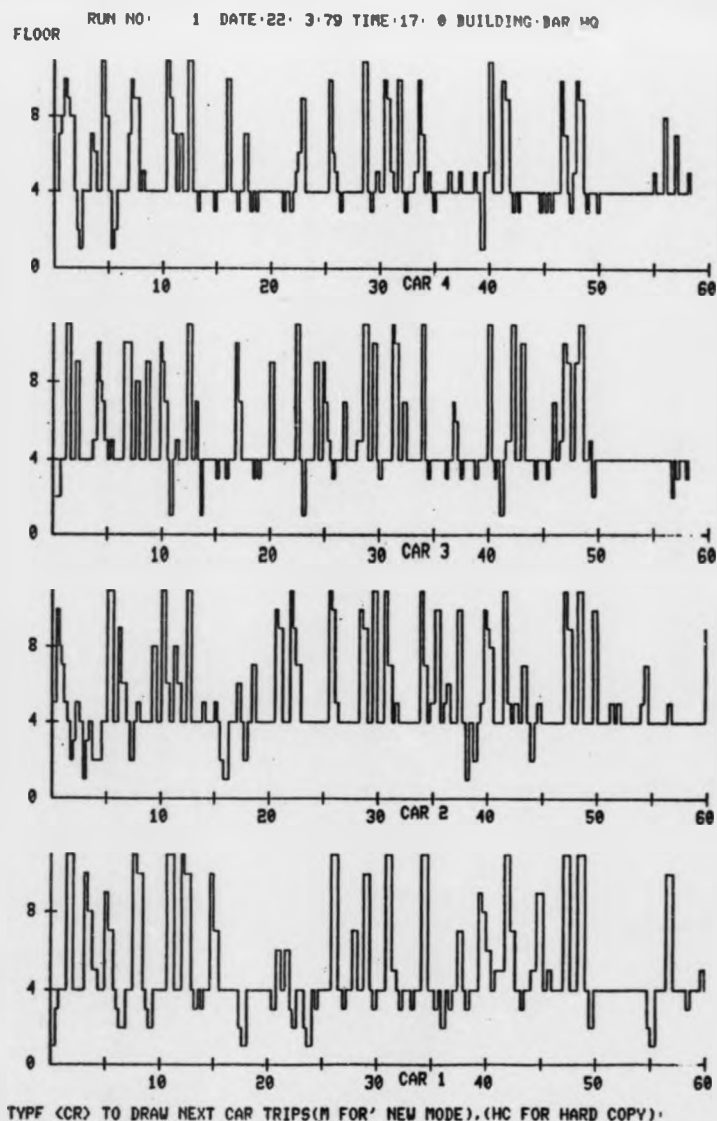
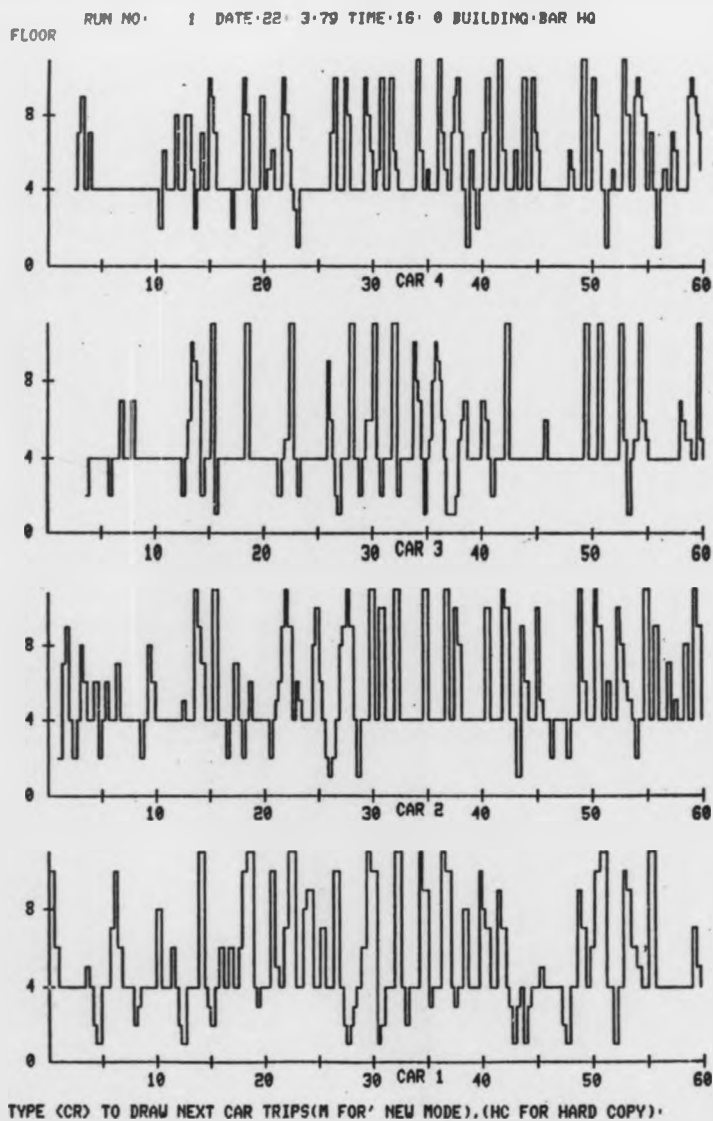


FIGURE 5.16 Car Movements Between 16.00 and 18.00 hrs.

one or even no stops on the downward return.

#### 5.4.1.3 Balanced Traffic

Figure 5.17 shows a tabulation of lift system activity for the whole day between 7:00 and 19:00 which was produced by the data analysis suite of programs. The tabulation reveals that although a small amount of traffic is travelling in an interfloor fashion, the majority of passengers are moving to or from the main terminal. This can be deduced by the large number of calls in both directions at the main terminal, and the large numbers of up calls at floors below the main terminal and down calls at floors above the main terminal. However, it is also probable that a heavy traffic flow exists at certain times during the day between the restaurant on floor 2 (NB. Floor 2 in this tabulation appears as floor 1 in graphs of stops, calls and system response time, due to an inconsistency in the analysis software) or the leisure facilities on floor 3 and the floors above the main terminal. Figure 5.18 shows that the canteen attracts a large number of stops during the lunch period i.e. 12:00 to 14:00 and the flow of traffic to the sports and leisure facilities was discussed in the section on down peak traffic. In view of the levels of traffic attracted to the floors below ground level from the main terminal it might be advantageous to install escalators between the main terminal and these levels. This would reduce traffic, which at the moment probably exerts a considerable degrading influence on the service provided to other passengers.

The number of stops is on average 2.5 stops/car/minute which is defined by Bedford (1966) as a heavily loaded lift system. It is impossible to tell how many stops are due to passengers and how many

BUILDING:BAR HQ

DATE:22: 3:79

SAMPLING PERIOD: 0 START: 7: 0

FLOOR NO:	* UP	NO. OF STOPS DOWN	* NO. OF CALLS U+D	* SUM SRT UP	* MAX SRT DOWN	* MEAN SRT U+D	* UP	DOWN	U+D	* UP	DOWN	U+D	* UP	DOWN	U+D
1	328	26	354	0* 94	0	94	2290	0	2290	176	0	176	24	0	24
2	466	179	645	0* 272	25	297	8358	674	9032	179	241	241	30	26	30
3	247	96	343	0* 103	25	128	3864	826	4690	222	123	222	37	33	36
4	1356	450	1806	0* 534	258	792	3185	4218	7403	84	112	112	5	16	9
5	208	236	444	0* 51	111	162	1109	3160	4269	88	106	106	21	28	26
6	242	332	574	0* 41	220	261	672	5548	6220	42	106	106	16	25	23
7	170	297	467	0* 34	173	207	718	4496	5214	55	101	101	21	25	25
8	115	231	346	0* 21	124	145	607	3583	4190	94	128	128	28	28	28
9	76	262	338	0* 9	144	153	261	4800	5061	53	137	137	29	33	33
10	44	279	323	0* 0	72	72	0	1969	1969	0	86	86	0	27	27
11	0	339	339	0* 0	32	32	0	978	978	0	72	72	0	30	30
12	0	0	0	0* 0	0	0	0	0	0	0	0	0	0	0	0
SUM	3252	2727	5979	0* 1159	1184	2343	*****	*****	*****	222	241	241	18	25	21
SUM-MT	1896	2277	4173	0* 625	926	1551	*****	*****	*****	222	241	241	28	28	28

FIGURE 5.17 Tabulation of data for whole day



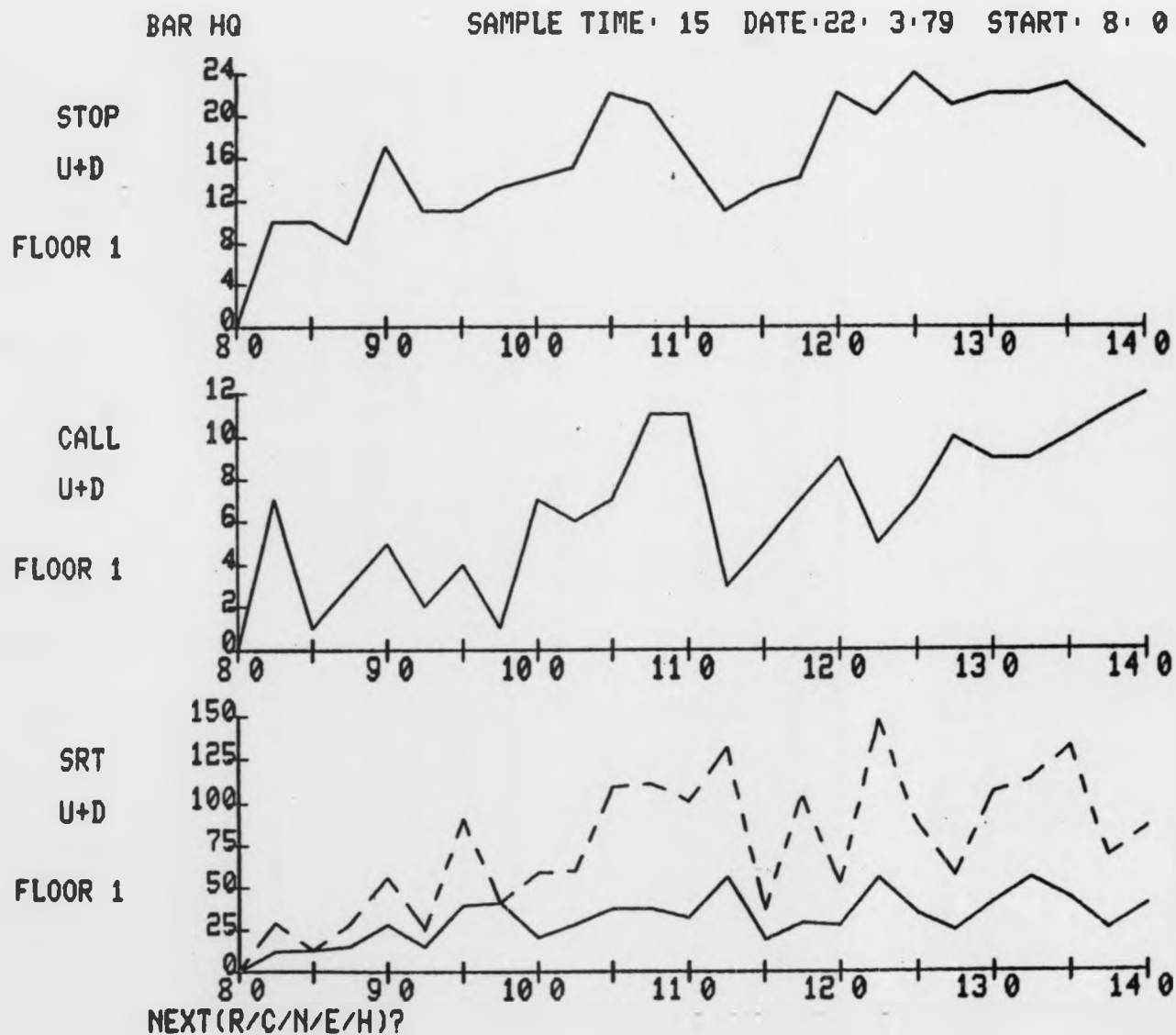


FIGURE 5.18 Activity at Floor 1

are imposed by the control algorithm. The latter has already been shown to be malfunctioning in a manner which causes unnecessary stops to be made. The graphs of lift car movements show that the cars are rarely idle.

#### 5.4.2 Building 2

Graphs of the activity in this building during the day under investigation are presented for stops, calls and system response time in up and down directions and for both directions summed. (figures 5.19 to 5.21). The sampling period of these graphs is 10 minutes which was chosen for the same reasons as were given in the previous building analysis.

##### 5.4.2.1 Up Peak

The up peak type traffic pattern can be seen, by plotting up stops and down stops on the same axes (figure 5.22). A peak in up stops can be clearly seen at 09:20. While up stops are approximately twice as frequent at this time as they are during the late morning, there are only half the number of down stops that can be seen later. This is verified by the graph of up stops divided by down stops, (figure 5.23), which reaches a maximum value of about 3 before falling rapidly to acquire a value of approximately 1. Figure 5.22 demonstrates the morning influx of building occupants to last for more than one hour between 8:50 and 10:00, though figure 5.23 shows that the peak of traffic imbalance for the lift system lasts for 40 minutes between 8:40 and 9:20. A similar situation, although less pronounced, may be identified between 13:30 and 14:30 with a peak at about 14:20; figures 5.24 and 5.25. Although this appears to be a very late return from lunch, confirmation

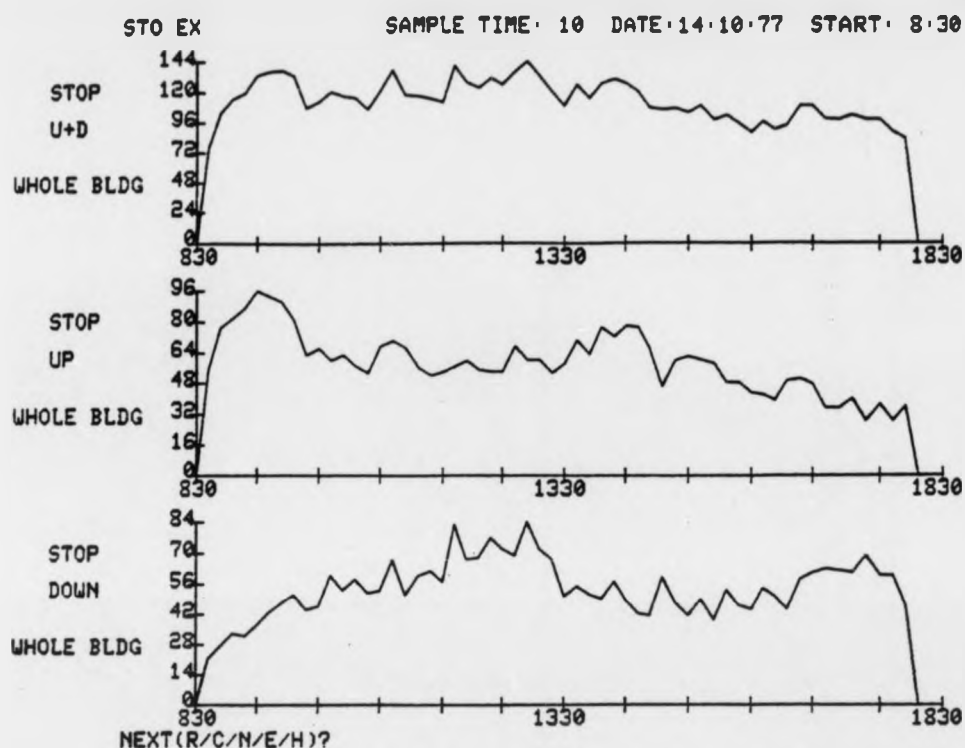


FIGURE 5.19 Stopping Rate

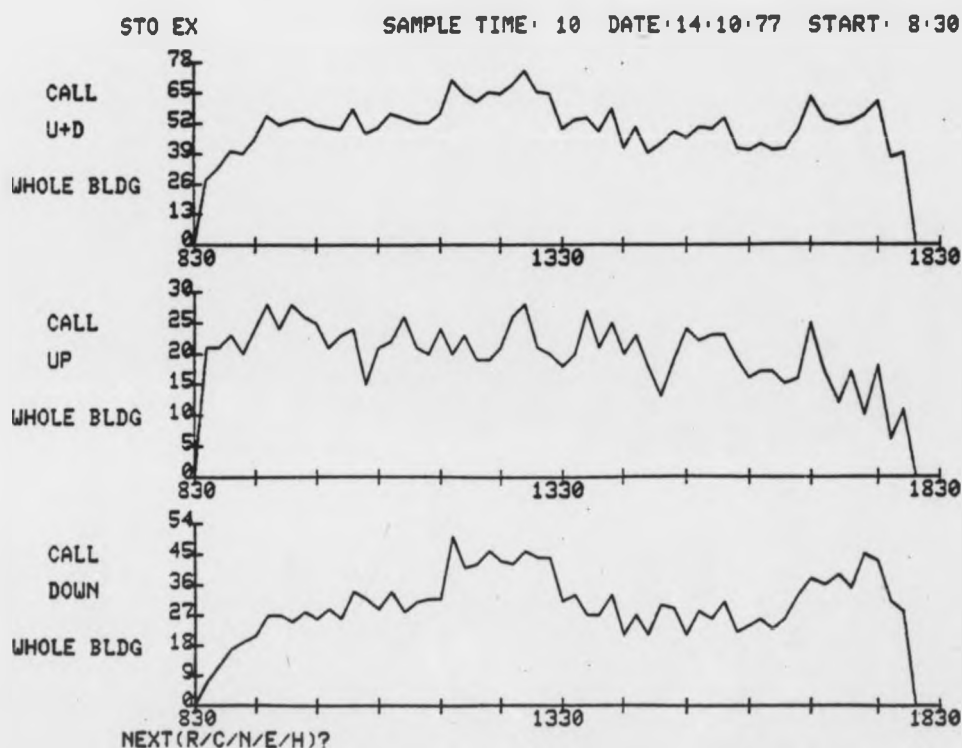


FIGURE 5.20 Call Registration Rate

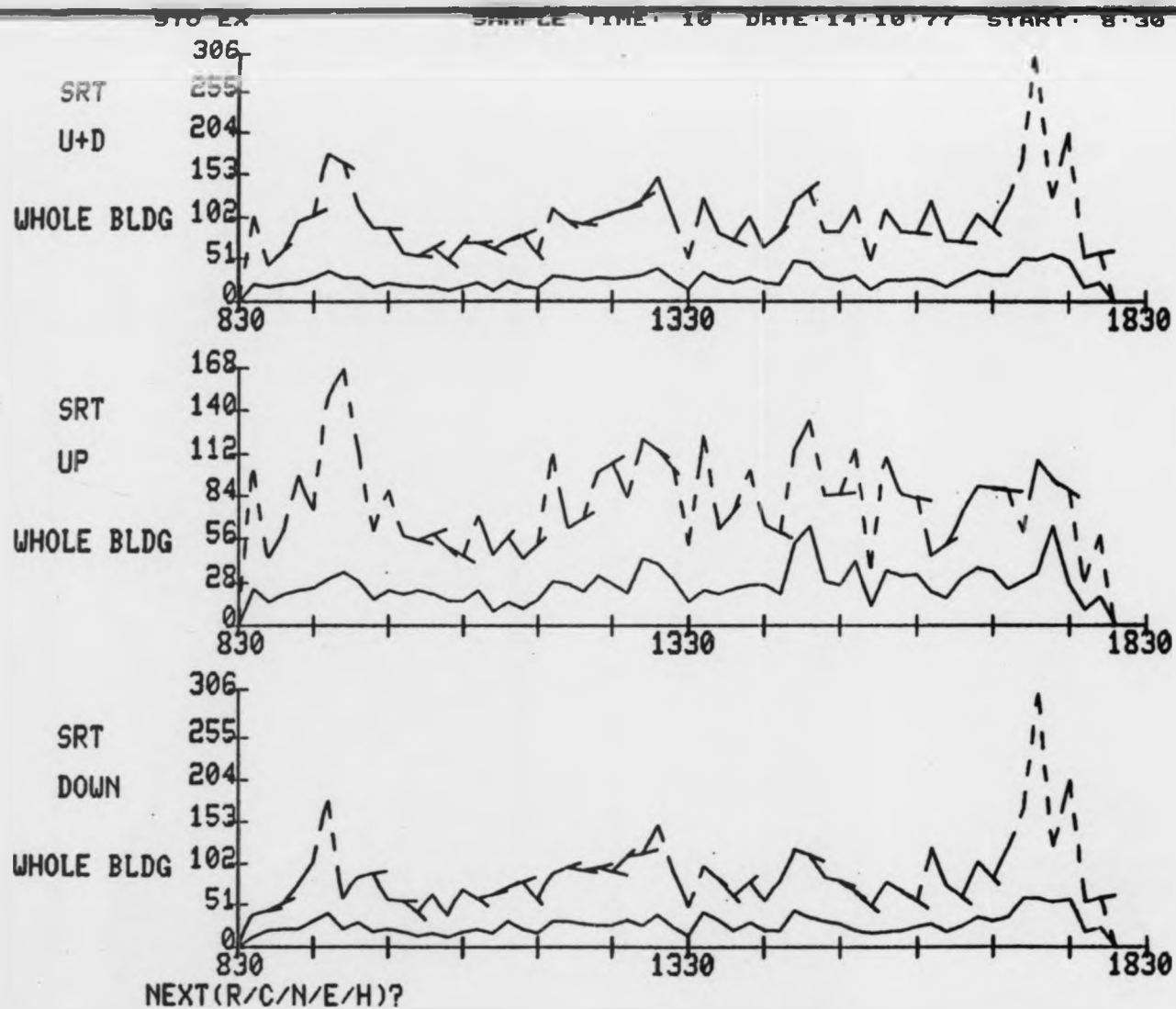
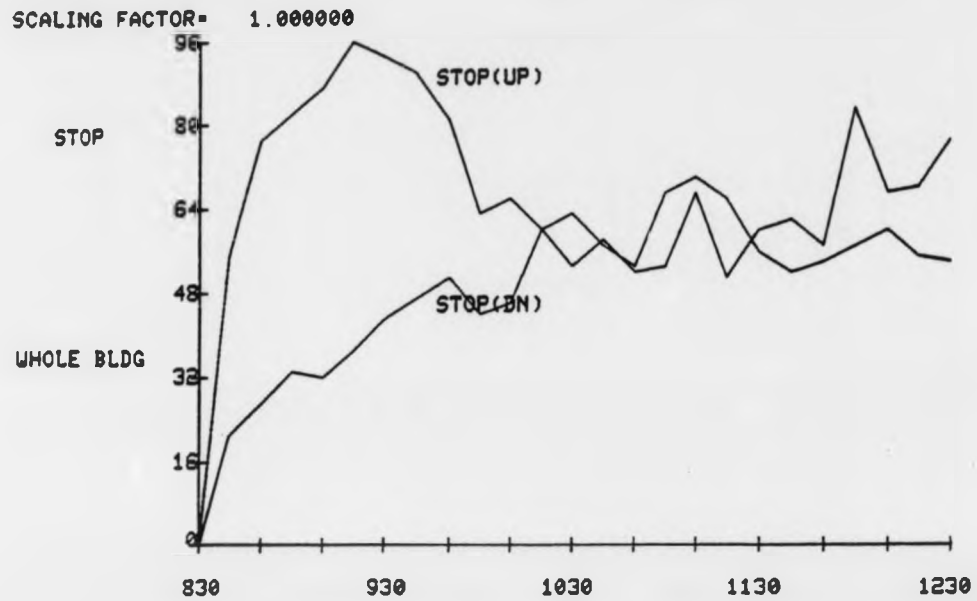


FIGURE 5.21 System Response Times (Mean and Max)

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30 138.

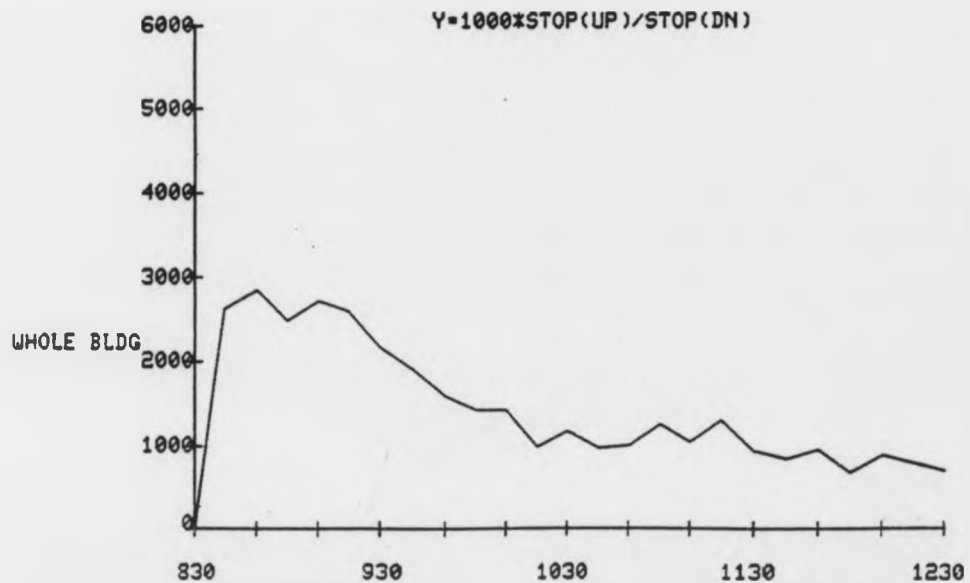


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.22 Up Stops and Down Stops

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30



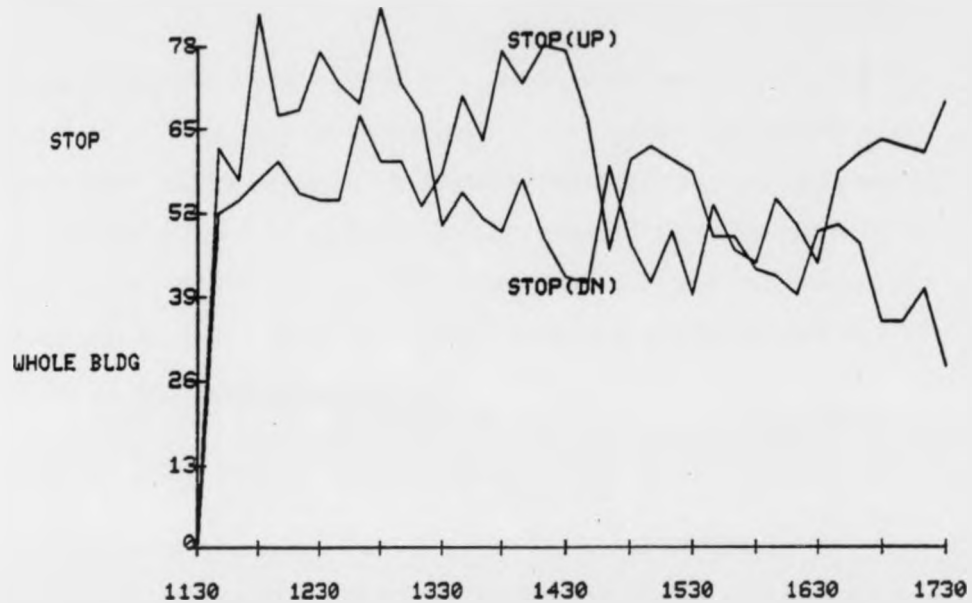
NEXT(R/C/S/P/N/E/H)?

FIGURE 5.23 Up Stops Divided by Down Stops

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 11.30

139.

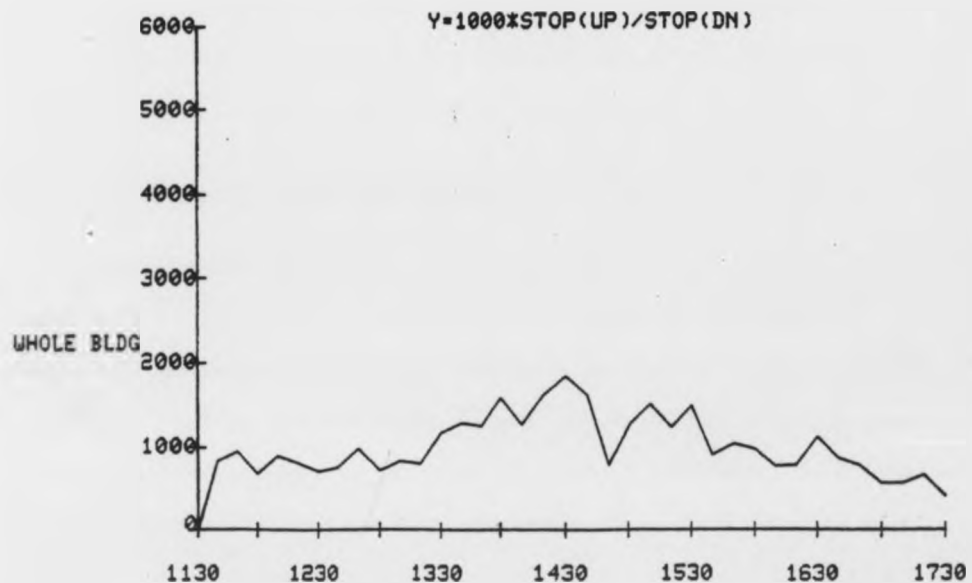


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.24 Up Stops and Down Stops - Afternoon

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 11.30



NEXT(R/C/S/P/N/E/H)?

FIGURE 5.25 Up Stops Divided by Down Stops - Afternoon

of this proposition was found in a manual observation, made before analysis of this data was conducted. This feature can probably be attributed to the nature of the work of many of the building users. It is noticeable that although system response is maintained with a mean value of 30 seconds or less throughout this period, max system response is consistently 90 seconds and rises to 180 seconds at 9:30 which is quite unacceptable.

#### 5.4.2.2 Down Peak

An increase in the rate of down call registration can be observed after 16:40 which achieves a peak between 17:20 and 17:40 (figure 5.26, first graph). This is matched by a similar increase in down stops shown in the second graph of figure 5.26. A concurrent drop in the upward stopping rate (figure 5.26, third graph) confirms that the building is being emptied. This is further illustrated by the graph of down stops divided by up stops (figure 5.27). System response time deteriorates badly during this period (figure 5.28) showing a mean value consistently reaching 50 seconds between 17:00 and 17:40. Maximum system response time actually reaches 280 seconds!

#### 5.4.2.3 Balanced Interfloor Traffic

In a multiple tenancy building, such as the one under consideration, a balanced traffic flow is more likely to exist in the form of concurrent movements to and from the main terminal. There is little reason for traffic between other floors since tenants of each floor work largely independently of other building occupants. This usage of the lift system is shown by the high ratio of up stops to up calls (figure 5.29) and the much lower value for the ratio of down stops to

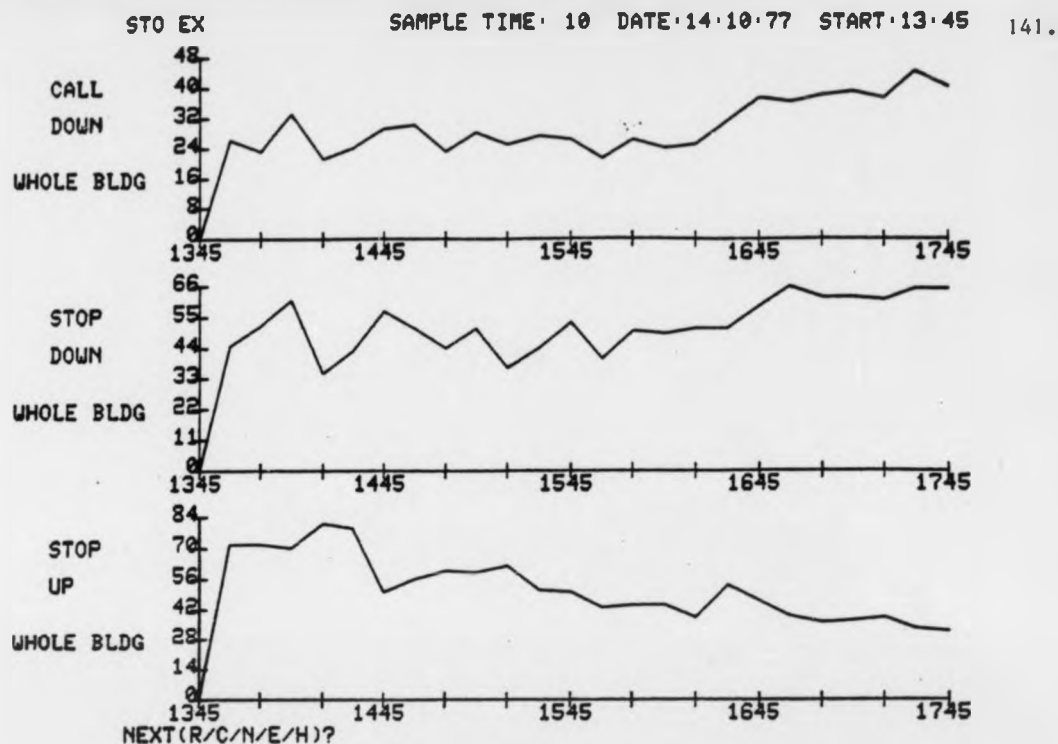


FIGURE 5.26 Afternoon Activity

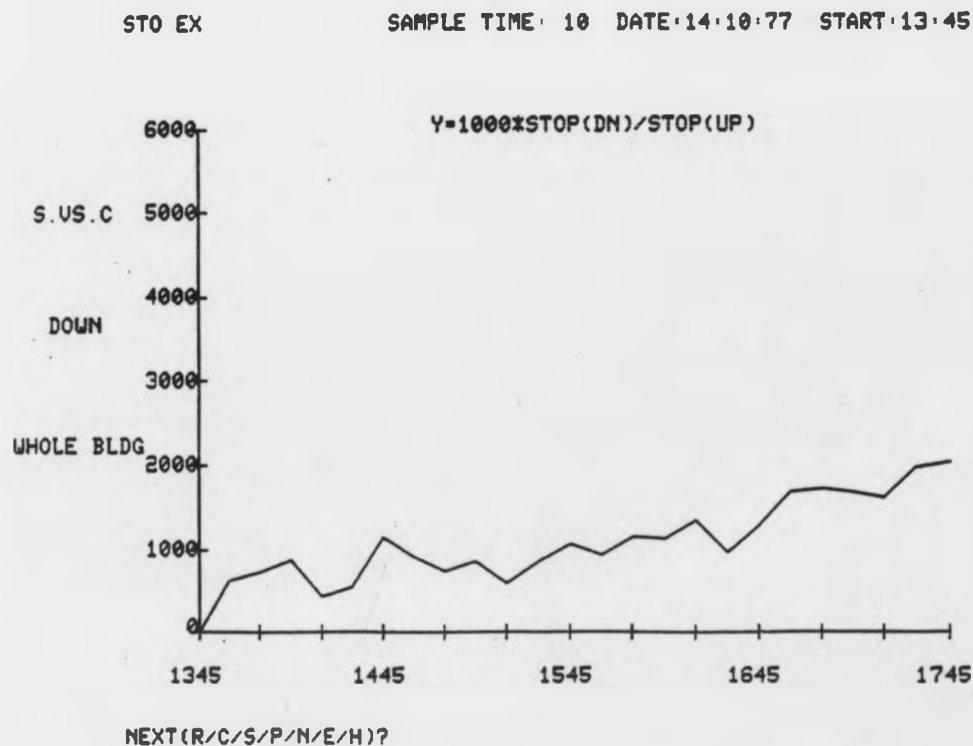
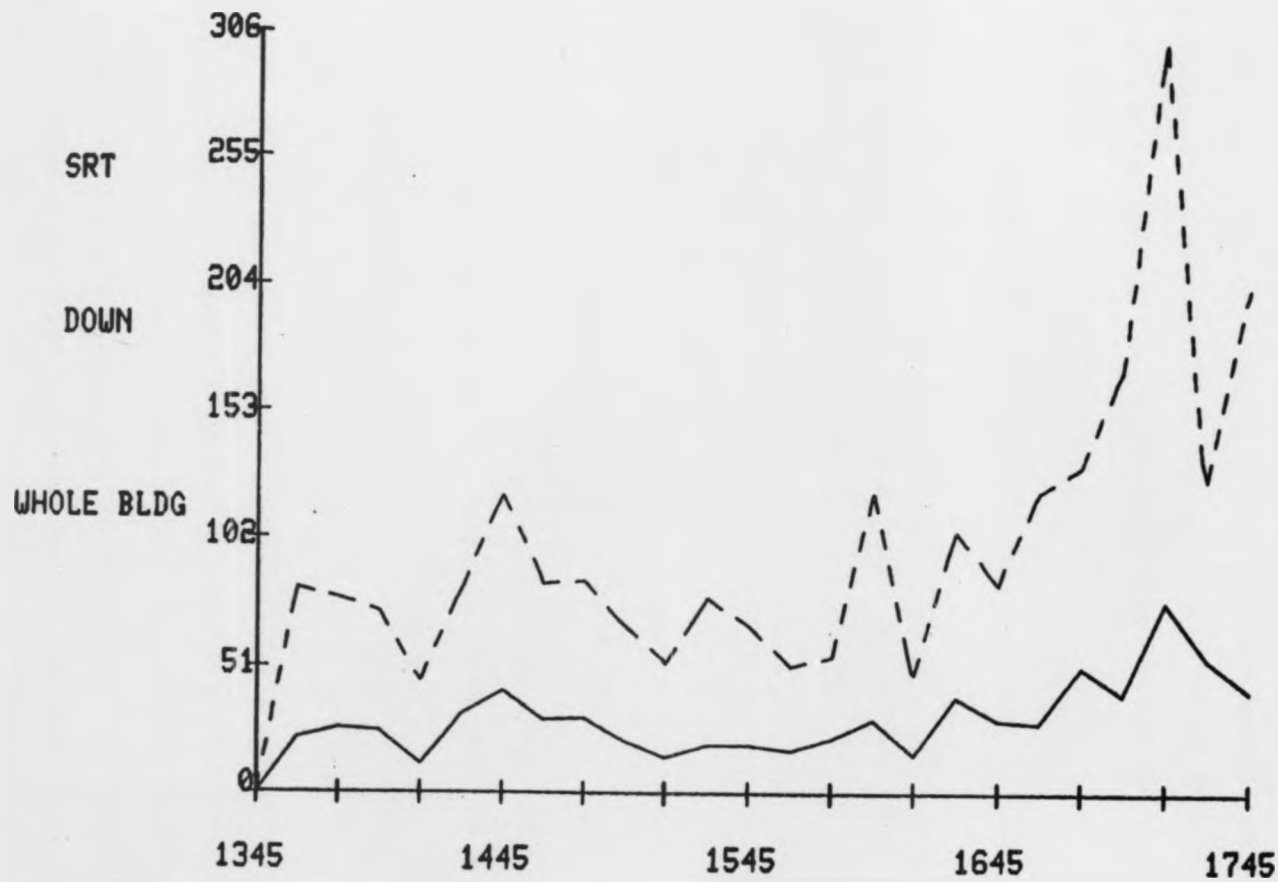


FIGURE 5.27 Down Stops Divided by Up Stops



STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 13.45



NEXT(R/C/N/E/H)?

FIGURE 5.28

System Response Times - Afternoon

down calls (figure 5.30), for the building without the main terminal. The almost constant unity value for the quotient of down stops divided by up and down calls for the whole building throughout the day (figure 5.31) demonstrates that the majority of down calls are made to leave the building and the majority of up calls are made from the main terminal. In other words, most of the down calls are made for the same destination, therefore

$$\text{STOPS (DOWN)} \approx \text{CALLS (DOWN)} + 1$$

remembering that an extra stop is incurred at main terminal. If most up landing calls are made from this common destination floor, then for each trip (up and down the building);

$$\text{CALLS (UP)} \approx 1$$

Thus for each trip

$$\text{STOPS (DOWN)} \approx \text{CALLS (DOWN)} + \text{CALLS (UP)}$$

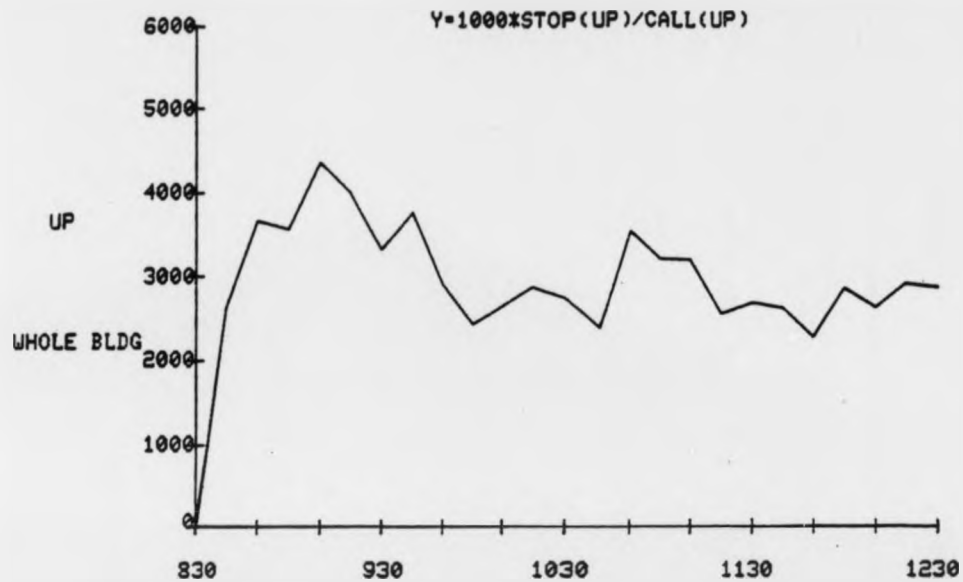
There are thus very few up calls from floors other than the common entry level and very few down journeys to floors other than this level.

#### 5.4.2.4 General Comments

This is a busy lift system. According to Bedford (1976), 2.5 stops per car per minute represents a heavily loaded system though in this example, the number of stops in both directions is consistently 50 to 55 per 5 minutes. Thus with four cars, the stopping rate can be expressed as 2.5 to 2.75 stops per car per minute. During peak times the stopping rate rises to 3 stops per car per minute.

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30 144.

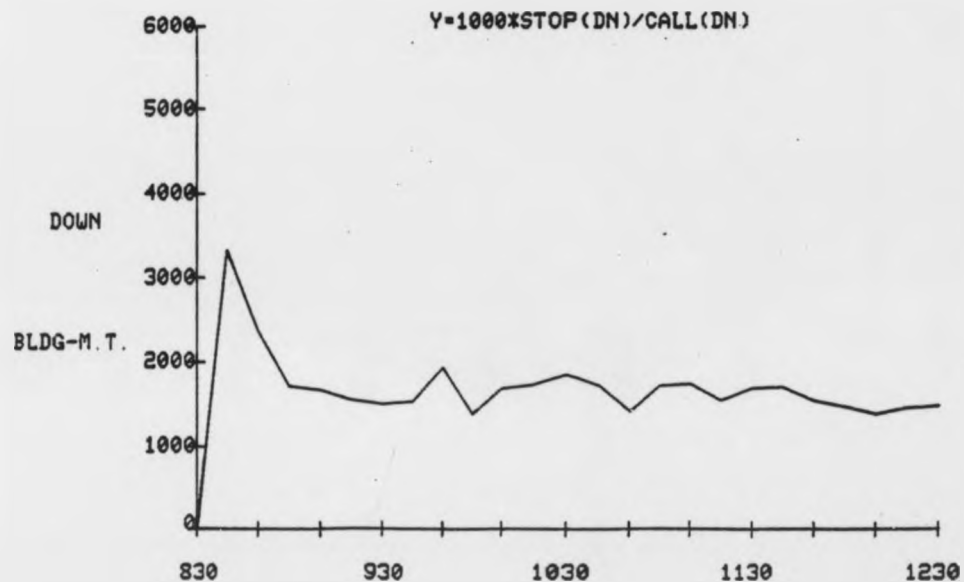


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.29 Up Stops Divided by Up Calls

STO EX

SAMPLE TIME: 10 DATE: 14.10.77 START: 8.30

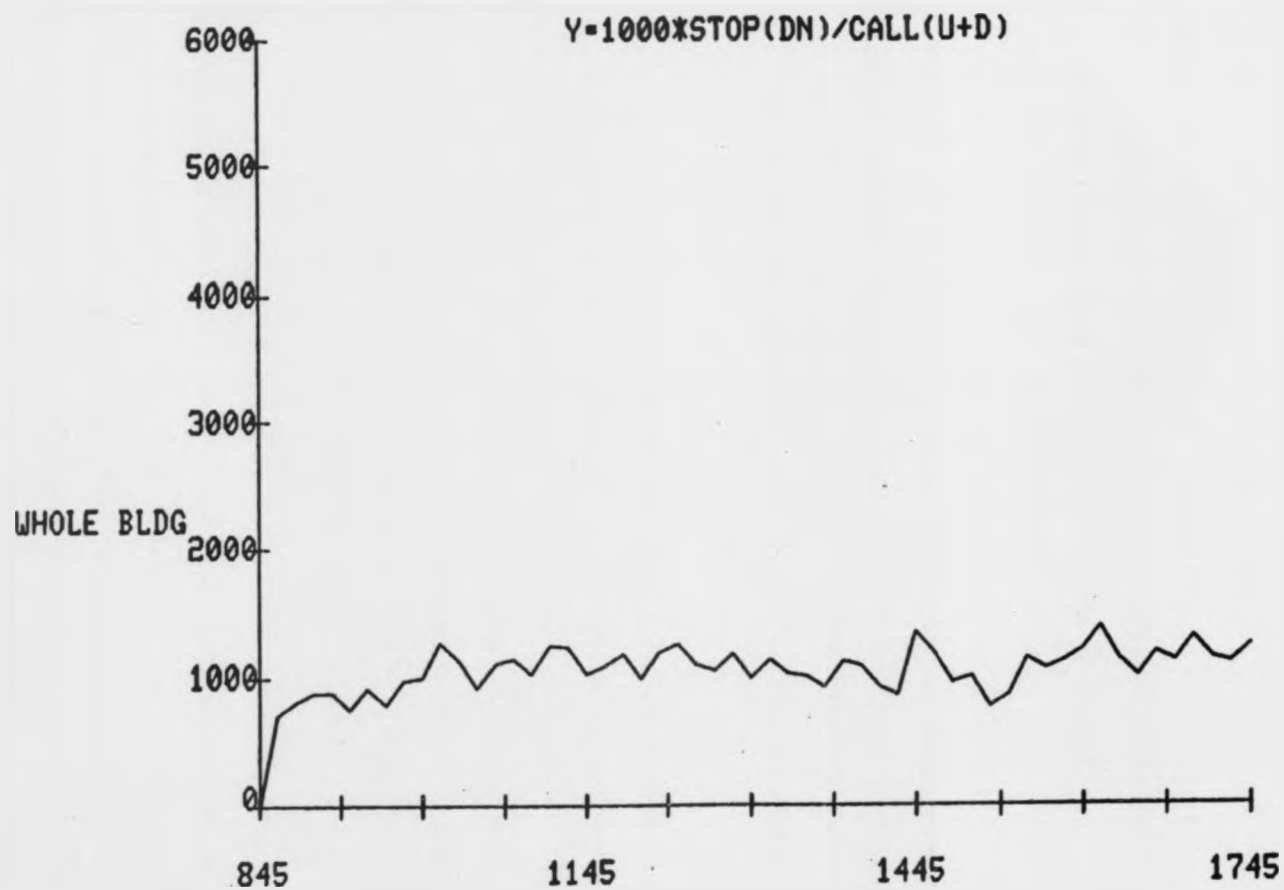


NEXT(R/C/S/P/N/E/H)?

FIGURE 5.30 Down Stops Divided by Down Calls

STO EX

SAMPLE TIME: 10 DATE: 14-10-77 START: 8:45



NEXT(R/C/S/P/N/E/H)?

FIGURE 5.31 Down Stops Divided By Up and Down Calls

#### 5.4.3 Discussion

The conclusions that may be drawn from this study of logged data are somewhat limited because only gross changes in the variables being monitored may be observed. Also the lack of a wide spectrum of environments and traffic demand levels prevents the formulation of standard values for the comparison of parameters between different lift systems. However, it has been demonstrated that it is possible to locate patterns of traffic movement which are associated with particular times of day or building environments. Unfortunately it is difficult to strictly formalise analysis procedures because of the uniqueness of each building. However, after an initial study of the major features of a building and its usage, it has been demonstrated that significant parameters may be isolated which will allow identification of salient features of traffic flow.

Both analysis examples show an up peak period or, more correctly, a filling of the building at the start of the day which lasts for considerably longer than is predicted by Barney and Dos Santos (1977, p.6). This may be due to staggered or flexible working hours. In particular, the presence of two influx periods (7:00 to 7:30 and 8:15 to 9:30) shown in figure 5.11 in the first example, suggests that two sets of building occupants are using the lift system.

The down peak or emptying of the buildings has also been identified and the duration of this period in both examples again appears to be longer than expected (Barney, 1977, p.8). However, the effects of some building occupants remaining after the majority has left or, as in example one, new arrivals, are difficult to determine.

Both buildings have been shown to suffer from very heavy demands throughout the day and the long response times resulting from this have been noted. In the first example the response of the lift system is degraded by an inadequate and malfunctioning group supervisory controller. Both examples demonstrate the need to optimise the control of the lift system by adapting it to the unique environment of each building. Suggestions for improved control policies might be formulated by examination of the graphs of car movements. These graphs help to identify high activity floors which might warrant preferential service. Floors experiencing particularly long response times might also benefit from special attention by the control policy.

Chapter 6

Performance Measurement

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The discussion presented in the previous chapter demonstrated the use of logged data from an operational lift system to identify major changes in traffic flow. However, the level of investigation possible, using the techniques which have been described, is not of the profundity envisaged during the specification of the lift management system proposed in chapters 3 and 4. This is particularly true of the lift Monitoring and Analysis function which is the main data processing operation of the lift management system. To execute this management function, a procedure is required whereby a quantification of lift system performance can be obtained. The objective of performance measurement is to produce a method of quantifying lift performance which is independent of the building, the passenger demands and the actual lift equipment. The concept of a performance index or indices is attractive. Such a quantification could be so normalised as to facilitate a comparison of performance of lift systems in different buildings or the same lift system under different traffic patterns or during different periods of history. Such a measurement may require additional information to be obtained from the lift system. Having gained a familiarity with the nature of data being handled, as discussed in the previous chapter, an investigation was undertaken with the aim of formulating the definition for a performance measurement of lift systems.

#### 6.1 Discussion of Lift System Performance

It is possible to consider a lift system in terms of classical control theory. It has a demand variable - passengers requiring service - and a system response variable - lift car movements. As in more conventional control systems, there is a controller connecting the two variables - the lift controller or traffic supervisory system. The



system is closed loop when viewed from the demand variable. To identify an index or indices of performance for a lift system, an equivalent of the conventional performance indices which relate rise time and overshoot to the conventional design criteria of gain and phase margin or M circle is required. Stability theory is probably less important for lift systems due to the longer time scales for system responses and the multiplicity of system servers (lift cars in a group). However, it is probable that unstable modes do exist and it may be that some of the observed anomalous behaviour could be attributed to this factor. The work of Alexandris (1977) suggests feedback effects and interdependence of cycle time and passenger demand as manifested by queue lengths. Figure 6.1 illustrates in block diagram form the possible interrelationships of system variables. To determine suitable performance indices it would seem that measurements must be made of those quantities which reflect traffic demands and those which reflect system response.

## 6.2 History of Performance Measurement

Several workers, recognising the need to assess lift system performance, have proposed criteria upon which analysis may be based.

Lauer (1978) suggests measuring the distance of travel and percentage occupancy of the total capacity of the system (i.e. system loading). The product of those two quantities, he argues, is a measure of the efficiency of the system, allowing a direct comparison between dissimilar installations. It would be possible to ascertain whether a building was over or underprovided with lifting capacity (i.e. the quantity of service). This is an important factor, since it is difficult to find a meaningful common measurement between two buildings because

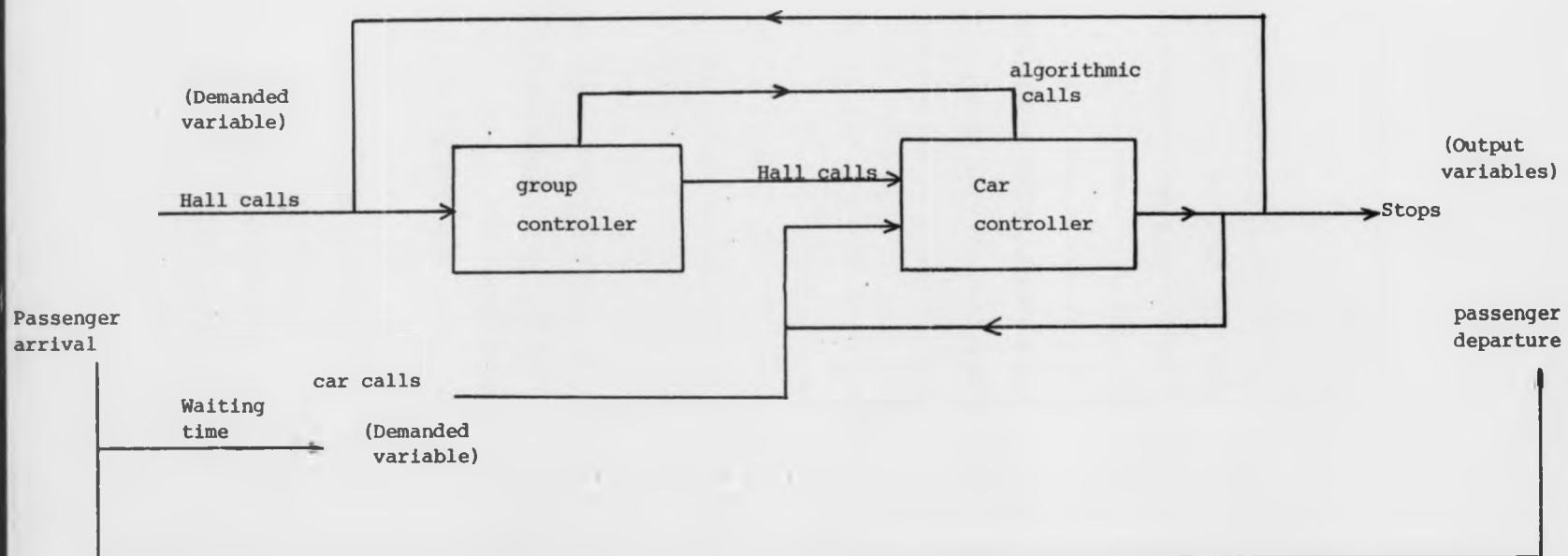


FIGURE 6.1 Lift Control System and its variables

the environment of each is likely to be unique. However, used by itself, this evaluation provides no information about features which are important to users of the lift system such as the time spent waiting for a lift car (i.e. quality of service).

Barney and Dos Santos (1977, p.201) discuss factors affecting quality of service. They conclude that waiting time, before a lift car arrives, is of paramount importance. Psychologically, this is more demanding than the time taken to arrive at the destination floor, once inside the car. This is because users waiting on a landing for service have no indication as to when, or even if, a car will stop in answer to their call. Once inside the car, passengers are assured by ample evidence that they are approaching their destinations.

Though waiting time is certainly an important consideration, it cannot, in isolation, provide a complete description of the system performance. In-car journey time is also of importance and is used by Closs (1970) in calculating performance cost functions for computer based lift control policies.

Dos Santos (1974) and Moussalalti (1974) compare the performance of a large number of simulated lift systems with various configurations and traffic demand levels. The performance criterion used in this work was either passenger waiting time or the sum of waiting time and in-car journey time which in this case was termed "journey time". To overcome the considerable variation in waiting time or journey time that could be attributed to differences in lift system configurations a normalising factor was included in the performance measurement. This factor is shown to render the performance figure sufficiently independent of

configuration qualities to allow direct comparison of quite dissimilar lift systems, though some dependence on the number of floors in a building is still exhibited. The performance figure is given by the equation:

$$P.F. = \frac{AWT}{UPPINT} \quad \text{or} \quad P.F. = \frac{AJT}{UPPINT}$$

where AWT and AJT are the average of waiting time or journey time respectively for each passenger over a period of 5 minutes. The normalisation factor which was chosen is the up peak interval, (UPPINT), calculated for 80% car loadings (Barney, 1977, p.22). The equation used to calculate the up peak interval demonstrates why it is a suitable normalising quantity.

$$UPPINT = \frac{2Htv + (s+1)ts + 2Ptp}{L}$$

UPPINT is thus dependent upon H, the average highest reversal floor (which in turn depends on the number of floors in the building), tv, a function of the lift car contract speed, s, the average number of stops per trip (dependent upon the size of the lift cars) and L, the number of lift cars. Thus, UPPINT is a function of the "resources" of the system and becomes smaller as resources are improved.

Finally, Levey et al (1977) suggest the use of a parameter which combines passenger waiting time and in-car journey time, again for the purpose of deriving a performance cost function for computer control. This is defined as the "busy period" which is the expected time that will be taken to clear the system of all passengers currently requiring service. This quantity has the advantage that it is dynamic, that is its value is always instantly available and does not have to be averaged

over 5 minutes. Also it describes the state of the whole lift system. The suggested controller minimises the busy period to derive an optimal control policy. Thus a consensus would indicate that important factors relating to performance of lift systems are:-

- i) System loading (in terms of passengers)
- ii) Average waiting time.
- iii) Average in-car journey time

During the process of designing a lift system, a performance analysis for the proposed system might be conducted using computer aided simulation. The simulation allows the designer to measure any variable in the model which might be considered relevant. However, some of the parameters which are used for design purposes are inaccessible or at least very difficult to measure in a real system. Unfortunately, this is true of all the variables listed above (i to iii) since they relate directly to passengers in the lift system. Furthermore, the listed parameters all refer to lift system response without consideration of the level of demand exerted on the lift system.

Dos Santos (1974) and Moussalatti (1974) present their performance figures as graphs plotted against percentage demand. This is defined as the number of potential passengers arriving at a lift system and requiring service during a 5 minute period expressed as a percentage of the up peak handling capacity of that system. Here, the up peak handling capacity represents a normalising factor which accounts for the varying "resources" of different lift system configurations. Unfortunately once again this parameter is intimately related to passenger movements which will render it very difficult to measure.

### 6.2.2 Practical Considerations

Some work has been undertaken to analyse data obtained from real lift systems but much of the documentation of this work remains unpublished. Barney and Dos Santos (1977, p.301) discuss the use of data on lift car movements to "improve performance" but such improvement is mostly concerned with diagnostic maintenance and no quantification of performance is produced. Bedford (1966) measures demand as the number of hall calls registered in a fixed period. Here, waiting time is the interval between landing call registration and the arrival of a lift car which cancels the call. This period is defined in Barney and Dos Santos (1977, p.273) as System Response Time. Bedford notes ".... the off peak period of the day when the actual number of passengers carried may be small in comparison with a peak period but the number of calls and lift movements to answer them may be extremely large." Thus the incidence of calls cannot be interpreted as an indication of traffic density but does represent a loading of or demand on the system resources. A consequence of this fact is that the more rapidly a call is answered, the fewer people will have accumulated at the same landing before the answering car arrives. Therefore it is likely that a faster system will automatically register more calls for the same number of passengers. Extrapolating this, an extremely fast system would have an equivalence between landing calls and passengers.

Otis (1976) also utilises system response time as a measure of waiting time. In addition, "percentage availability" is assessed which although not clearly defined, appears to be percentage of time that a car is free to answer landing calls immediately they are registered.

### 6.3 Formulation of a Performance Index

No work has, as yet produced a workable performance index. Clearly, some practicable measures of "demand" and "response" must be defined before such a goal may be achieved.

Most workers are agreed that average passenger time spent in the system is the most significant indication of response and of user satisfaction. This time should be minimised to optimise response, and of the constituent periods, passenger waiting time on landings is most important in this respect. Average system response time is the closest approximation to average waiting time that can be readily measured in a working lift system. As a criterion of response it is perhaps more rigorous than average waiting time since it represents the longest waiting time for each landing call. System response time does, in fact, describe the service ("response") provided by the lift system since for most lift controllers, the number of waiting passengers is unknown, the only input information being landing calls of the first arriving passengers.

A measurable variable which reflects demand is more difficult to isolate. This difficulty arises because of the closed loop nature of the lift system which means that response of the system is intimately related to the parameters which might reflect demand. For example, as the earlier discussion of Bedford's work demonstrated, a system which responds quickly to landing calls is likely to register more landing calls than a slower system with the same arrival rate of passengers. Thus, the call registration rate cannot alone be used as a demand indicator. There is common agreement that demand on the lift system is

the rate of arrival of passengers, though Closs (1970) and Levey (1977) who both consider the problem of optimal control, also recognise the importance of passenger destination. Obviously, a greater demand is created by several passengers arriving at one landing, each with a different destination than if all these passengers had the same destination in common.

The average number of stops made in a sampling period was used in the previous chapter to locate peaks in demand but this measure proved to be insensitive to small changes and therefore difficult to interpret. Dos Santos (1974) and Moussalatti (1974) demonstrate a relationship between arrival rate expressed as a percentage of up peak handling capacity and the stopping rate per lift car. A graph of this function, at five levels of passenger demand (arrival rate/up peak handling capacity) for thirty six unique lift systems, produced by simulation is shown in figure 6.2. The graph shows a saturation of the stopping rate variable (at about 4.5 stops/car/minute) which therefore renders the function insensitive to changes in demand for high demand levels. Thus stopping rate is not a satisfactory measure of demand. However, the stopping rate might provide a useful indication as to how closely a lift system is loaded to its maximum capacity. A stopping rate well below the saturation level demonstrates that periods exist when the lift system has spare handling capacity i.e. cars standing idle for short periods. A car is idle if it is stationary with its doors closed.

Thus  $\text{Idle Time} = \text{Time between stops} - (\text{Door operating time} + \text{Door opened time} + \text{flight time})$



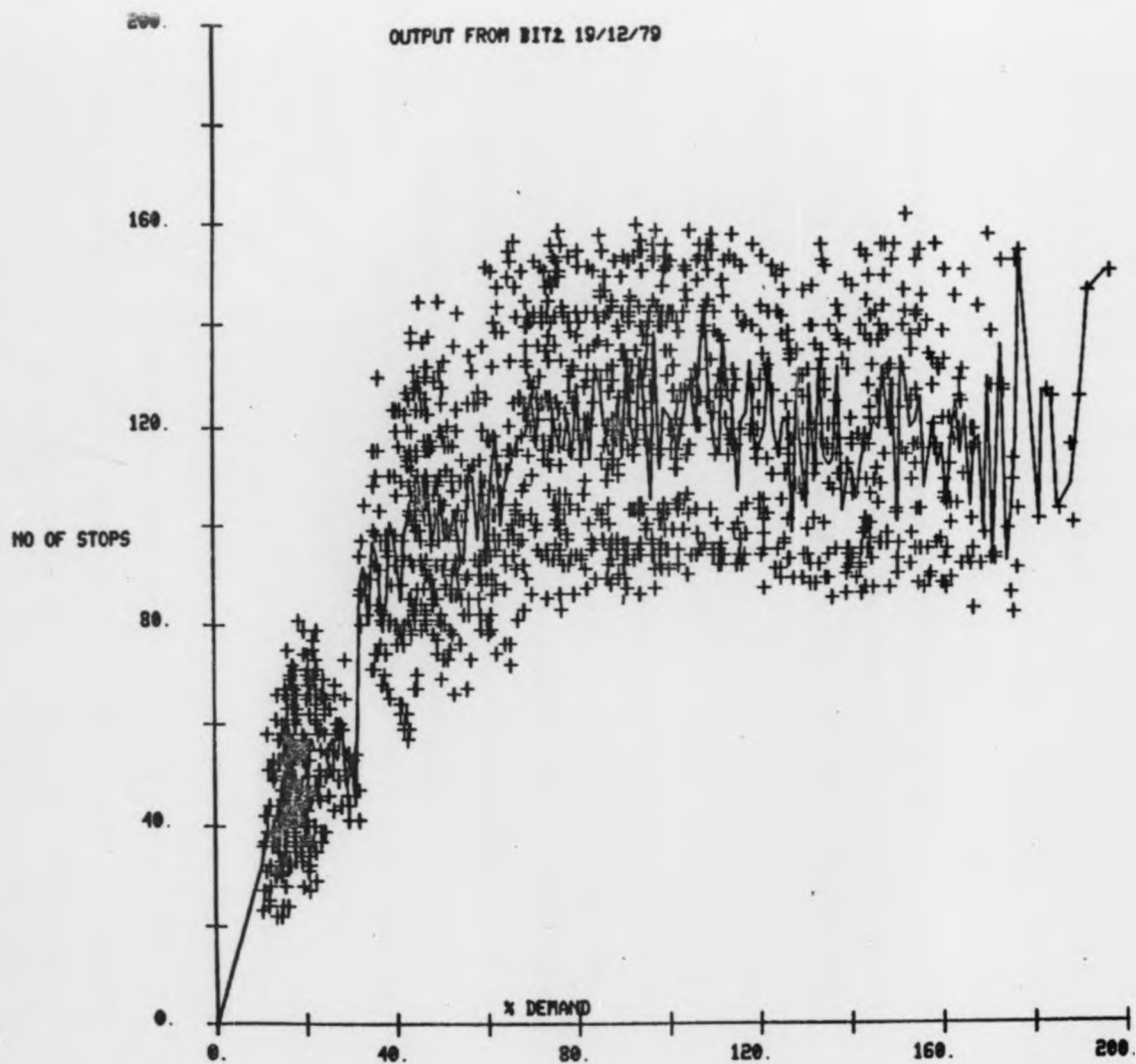


FIGURE 6,2 Saturation of Stopping Rate with Increased Demand

Taking some typical 5 minute average figures over an hour:-

door operating time	5.5 secs
door opened time +	
flight time	<u>12 - 16 secs</u>
	17.5 - 21.5 secs

If the same system generates about 160 stops/car/hour, in that hour, this means a car stops about every 22.5 seconds. Obviously, cars are not busy all the time. Here idle time varies between 4% and 32%. The contract speed of the lift cars is not thought to affect the saturation stopping rate very noticeably, since the large number of stops prevent the lift car attaining its rated speed before it must decelerate for the next stop.

An approach suggested by Levey (1977) to measure just the rate of arrival of passengers involves evaluating the time between a lift car leaving a landing and the registration of the next landing call. Although it represents the time that passengers are not present at the landing, this quantity seems to bear no relation to the arrival rate of passengers since no account is given to the timing of the lift car movements in relation to the time of arrival of the last passenger to board the departed car. Thus the technique must be discounted.

A suitable variable for demand was finally arrived at with Levey's notion of a busy period (Levey, 1977). Although originally conceived as a response indicator for optimal control, this parameter very concisely defines the actual demand level placed upon the lift system at any instant. It represents an estimate of the time involved in clearing all currently acknowledged passenger demand (both landing and

car calls) from the system and therefore represents the "business" of the system. Furthermore, the use of this variable as a demand indicator allows the possibility of normalisation for comparison of demand between different lift systems. The busy period must be predicted according to the rules of a control policy. If a standard control policy is used for this purpose, irrespective of the actual policy implemented in the measured system, then a busy period in one system represents a similar demand in another. A normalising factor must also be used for the response variable if performance comparisons are to be made between lift systems. Such a factor is provided by Dos Santos (1974) and Moussalatti (1974) in the calculated up peak interval for 80% car loads which is described earlier in this section.

#### 6.4 Implementing Performance Index Measurement

The practicalities of estimating a performance index may now be considered. Average system response time can be measured simply by timing the duration of landing calls for all landing calls in both up and down directions. A sampling period over which system response time may be averaged must be chosen. The length of this period will depend on the level of activity within the lift system but an interval of between 5 and 10 minutes should be chosen according to which gives the best results on a trial and error basis. In the proposed lift management system, all the necessary information for the calculation of average system response time is provided by the low level functions. The average may be taken over the sampling period immediately preceding the calculation and be continuously updated at very short intervals (i.e. ten seconds). Thus results are obtained as soon as one half of

a sampling period after the interval to which they relate. Effectively this means that the averaging calculation is made through a "moving window" the width of which is equal to the sampling period (see figure 6.3)

The up peak interval, for normalisation of the response factor of the proposed performance index, can be calculated from the manufacturer's specification of the lift system, and features of the building, according to the method described by Barney and Dos Santos (1977, p.21). Passenger transfer time must be guessed but it is usually assumed to be 1.2 seconds per passenger.

Calculation of the demand factor requires considerably more work than the response variable. A control algorithm must be simulated for this purpose, which operates in parallel with the real lift controller to allow prediction of the busy period. The simulated control policy should be chosen to be a simple algorithm which is consistent under all traffic conditions but should also be capable of operating in parallel with a wide range of commercially available controllers. If a parking policy is included this should be of a very simple nature. The purpose of the simulated control policy is merely to provide a reference which can be widely applied to facilitate a comparison of demand levels in different lift systems. Thus it is not important for this control policy to be matched to the building or traffic patterns where it will be used. For these reasons the CCL algorithm described by Barney and Dos Santos (1977, p.135) was chosen, which is a simplification of a commercial system developed by the Marriot and Scott company. The algorithm which is designed for a minicomputer based controller, actually predicts the system response for each landing call with every possible

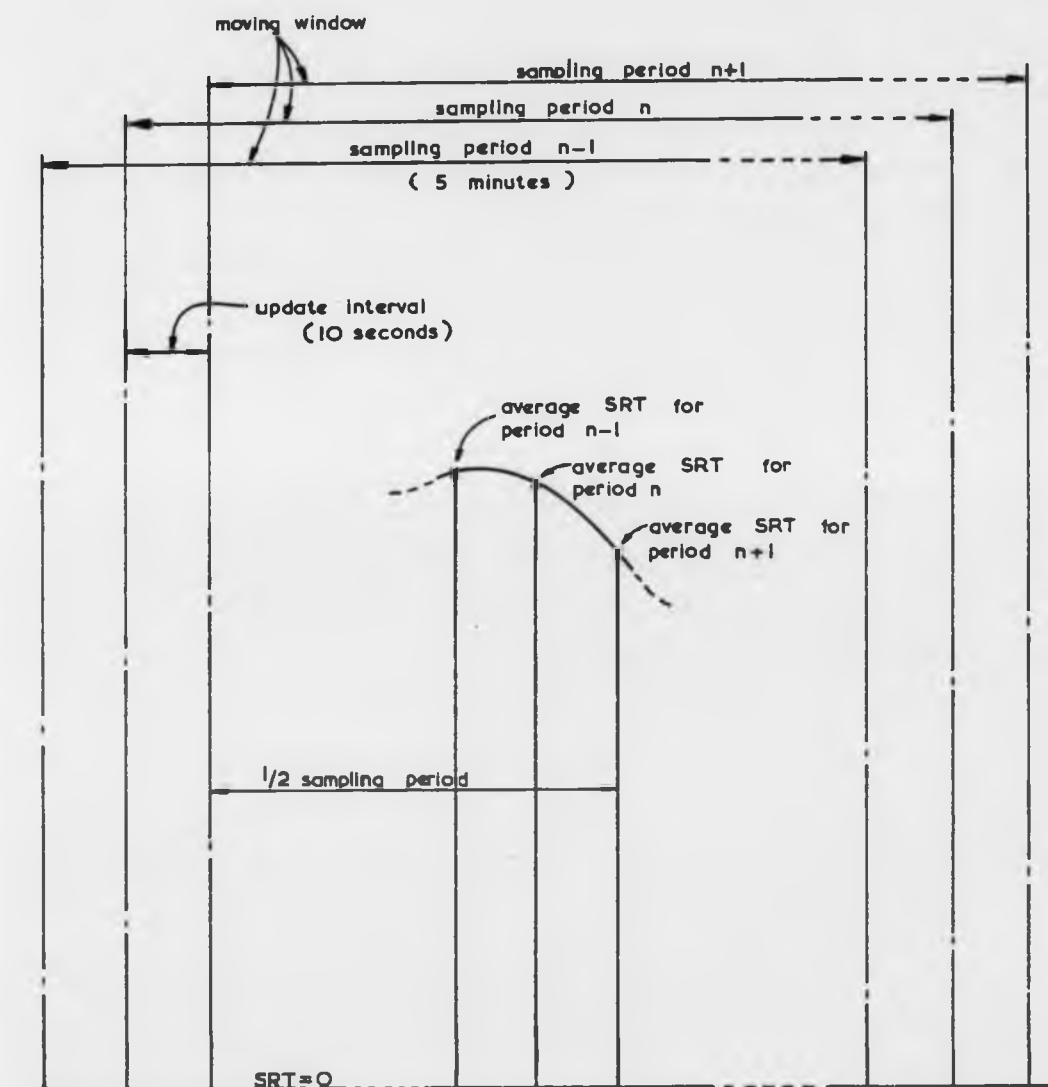


FIGURE 6.3 "Moving Window" Averaging of System Response Time

assignment of lift cars to calls and adopts the minimal solution. The process is continuous and cars are reallocated to calls dynamically until the last possible instant that an allocation may be changed. A number of conditional features allow long-wait calls, high activity floors and priority floors to receive preferential service. A full description of this algorithm is included in Appendix A.

Since the simulated control process involves a prediction of lift system timings, it is ideally suited to the proposed calculation of the busy period. Furthermore, the logic of this algorithm is quite simple and consistent so that it possesses the same characteristics under different traffic conditions. To enhance this quality, it may be desirable to remove the conditional features which allow preferential service in certain cases since it might be difficult to standardise test values for the application of the conditions. The process of evaluating car journey time to answer a single landing call is conducted by considering all the car call, and the landing call stops to which the car is currently committed. The number of each type of call between the car and the end of the journey is evaluated. The journey time can then be calculated as the sum of several constituent periods including flight times between stops, door operating times and landing and car call passenger transfer times. The algorithm allows a transfer time of 3 seconds for each stop due to a landing call. For car calls both the estimated number of passengers (from load detectors on the car) in the car and the number of relevant car calls are considered and the transfer time is assumed to be twice the larger of these two numbers in seconds. Exactly the same timings can be applied in the calculation of the busy period except that here, only the final, optimal assignment of cars is considered.

This approach is applicable for any demand measurement in any lift system which operates a full collective algorithm. In the exceptional case where destination information is given by passengers via landing calls (Closs, 1970) compatibility is still possible. To obtain a true comparison of demands in other lift systems, in this case a small amount of preprocessing of landing call information is required, to simulate a two button full collective system. This could be achieved by calculating whether the destination-type landing call requires up or down travel and registering a landing call with that direction immediately. Then, when the answering car departs, the passenger's destination is revealed as a car call.

The proposed demand measurement scheme allows direct comparison of almost any two lift systems. If this measurement is to be made in the proposed lift management system, additional car call information must be provided by the low level management functions.

Chapter 7

Conclusions And Suggestions For Future Work



#### 7.1.1 Further Development of Performance Measurement

Before a complete lift management system can be produced for commercial use, it is necessary to prove the validity of the proposed performance analysis and in particular the suitability of the suggested performance index. This could be achieved, initially by simulation and subsequently by collecting real data. Preliminary simulation studies should be directed towards assessing the sensitivity of system response time as a measure of response, and the qualities of the busy period in representing demand. Initial investigations have shown a close relationship between average system response time and average waiting time, reinforcing the argument for its use as a response measurement. Figures 7.1 and 7.2 echo the work of Moussalatti (1974). Figure 7.1 shows the original graph of average waiting time as a percentage of up peak interval plotted against percentage demand (arrival rate as a percentage of up peak handling capacity). To obtain this graph, simulations were conducted for 36 lift system configurations using a dynamic sectoring algorithm at five different levels of passenger arrival rate representing a balanced interfloor traffic flow (see Table 7.1). Each configuration and arrival rate was simulated for the equivalent of one hour of lift activity and a detailed discussion of this work is contained in the dissertation of Moussalatti (1974). For these experiments, percentage demand is used to represent the arrival rate of passengers throughout the building, expressed as a percentage of the up peak handling capacity of a particular lift configuration. Figure 7.2 shows a similar graph, but here average system response time is substituted for average waiting time. The two graphs show great similarity, particularly at realistic traffic intensities (i.e. 20% to 50% of up peak handling capacity, or up to about 100% of building population using the lifts in one hour).

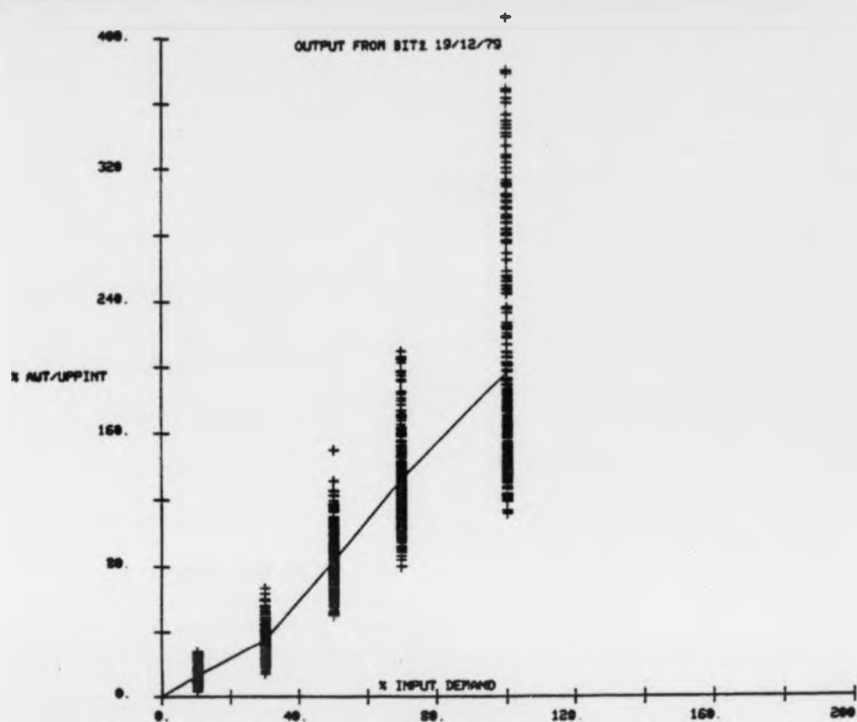


FIGURE 7.1 Percentage Average Waiting Time vs. Percentage Demand

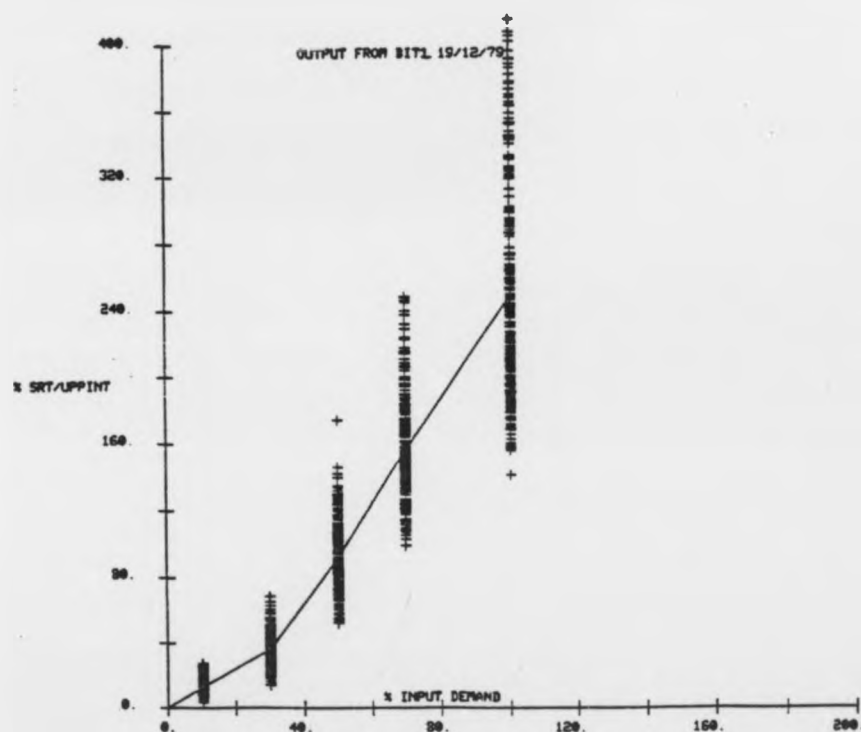


FIGURE 7.2 Percentage Average System Response Time vs. Percentage Demand.

Table 7.1Fixed Parameters

Number of floors	= 16
Control Algorithm	= Dynamic Sectoring
Distance between floors	= 3.3 m
Door width	= 1.1 m
Passenger transfer time	= 1.2 s
Floor population distribution	= equal

Variable Parameters

Number of cars	= 4, 5, 6
Capacity of cars	= 8, 16, 24 persons
Door operating times	= 4, 5 s
Contract speed of cars	= 3.0, 4.5, m/s
Percentage demand	= 10, 30, 50, 70, 100 % of UPPMC

Finally figure 7.3 shows the relationship between average waiting time divided by up peak interval and average system response time divided by up peak interval. The results shown above were obtained by executing simulation as a continuous process by controlling the lift system simulator from an external program (see Appendix B). This allowed the simulation suite to remain unchanged while processing input data in this unusual manner. The output data files prepared by the simulation are sufficiently detailed to allow plotting of the graphical data presented in figures 7.1 and 7.2. However, when the study of busy period as a demand variable was considered, it was found that major alterations would be needed in the simulation software. Information must be generated which has a similar form to the data which will be logged from operational lift systems, as an event-by-event record of activity. This is not immediately possible since, in general, the output from the simulation is sampled over five minutes to yield average values. Some of the simulation modules can produce a very precise record of the state of internal variables during simulation. This was implemented as a software test facility and is invoked by the specification of a "hidden" option during the execution of the input module to the simulator. However it was found that the variables of the simulation could not be relied upon to uniquely define the state of the lift system. For example, ambiguities often arise as to whether a car is moving between floors or is in fact parked at a floor. Thus simulation, for the measurement of the busy period of a lift system, was temporarily abandoned as it represented a considerable quantity of work in rewriting modules of the simulator software. This work is, however, seen as the inevitable precursor to actually measuring demand in a real lift system. In the real lift system it is not possible to examine the effects of a wide range of traffic levels

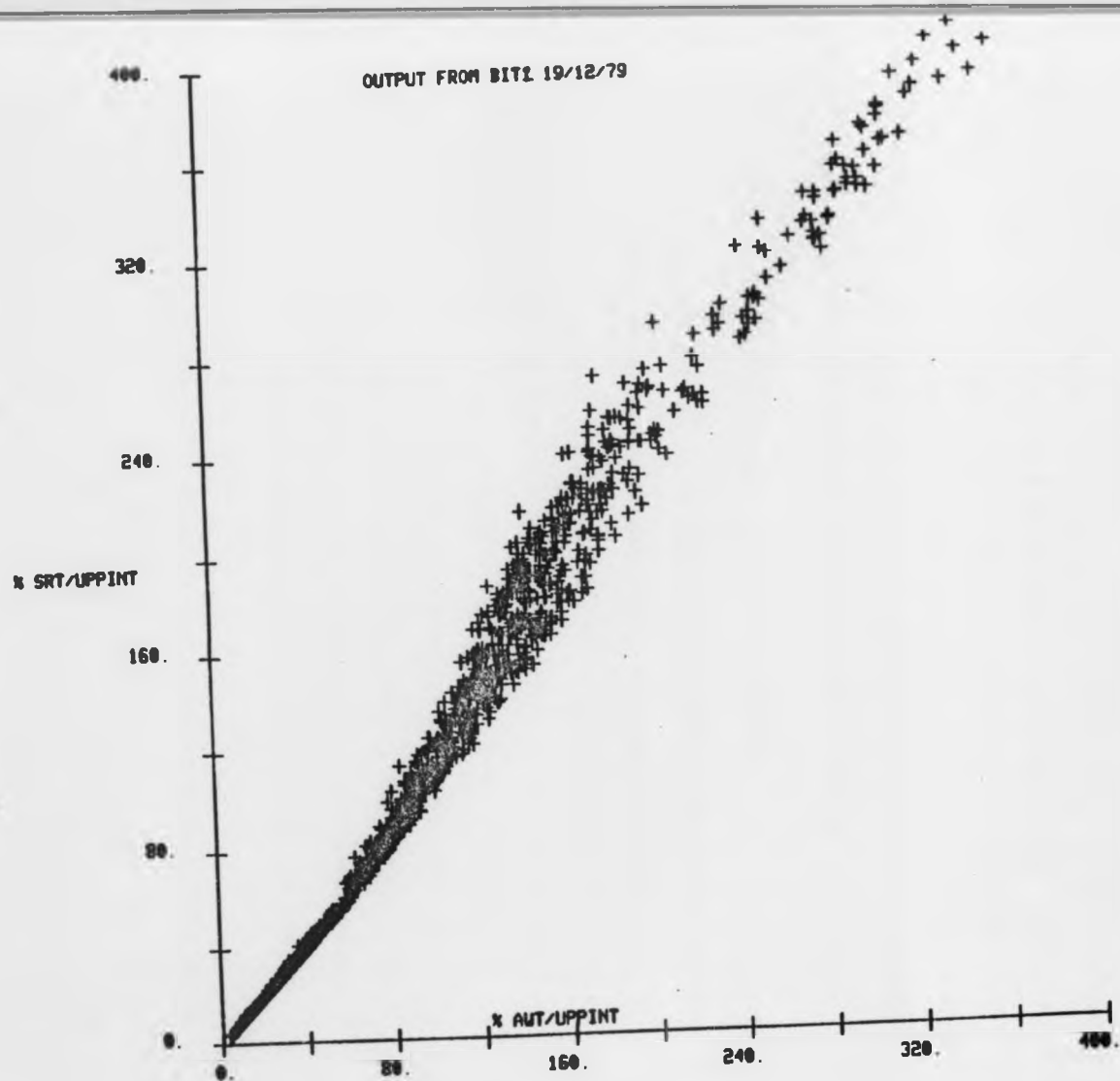


FIGURE 7.3 Percentage Average System Response Time vs. Percentage Average Waiting Time

on the demand indicator since, in general, traffic flow appears to be fairly stable during much of the day. Also the ease with which parameters may be changed make simulation a far more suitable test facility for the evaluation of demand.

Having established the viability of the demand and response parameters, it should be possible to move to an operational lift system. By using the hardware specified for the commercial lift management system in chapter 4, a performance evaluation of the lift system may then be obtained. Adjustments of the operating characteristics of the lift system (e.g. door timings, control policies etc.) should then produce measurable improvements or degradations in the performance index.

#### 7.1.2 Concluding Remarks on Lift Management

Acceptance of the commercial lift management system by building managers will depend considerably upon the simplicity with which it operates. Obviously, while being used for the purposes of research, the system will be required to provide immediate access to the fundamental management processes to allow the user a maximum of flexibility. However, in the commercial environment, the emphasis in system design must be placed on simplicity of operation. Thus considerable effort will need to be expended in discovering exactly what a building manager requires from the lift management system. This might not initially be clear, even to him! Additionally, trouble should be taken during design to make the use of the system as interesting as possible. This could be achieved in a number of ways including reducing tedious interactive question and answer sequences, creating colourful and aesthetically pleasing, yet simple graphical displays,

and minimising continuous heavy processing during which the machine appears to be unavailable to the user. This last objective might be partially effected by generating short messages, during heavy processing activities, which describe the progress of the processing to the user.

Since the initial impression of the usefulness of the lift management system will be crucial to its acceptance, it may be sensible to introduce levels of sophistication slowly to the building manager. In this way the need for a particular capability of the system would become apparent to the user by its absence. Also the gradual introduction of more sophisticated facilities would allow the system to be closely tailored to the requirements of the individual building manager and lift system.

## 7.2 Conclusions

Research into the operation of lift systems in large buildings has been hampered by the lack of facilities for acquiring and analysing data from active lift systems. In this thesis, requirements for data concerning lift activity and methods by which it might be obtained have been discussed. It was acknowledged that data could not be satisfactorily acquired by merely connecting recording equipment to a lift system for several days. There is a need for diagnostic fault analysis to purge the lift system of malfunctions before recording commences. Furthermore, to fully utilise the recorded data, there is a requirement to be able to perform on-line information analysis while data is still being generated. This allows those examining the recordings to make adjustments to the lift system and witness the results via fresh data. Also any unexpected occurrences may be identified, (from public transport

strikes to bomb scares), which might produce unusual features in the data. Realising the need for such research tools, it was observed that they would also bring significant advantages to lift owners and managers if developed into a commercially viable lift management system. Though management facilities for fault detection and performance optimisation are badly needed, these services are not provided by lift manufacturers in a form which can be adequately controlled by building owners and managers. Thus design specifications for tools, required for research purposes, were developed into a general purpose lift management system for commercial use. Facilities offered by this system are:-

1. In-service indication
2. Diagnostic status measurement
3. Data monitoring and performance analysis
4. Optimal control

Two building environments were considered. Firstly, the commercial building with high traffic density and demands for fast service from tenants using the lift system. Thus the requirements of this case are for optimal performance and quality of service. Secondly, the residential building environment was considered. In this case traffic is generally lighter and travellers are prepared to tolerate longer waiting times. Here, the management problem is more concerned with maintenance and continuity of service, the traffic not being dense enough to warrant performance optimisation. A number of residential buildings, distributed over a wide area, are often under the supervision of a single building manager. Thus additional communications problems also exist.

The proposed lift management system is modular and hierarchical



and each system may be built up of only those constituent functions which are required by a particular application. Thus building managers may specify a lift management system which fits their budgets in addition to the requirements of the building.

Microcomputer hardware is used extensively throughout the system because it offers inexpensive, compact yet sophisticated facilities with which to perform the complex management functions. Ease of reprogramming, offered by this technology, engenders great flexibility in the lift management system.

The completion of a commercial lift management system is dependent upon the successful conclusion of the research from which it was conceived. The research objective concerns traffic analysis and performance measurement in operational lift systems. These objectives have been discussed and it was shown that it is possible to deduce traffic flow information from records of lift system activity although only gross changes in these features may be detected. The three elementary traffic flows, up peak, down peak and balanced interfloor, were discussed and features of each were shown to exist in the data obtained from two office buildings. The effects of building configuration and usage were shown to relate to the activity in the lift system under balanced daytime traffic flow.

Performance analysis has been discussed, acknowledging that initial effort must be concentrated on defining a parameter which concisely defines performance. A systematic approach to the measurement of performance is proposed which defines a performance index. This relates input or demand to output or response and is thus the equivalent of a transfer function in conventional systems analysis. After discussion of

suitable parameters for the representation of demand and response, the busy period (the instantaneous business of the system in terms of the time involved to discharge current commitments) and average system response time divided by estimated up peak interval respectively, were chosen. The consistent use of the same control algorithm to calculate the busy period, and the divisor of up peak interval introduce normalisation into the performance index. This allows comparison of lift systems in different buildings with different control algorithms and operating under different traffic flows.

Throughout this thesis, references have been made to the use of a lift system simulator, which has been employed in a number of ways to illustrate and prove hypotheses. Thus in addition to providing a versatile and valuable design tool, the simulator has proved to be a very convenient testing ground for new ideas. A similar utility may be foreseen for the lift management system. This system not only provides much needed facilities to aid managers and owners in maintaining a high performance from their lifts, but also may be utilised as a source of real data and an analysis aid upon which future research may be conducted.

Appendix A

Functional Description Of The CCL Supervisory Control Algorithm

A minicomputer based lift control scheme is described by Barney and Dos Santos (1977, p. 135) which derives its principal features from a proprietary system, used by the American company U.S. Elevator Inc. The primary characteristic of this system (designated CCL by Barney and Dos Santos), is a fast collection of lift data and the use of the computational abilities of a minicomputer to process this data and make control decisions. Every tenth of a second, the system scans registered car and landing calls and the position, direction of travel and status of lift cars, including an estimation of the number of passengers in each car, based on weighing devices in each car floor. The time elapsed since call registration is updated for each landing call during the scan period. Newly registered calls are allocated to the lift cars according to certain arithmetic and logical rules. All allocations are re-evaluated every second.

To assign a landing call to a lift car, the allocation procedure estimates the car journey times for every car which is committed to move towards the call in the same direction as the call and also for any uncommitted cars. Any lift car which is not within these conditions is acknowledged to be "in service" and is not considered for allocation. Car journey time is defined as the time which a car will take to answer the landing call. The call is assigned to the car offering the shortest car journey time, after certain priority rules have been taken into consideration.

Any landing call that has been awaiting service for more than three times the current average waiting time (evaluated for the previous 20 seconds) is treated as a priority call, and a car is assigned to make a special run to deal with such a call. Also, any floor presenting an

activity level at least three times larger than the current average landing activity is declared as a high activity landing and is given priority for as long as the condition applies. This facility caters for sudden heavy local demands.

A number of up to four predefined floors can be declared as priority floors and given permanent service priority. Typical examples are the main terminal, restaurant and executive floors, where heavier than average traffic is expected or special "director's service" is required. The priority floors are also taken as parking floors for free cars, thus placing these cars at the landings where they are most likely to be required.

Lift cars are thus assigned to landing calls according to a priority structure. The system deals first with long wait priority calls, second with high activity floors, next with predefined priority floors and finally with the remaining landing calls. In all these cases the car journey times to the landing floor are evaluated and the call is assigned to the car providing the shortest journey time.

The procedure to evaluate car journey times for a normal landing call considers the car call stops and the landing calls to which the car is already assigned. The number of such calls between the car and the calling floor is evaluated and the car journey time is made up of several times, including flight times for the car to reach the calling landing, door operating times and car and landing call transfer times. The algorithm considers a transfer time of 3 seconds for each stop due to a landing call. For car calls, both the estimated number of passengers in the car and the number of relevant car calls is considered. The transfer

time is taken to be twice the larger of these two numbers, in seconds.

A car assigned to service a long wait priority call, a high activity floor or a priority floor is only allowed to stop in response to car calls before reaching the calling floor. Thus, a different procedure must be adopted to evaluate car journey times, by considering only car calls to determine stopping floors and transfer times. It may happen that a car which is assigned to service such priority calls discharges its last passengers at a floor where some traffic demand exists. In this case, an information signal will be illuminated in the lift to show its special service condition and dissuade passengers from entering the car. The landing call is obviously not cancelled.

A parking algorithm is provided to distribute free cars around the building and provide special service to the priority levels, by placing free cars there in anticipation of demand. Up to five parking floors may be chosen (including the priority levels), but the number should not exceed the total number of cars. The parking algorithm detects empty cars with no call demand (free cars) and parks them at the parking floors, with doors closed. If all parking floors are occupied by other parked cars, then free cars park at their current floors. Cars, when parked, are immediately available for demand at any floor.

Up peak traffic conditions are detected by the normal heavy demand feature when cars leave the main terminal floor with a load three times greater than the average floor activity. Whilst the up peak condition continues, a number of cars are despatched to the main terminal, the number of cars being dependent on the intensity of the peak demand. No special algorithm is provided for down peak traffic. Although the normal

operation algorithm can cope with down peak traffic, the system is liable to provide a poorer service to the lower floors in the building. Indeed, the allocation of cars based on computed car journey times gives no assurance that the lower landing calls will be given the same service as the upper calls, since calls are assigned individually and independently. Again, although some account is taken of the time landing calls have remained unanswered in the allocation procedure, this is only partially effective. The normal allocation does not consider call waiting times; it is only when a call has actually waited for too long that it is given priority. This is no more than a "forgotten man" feature, where passengers have to suffer a long wait before being considered for attention.

The system includes a number of extra features which are usually provided by good supervisory control systems, namely a car preference, key operated switch in each car and "anti-nuisance" devices that prevent an empty car from answering false car calls.

Appendix B

Batch Processing Of Multiple Simulations



When it is necessary to perform a large number of simulations using the LSD lift system simulator, (Dos Santos, 1974), it is desirable to conduct the processing during the night when computer time is least expensive. Additionally, a batch processing environment is to be preferred to relieve the user of the arduous task of staying awake all night to control the progress of interactive programs. Moussalatti (1974) describes techniques to achieve overnight, batch processing of many hours of simulated lift activity. Unfortunately, the structure of the simulation package has been subsequently changed (to incorporate link-overlay virtual memory techniques), and it is now no longer possible to utilise the CHAIN facilities, in the manner described by Moussalatti. However, the PDP-10 systems software includes facilities for the initiation and control of interactive programs in a batch processing environment.

Using the macro interpreted command (MIC) processor, (see DEC System 10 users manual), offers the advantage of a complete record of every user command and machine response for both interactive applications and systems software. Thus critical points in the processing, such as error messages indicating exceeded allocations in a simulation, can be isolated and corrective action taken after the batch processing has concluded. Additionally, the MIC processor allows the manipulation of simple parameters for the purposes of data input to interactive programs and the control of program execution. Thus, the simulator may be run hundreds of times from a MIC command file consisting of a single control loop of user responses, substituting input parameter values from several small lists. Such a command file is listed at the end of this appendix (see BIT1.MIC), which controls the simulation of 180 hours of lift activity. Thirty six different lift configurations are simulated, each at five

different traffic demand levels.

The batch control (BATCON) processor (see DEC System 10 users manual), is only activated during the hours of the night when computer time is cheapest. Programs are executed very quickly during this period because the number of users sharing the computer is low (often the user of the batch processor has the machine alone). To initiate execution of a job under BATCON, the SUBMIT command is used to place a request in the queue which will be processed when BATCON is activated during the night. The SUBMIT command specifies the job name, the command file name and the filename for logged output of the job's progress.

The method of executing and analysing the results of a large number of simulations is shown in flow diagram form in figure B.1. The processing is divided into two subjobs:

- i) Simulation
- ii) Analysis

with data being stored in the interim on magnetic tape. When the simulation subjob is complete, all files required for input and those created by the LSD simulator, for each hour of lift activity, are stored in 'savesets' on the magnetic tape. Saveset names consists of three letters and one digit defining a particular group of simulation studies (i.e. BIT1 defines the first group of simulations run under balanced interfloor traffic conditions) and up to 5 digits defining the particular combination of parameters chosen from the input list. Also, a disk file exists containing all the output generated by the simulation, which appears normally as a graph on the user terminal, for each simulation run. If an error message is generated during simulation (i.e. ALLOCATIONS

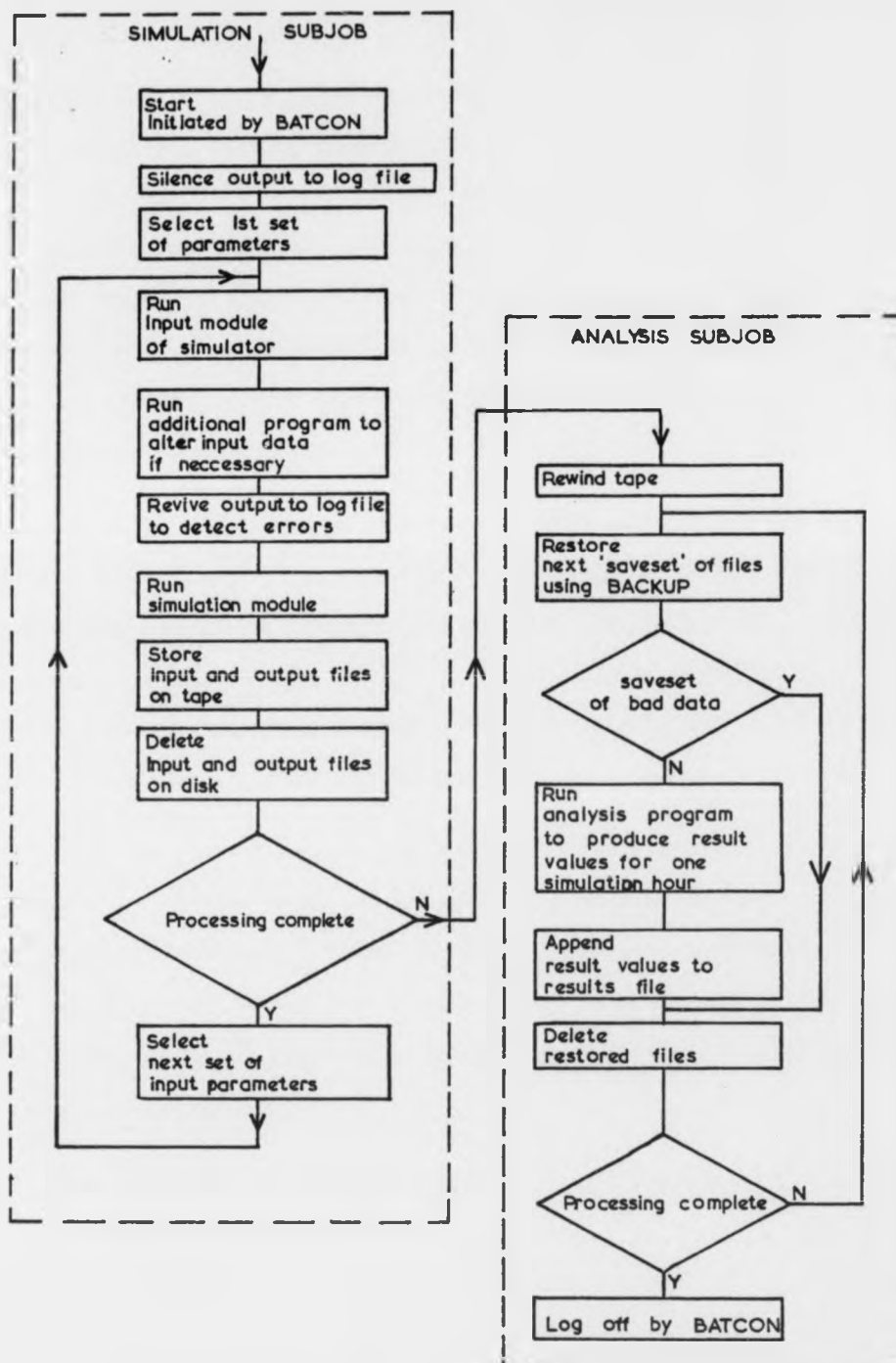


FIGURE B.1 Batch Control of Simulation and Analysis

EXCEEDED.....) it is appended to this text. Thus, using a text editor, it is possible to search through this disk file for the string "ALLOCATION ...". This can then be associated with the simulation run number (output at the start of each simulation run), which is set equal to the number of runs already executed plus one during the data input stage. The run in question can now be specified as "bad" and therefore to be excluded from the analysis subjob processing by the use of a conditional test in the analysis command file.

Analysis consists of restoring data from the magnetic tape, one saveset at a time. Data, relating to the number of stops, landing calls, system response times, average waiting times and number of passengers can be deduced for the worst 5 minute interval (up peak analysis) or for all twelve 5 minute intervals (balanced interfloor analysis) from these files. Up peak handling capacity and interval may also be calculated from the input data file.

When the analysis subjob is complete, a disk file exists which consists of a large number of identically formatted records. Each record represents the processed results of one hour of simulation. It is then simple to construct a program which selects specific parameters from each record and displays a scattergram on a graphics terminal as in figures 7.1 and 7.2.

The following listings are examples of command files for the simulation (BIT1.MIC) and analysis (ANAL.MIC) subjobs, the analysis program itself (ANAL.F4) and the scattergram generator program (SCTRGM.F4).

Listing of BIT1.MIC

(Command file to control multiple simulations)

```

.SILENCE
.ON ERROR:GOTO ERR1
.SET DEFAULT PROTECTION 111
.ASSIGN MTA0:
.R SETSRC
*M/LIB[40000,5]
*C DSKB,DSKC
*^C
.LET A=1,B=1,C=2,D=1,E=3,Z=3,Y=3,X=2,W=2,V=5,K=85,M="^M"
START::.LET A=A+1
        .IF(A<Z) .GOTO LABEL1
        .LET A=1,B=B+1
        .IF(B<Y) .GOTO LABEL1
        .LET B=1,C=C+1
        .IF(C<X) .GOTO LABEL1
        .LET C=1,D=D+1
        .IF(D<W) .GOTO LABEL1
        .LET D=1,E=E+1
        .IF(E>V) .GOTO END
LABEL1::.IF(A=1) .LET I="4",Q="7 3 5 5 5 4 5 5 1 0 0 0 0"
        .IF(A=2) .LET I="5",Q="9 4 4 4 4 3 3 3 4 4 1 0 0 0"
        .IF(A=3) .LET I="6",Q="11 5 3 3 3 3 3 2 3 3 3 3 1 0"
        .IF(B=1) .LET H="8"
        .IF(B=2) .LET H="16"
        .IF(B=3) .LET H="24"
        .IF(C=1) .LET G="2.5"
        .IF(C=2) .LET G="3.5"
        .IF(D=1) .LET F="3.0"
        .IF(D=2) .LET F="4.5"
        .IF(E=1) .LET P="10"
        .IF(E=2) .LET P="30"
        .IF(E=3) .LET P="50"
        .IF(E=4) .LET P="70"
        .IF(E=5) .LET P="100"
        .LET K=K+1
        .LET J=A+(B-1)*10+(C-1)*100+(D-1)*1000
        .RU LSD5
        *INP
        *'K
        *BIT1
        *N
        *A
        *15
        *50
        *'I
        *'H
        *1100
        *'F
        *'G
        *N
        *1.5
        *OK
        *FSO
        *4
        *1

```

```
*5
*5
*5
*Y
*S
*4
*0
*DEF
*STEP
*Y
*1 2 3 4 5 6 7 8 9 0 1 2
*Y
*Y
*50
*1.2
*'M
*Y
*8.0
*E
*E
.RU ARRATE
*'P
*'Q
./SIM
.BACKTO START
ERR1:: .REVIVE
;'K
;'J
END:: .MIC EXIT
%FIN:: .MIC ABORT
```

Listing of SIM.MIC

(Called by BIT1.MIC)



```
.LET J=J1
.LET K=K1
.REVIVE
;RUN NO 'J
.RU LSD5
*SIM
*STFIL
*F
*Q
*E
.SILENCE
.LET R="WT"+$J+".DAT"
.REN 'R=WT.DAT
.LET R="CA"+$J+".DAT"
.REN 'R=CAR.DAT
.LET R="F1"+$J+".DAT"
.REN 'R=FOR21.DAT
.LET R="F4"+$J+".DAT"
.REN 'R=FOR24.DAT
.LET R="DSKB:F0"+$J+".DAT"
.REN 'R=FOR01.DAT
.LET R="BIT3"+$J
.R BACKUP

*TAPE MTAO
*SSNAME 'R
*SAVE DSKB:*.DAT
*EXIT
.DEL DSKB:*.DAT
```

Listing of ANAL.MIC

(Command file to control analysis of simulation data)

```

.SILENCE
.ON ERROR: REVIVE
.R SETSRC
*C DSKB,DSKD,DSKC
*^C
.ASS MTAO:
.LET A=0,B=1,C=1,D=1,E=1,Z=3,Y=3,X=2,W=2,V=5,K=0
START:: .LET A=A+1
        .IF(A<=Z).GOTO LABEL1
        .LET A=1,B=B+1
        .IF(B<=Y).GOTO LABEL1
        .LET B=1,C=C+1
        .IF(C<=X).GOTO LABEL1
        .LET C=1,D=D+1
        .IF(D<=W).GOTO LABEL1
        .LET D=1,E=E+1
        .IF(E>V).GOTO END
LABEL1:: .LET J=A+(B-1)*10+(C-1)*100+(D-1)*1000,K=K+1
        .LET R="BIT3"+$J
        .DEL DSKB:FOR01.DAT,DSKB:FOR21.DAT,DSKB:FOR24.DAT,DSKB:CAR.DAT,DSKB:WT.D
T
        .R BACKUP
        *TA MTAO
        *RESTORE DSKB:=*.*
        *EXIT
        .REN FOR01.DAT=FO?????.DAT
        .REN FOR21.DAT=F1?????.DAT
        .REN FOR24.DAT=F4?????.DAT
        .REN CAR.DAT=CA?????.DAT
        .REN WT.DAT=WT?????.DAT
        .RU ANAL2
        .BACKTO START
END::   ;'J
        ;'K
        .MIC EXIT
%FIN:: .MIC ABORT

```

Listing of ANAL2.F4  
(Fortran program to analyse simulation data)

```

PROGRAM ANAL2
C   Program to analyse data on system response time and average
C   waiting time from file "WT.DAT" produced by LSD simulator.
C   Only data from the worst 5 minute period is used and averages over this
C   period are found for SRT and AWT.
C   Output is appended to a binary file "AWTSRT.DAT" of 2 dimensional-
C   records, representing x and y coordinates on a scattergram of
C   average SRT vs average AWT.

COMMON /INDAT/NF,DISIFL,TSP,TJUMP,DOT,DCT,NCA,PTT
REAL PWT(10),PTIME(10)
INTEGER AWT(25),AJT(25),AWTSUM(12),IPDIR(10),NCINSM(12),AWTMAX
DIMENSION IPFL(10),IPWT(10),IPTIME(10),NRATE(12,25)
C ,MWT(25),MJT(25),NCIN(25),NCOU(25),NSDWT(25)
C ,NSDJT(25),DNAME(4),NFZ(12),PRINT(12),TJUMP(8)
C ,INBIAS(25,12),BIAS(25),ARATE(12,25),NPOP(25)

C   Read in data concerning lift system, building, etc.
C   Same as in module INPOO of LSD.
CALL IFILE(1,'FOR01')
READ(1)NRUN,DNAME,ZONE,NEF,NF,EXPTIM,NCA,ICOCCA,DSIZ
C ,TSP,(TJUMP(I),I=1,8),SLOPE,DCT,DOT,SS,ARPAT,ARPRO
C ,((NRATE(J,I),I=1,NF),J=1,12)
READ(1)IPOP,PTT,DEC1,LFAC,LINT,UPDINT,MTERM,MT2,MT1BI
READ(1)NZ,NUPZ,(NFZ(I),I=1,12),(PRINT(I),I=1,12),MZ
READ(1)CRFUN,MAXWT,MINWT
IF(DEC1.NE.'PRD')GO TO 1631
DO 1632 J=1,12
1632 READ(1)(INBIAS(I,J),I=1,NF)
GO TO 1633
1631 READ(1)(BIAS(I),I=1,NF)
1633 READ(1)NLF,DIST,EDIST,ADT,PRINT,A,DISIFL,
C ((ARATE(J,I),I=1,NF),J=1,12),(NPOP(I),I=1,NF),PRO
CALL RELEAS(1)

C   Procedure to locate worst 5 minutes
CALL IFILE(24,'FOR24')
DO 140 II=1,12
READ(24)(AWT(I),I=1,NF),(AJT(I),I=1,NF),(MWT(I),I=1,NF)
C ,(MJT(I),I=1,NF)
READ(24)(NCIN(I),I=1,NF),(NCOU(I),I=1,NF),(NSDWT(I),I=1,NF)
C ,(NSDJT(I),I=1,NF)
DO 150 I=1,NF
NCINSM(II)=NCINSM(II)+NCIN(I)
150 AWTSUM(II)=AWTSUM(II)+AWT(I)
140 CONTINUE
DO 170 II=1,12
C   Convert accumulated waiting time into average WT.
AWTSUM(II)=AWTSUM(II)/NCINSM(II)
IF(AWTSUM(II).GT.AWTMAX)GO TO 180
GO TO 170
180 AWTMAX=AWTSUM(II)
IWORST=II
170 CONTINUE

```

```

CALL RELEAS(24)
DO 600 IWORST=4,11
OPEN(UNIT=21,DEVICE='DSK',FILE='AWTSRT.DAT',MODE='BINARY'
C ,ACCESS='APPEND')
CALL IFILE(23,'WT')

C      Next line calculates start time (in seconds) of worst 5 minutes
C      and includes first 5 minutes simulator initialisation -(really !!).
      STMST=(IWORST)*300.0
C      Calculate up peak interval for worst 5 minutes
      UPPINT=20.0
      IF(NCINSM(IWORST).EQ.0)GO TO 601
      CALL CAL80(ICOCCA,H,S,P,UPPINT)

C      Follow cars through building stop by stop, counting passengers.
      INSUM=0
      SMAWT=0
      SMSRT=0
      ICOUNT=0
      STPSUM=0
      REVCNT=0
      K=0
100  READ(23,END=900)(IPFL(I),I=1,10),(IPWT(I),I=1,10)
      C      , (IPTIME(I),I=1,10)
C      Correct -ve values which occur in IPTIME which indicate downward
C      direction of call.
      DO 110 I=1,10
      IPDIR(I)=1
      IF(IPTIME(I).LT.0)IPDIR(I)=2
      IF(IPTIME(I).LT.0)IPTIME(I)=IPTIME(I)*(-1)
      PWT(I)=IPWT(I)*UPPINT
110  PTIME(I)=IPTIME(I)*UPPINT
5000  FORMAT(' IPFL =',10(I4,','),/, ' IPWT =',10(I4,','),/
C      , ' IPTIME=',10(I4,','),/)
      IF(K.NE.0)GO TO 120
      PLSTM=PTIME(1)
      IPLSFL=IPFL(1)
      IPLSDR=IPDIR(1)
      K=1
120  DO 160 I=1,10
      IF((PLSTM.NE.PTIME(I).AND.PWT(I).NE.0).OR.IPLSFL.NE.IPFL(I))
C      GO TO 300
130  SUMWT=SUMWT+PWT(I)
      IPCNT=IPCNT+1
      IF(ZMAXWT.LT.PWT(I))ZMAXWT=PWT(I)
      IPLSFL=IPFL(I)
      PLSTM=PTIME(I)
      IPLSDR=IPDIR(I)
160  CONTINUE
      GO TO 100

```

```

C      Procedure to process info relating to each car stop which
C      picked up passengers.
300    AVAWT=SUMWT/IPCNT
C      PCNT=FLOAT(IPCNT)
C      WRITE(21)AVAWT,PCNT
      IF(PTIME(I).GE.STMST.AND.PTIME(I).LT.STMST+
C 300)GO TO 400
      IF(PTIME(I).GE.STMST+300)GO TO 500
310    SUMWT=0
      IPCNT=0
      ZMAXWT=0
      GO TO 130

C      Procedure to calculate accumulated values for AWT & SRT
C      only during worst 5 minutes.
400    SMAWT=SMAWT+AVAWT
      SMSRT=SMSRT+ZMAXWT
      ICOUNT=ICOUNT+1
C      PCNT=FLOAT(IPCNT)
C      WRITE(21)AVAWT,PCNT
      INSUM=INSUM+IPCNT
      GO TO 310

C      Procedure to calculate averages for AWT & SRT.
C      Called immeddeately after worst 5 minutes.
500    SMAWT=SMAWT/ICOUNT
      SMSRT=SMSRT/ICOUNT
      CALL IFILE(22,'CAR')
      CALL STOPS(IWORST,STPSUM,REVCNT)
      CALL RELEAS(22)
      XLOAD=P/ICOCCA
      WRITE(21)NRUN,ICOUNT,SMAWT,SMSRT,INSUM
C      ,STPSUM,REVCNT,UPPINT,H,S,P,NCA,ICOCCA
601    CALL RELEAS(21)
      CALL RELEAS(23)
600    CONTINUE
      CALL OFILE(21,'NRUN')
      WRITE(21,2100)NRUN
2100   FORMAT(' Run',I4,' completed')
      CALL RELEAS(21)
800    STOP
900    OPEN(UNIT=21,DEVICE='DSK',FILE='ERRMSG.DAT',MODE='ASCII'
C      ,ACCESS='APPEND')
      WRITE(21,2101)NRUN
2101   FORMAT(' Bad data for run',I4)
      CALL RELEAS(21)
      GO TO 800
      END

```

```

C      SUBROUTINE CAL80(ICOCCA,H,S,P,UPPINT)
C      Subroutine to calculate H,S,P & up peak interval
C      assuming average car loading of 80% at main terminal.
      DIMENSION TJUMP(8)
      COMMON /INDAT/NF,DISFLR,TSP,TJUMP,DOT,DCT,NCA,PTT
      N=NF-1
      XN=FLOAT(N)
      P=0.8*ICOCCA
      S=XN*(1-(1-1/XN)**P)
      H=0
      DO 100 I=1,N-1
100    H=((1/XN)**P)+H
      H=XN-H
      RTT=(2*H*DISFLR/TSP)+(S+1)*(TJUMP(1)-
C      (DISFLR/TSP)+DOT+DCT)+2*PTT*P
      UPPINT=RTT/NCA
      RETURN
      END

```



```

SUBROUTINE STOPS(1WORST,STPSUM,REVCNT)
C Subroutine to produce potentially useful information on number
C of stops made by lift cars during the worst 5 minutes of a one
C hour simulation. Information is
C   1 ) STOPS per 5 minutes (for whole building)
C   ii) STOPS per car-reversal (averaged over 5 minutes)
COMMON /1NDAT/NF,DISFLR,TSP,TJUMP(8),DOT,DCT,NCA,PTT
DIMENSION CPOS(30,8),CTIME(30,8),NSTOPS(30)
INTEGER LSTPOS
DO 100 I1=1,IWORST
100 READ(22)(NSTOPS(IC),IC=1,NCA),
C ((CPOS(1,IC),I=1,NSTOPS(1C)),IC=1,NCA),
C ((CTIME(1,1C),I=1,NSTOPS(1C)),IC=1,NCA)
DO 200 IC=1,NCA
STPSUM=STPSUM+NSTOPS(1C)
LSTPOS=CPOS(1,IC)
DO 200 I=1,NSTOPS(1C)
IF(CPOS(I,IC).GT.LSTPOS.AND.DIR.NE.'U')
C CALL REVERS(REVCNT,ISTOPS,DIR)
IF(CPOS(I,IC).LT.LSTPOS.AND.DIR.NE.'D')
C CALL REVERS(REVCNT,ISTOPS,DIR)
LSTPOS=CPOS(I,IC)
200 CONTINUE
RETURN
END

```

```

SUBROUTINE REVERS(REVCNT,ISTOPS,DIR)
C To deal with a reverse in lift-car direction
OLDDIR=DIR
IF(OLDDIR.EQ.'U')DIR='D'
IF(OLDDIR.EQ.'D')DIR='U'
IF(OLDDIR.EQ.C)GO TO 100
REVCNT=REVCNT+1
200 RETURN
100 DIR='U'
GO TO 200
END

```

Listing of SCTRGM.F4

(Fortran program to display analysed data as a scattergram)

```

PROGRAM SCTRGM
DIMENSION ARRAY(200,2)
XSCALE=100.0
YSCALE=5.0
CALL DSTART(1)
CALL ERASE
CALL SCALE(XSCALE*0.55,YSCALE*0.55)
CALL OSHIFT(XSCALE*0.5,YSCALE*0.5)
CALL AXIS(0.0,XSCALE,0.0,YSCALE,XSCALE*0.1,YSCALE*0.1
C ,0.0,0.0,2,4.0,2,4.0)
CALL PLOT(XSCALE/2,YSCALE*0.03,1)
CALL DF4IO
WRITE(5,500)
500 FORMAT(/,45X,' % INPUT DEMAND ')
CALL PLOT(-XSCALE*0.1,YSCALE/2,1)
CALL DF4IO
WRITE(5,600)
600 FORMAT(' STOPS/CAR/MIN')
610 FORMAT(' SRT ')
CALL PLOT(XSCALE*0.5,YSCALE,1)
CALL DF4IO
WRITE(5,520)
520 FORMAT(35X,' OUTPUT FROM BIT1 21/12/79')
CALL IFILE(21,'AWTSRT')
100 READ(21,END=900)NRUN,ICOUNT,SMAWT,SMSRT,INSUM
C ,STPSUM,IRVCNT,UPPINT,H,S,P,NCA,ICOCCA
REVCNT=FLOAT(IRVCNT)
IF(SMAWT.EQ.0.OR.SMSRT.EQ.0.OR.UPPINT.EQ.0
C .OR.INSUM.EQ.0)GO TO 100
IOLDR=NRUN
SMAWT=100*SMAWT/UPPINT
SMSRT=100*SMSRT/UPPINT
CALLS=FLOAT(ICOUNT)
STOPS=STPSUM/(5*NCA)
DEMAND=UPPINT*INSUM/(2.4*P)
IF(NRUN.LE.36)E=10
IF(NRUN.GT.36)E=30
IF(NRUN.GT.72)E=50
IF(NRUN.GT.108)E=70
IF(NRUN.GT.144)E=100
X=E
Y=STOPS
IX=IFIX(X)
IY=IFIX(Y)
IF(IX.LT.1.OR.IX.GE.XSCALE)GO TO 110
ARRAY(IX,1)=ARRAY(IX,1)+Y
ARRAY(IX,2)=ARRAY(IX,2)+1
110 CALL SYMBOL(X,Y,1)
GO TO 100
900 CALL PLOT(0.0,0.0,1)
DO 200 I=1,IFIX(YSCALE)
IF(ARRAY(I,1).EQ.0.OR.ARRAY(I,2).EQ.0)GO TO 200
Y=ARRAY(I,1)/ARRAY(I,2)
X=FLOAT(I)
CALL PLOT(X,Y,2)
200 CONTINUE
300 CONTINUE
5050 FORMAT(1H+,F4.0)
CALL DEND
CALL DELAY(0)
CALL HCOPY(N)
END

```

Appendix C

The LAN Logged Data Analysis Package

In its most recent form, the scheme for logging and analysing data from operational lift systems utilises floppy disks as a recording medium. Disks carrying the recorded data are brought from the remote lift system to UMIST, where the Lift data ANalysis (LAN) package of programs can be run, utilising the facilities of the DEC PDP-10 timesharing computer in the Control Systems Centre. Since the PDP-10 has no floppy disk handling peripherals, an intermediate process was developed to transfer data to DECTape magnetic tapes involving the use of the DEC PDP-11 minicomputer also located in the Control Systems Centre. The program which runs on the minicomputer extracts data from the floppy disk and removes any extraneous information or null data blocks before recording it on the DECTape. In this form the data is directly compatible with the LAN package of programs.

The LAN package resides on the library area of the computer disk space [40000,11] and is thus available to any user of the system. It includes facilities for:-

- i) Validating 'raw' data (isolating strings of corrupted data)
- ii) Maintaining an index of data (cataloguing a library of DECTapes)
- iii) Inputting data from a DECTape library
- iv) Analysis of recorded data (producing graphical and tabulated output)

Figure C.1 shows the facilities provided by the package and the series of operations that must be performed to utilise them. Help messages are included at most points in the programs where interaction with the user is required and user input is checked for obvious errors. Thus use of the package is reasonably simple and an operator soon becomes familiar with the various modes of operation.

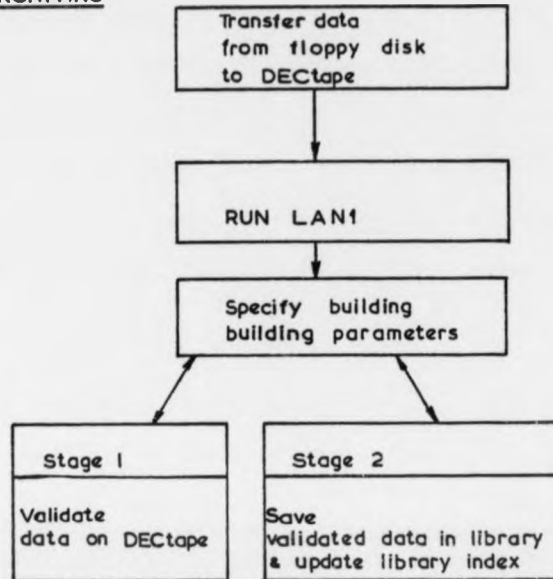
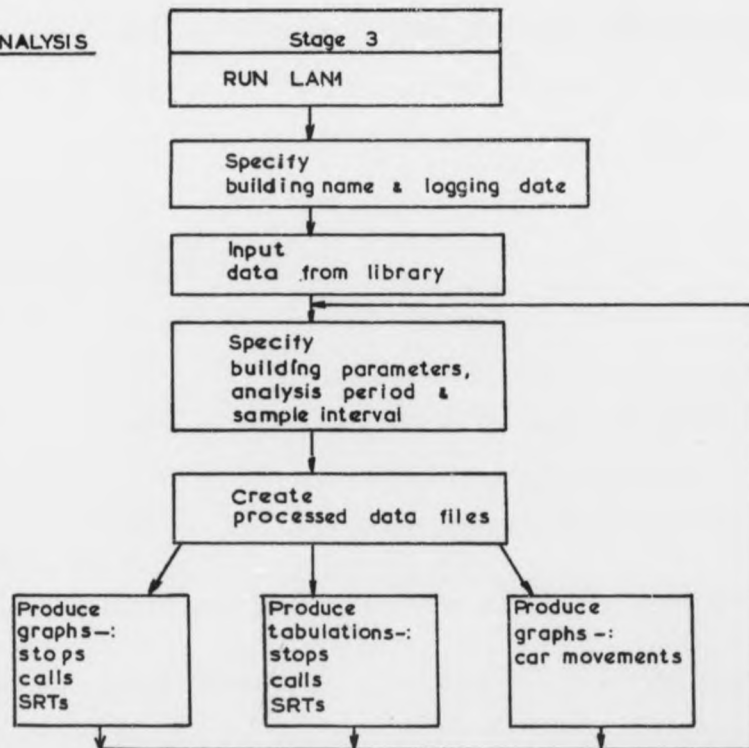
ARCHIVINGANALYSIS

FIGURE C.1 Facilities of the LAN1 Package

Data on a DECTape from the PDP-11 minicomputer is transferred to the user's disk area by the validation module and is checked for erroneous characters and parameter values which exceed those specified for the building or lift system. When validation is complete the user then updates the directory of logged data files. The directory contains the following information which describes each file:-

Building Name	(20 characters - blank filled)
Date of logging	(DDMMYY format - 6 digits)
Number assigned to dectape in library	(2 digits)
Start time of logging	(HHMM format - 4 digits)
Day number of end of logging	(logging starts day 1 - 2 digits)
End time of logging	(HHMM format - 4 digits)

This information is stored in the file INDEX.DAT. Validated data is placed on a new DECTape, to become part of the library, during this process and the data filename reflects the date on which logging occurred in the following way:-

filename = yyndd.DAT

where: yy are two letters representing the year

e.g. HG = (19)76

m is a single letter representing the month

e.g. B = February

dd are two digits representing the day of the month

Thus HJC22.DAT was recorded on the 22nd of March 1979.

The input facility allows data to be retrieved from the library. Information is requested from the user as to the date and building name to which the logged data relates and the user is then told which

DECTape to select from the library.

The analysis module processes the logged data strings and produces four files containing information on the number of stops made by lift cars, calls made by passengers at landings and values of system response and door opened times. Data is processed for a sampling period specified by the user, and then dumped into the files for the duration of a time span also specified by the user. The output data files contain information for each sampling period on:-

- i) STOPS -  $\left\{ \begin{array}{l} \text{up direction} \\ \text{down direction} \\ \text{both directions} \\ \text{parking only} \end{array} \right\} \text{ for } \left\{ \begin{array}{l} \text{each floor} \\ \text{whole building} \\ \text{building minus main terminal} \end{array} \right\}$
- ii) CALLS -  $\left\{ \begin{array}{l} \text{up direction} \\ \text{down direction} \\ \text{both directions} \end{array} \right\} \text{ for } \left\{ \begin{array}{l} \text{each floor} \\ \text{whole building} \\ \text{building minus main terminal} \end{array} \right\}$
- iii) SRT -  $\left\{ \begin{array}{l} \text{up dir.} \\ \text{down dir.} \\ \text{both dirs.} \end{array} \right\} \text{ for } \left\{ \begin{array}{l} \text{each floor} \\ \text{whole building} \\ \text{bldg. minus M.T.} \end{array} \right\} \text{ as } \left\{ \begin{array}{l} \text{sum} \\ \text{mean} \\ \text{max} \end{array} \right\} \text{ of values}$
- iv) Door -  $\left\{ \begin{array}{l} \text{up dir.} \\ \text{down dir.} \\ \text{both dirs.} \end{array} \right\} \text{ for } \left\{ \begin{array}{l} \text{each floor} \\ \text{whole building} \\ \text{bldg. minus M.T.} \end{array} \right\} \text{ as } \left\{ \begin{array}{l} \text{sum} \\ \text{mean} \\ \text{max} \end{array} \right\} \text{ of values}$   
open  
time

Once the four processed data files have been created, the user has a choice of data display modes. Graphs of stops, calls, system response or door opened times may be generated, car journeys may be plotted or a tabulation may be printed giving stops, calls and system response times at each floor for every sampling period.



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