LIFT PASSENGER TRAFFIC PATTERNS: APPLICATIONS, CURRENT KNOWLEDGE, AND MEASUREMENT

Richard D Peters[†‡], Pratap Mehta[†], John Haddon[‡]
[†]Brunel University, Uxbridge, Middlesex, UB8 3PH, UK
[‡]Ove Arup & Partners, 13 Fitzroy Street, London W1P 6BQ, UK

ABSTRACT

In order to calculate the performance of a new or refurbished lift installation we need to estimate likely passenger traffic patterns. These traffic patterns are also recognised by the lifts' traffic control system which adjusts the dispatcher algorithm accordingly. In this paper the authors summarise current, published knowledge of lift passenger traffic patterns and review these against actual survey results. Having identified a need to improve our knowledge of passenger traffic patterns, various means of collecting this data are discussed including: manual surveys, computer vision techniques, infra-red counters, and analysis based on data logged by lift traffic control systems or traffic analysers.

1 INTRODUCTION

Assessment of performance is a crucial element in lift (elevator) design. If lifts are too small, slow, or insufficient in number, passengers have to wait for excessive periods for a lift to arrive in response to landing calls. Furthermore, passengers travelling more than a few floors in under-lifted installations often endure long journey times - the result of the lifts having to stop to answer other calls at most of the intermediate floors. On the other hand, the luxury of an over-lifted building is an expensive one - floor area that could be let to tenants is lost to additional or larger lift lobbies and shafts; capital, maintenance and energy costs of the installation are higher.

The need to specify appropriate numbers of lifts, their capacity and speed, etc. has led to the study of lift traffic analysis. Lift traffic analysis allows us to assess the performance of a proposed lift installation based on estimates of building passenger traffic patterns. Lift traffic analysis techniques ranging from up peak calculations(1)(2) to general analytical formulae(3) and simulation techniques(4) are well developed and widely applied. But lift performance results from lift traffic analysis are of no better quality than the estimated passenger traffic patterns that are used in the calculations or simulations.

In operation, lift control systems adapt to changing demands based on their designers' understanding of passenger traffic patterns. Control strategies appropriate to the current traffic pattern (e.g. up peak, down peak algorithms) can improve performance significantly.

In this paper the authors summarise current, published knowledge of lift passenger traffic patterns and compares this with survey results. Current design guidelines are questioned, and means of improving our knowledge of lift passenger traffic patterns are discussed.

2 CURRENT KNOWLEDGE OF TRAFFIC PATTERNS

2.1 General Approach

In estimating prospective passenger traffic patterns, a designer might consult:

- Elevator Traffic Analysis Design and Control[1]
- Vertical Transportation, Elevators and Escalators[2]
- CIBSE Guide D, Transportation Systems in Buildings[5]
- Standards, e.g. in the UK, BS 5655 Part 6[6]

There are other sources of information, including manufacturers' planning guides, but these tend to re-iterate the recommendations of above. Barney, dos Santos[1] and Strakosch[2] present example diagrams of passenger traffic in a commercial, office building. These diagrams have been re-drawn in Figures 1 and 2.

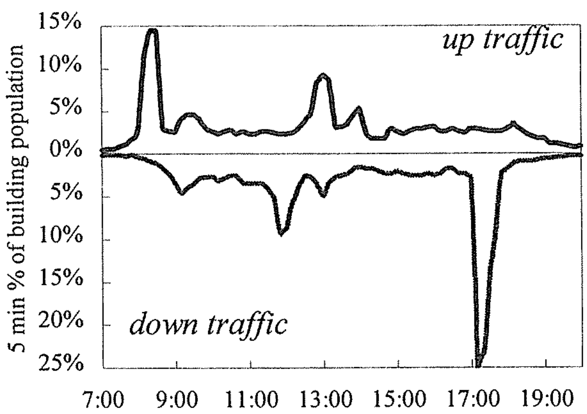

Figure 1 Typical Office Traffic, Barney[1]

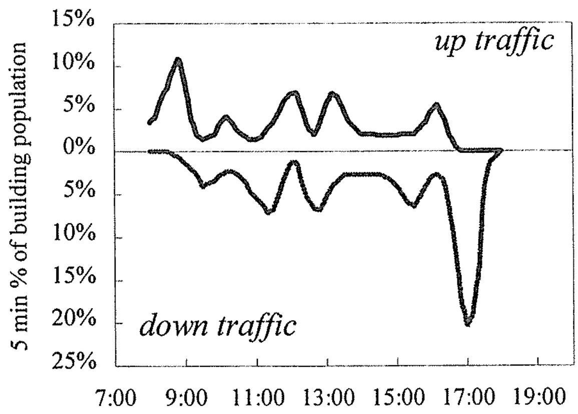

Figure 2 Typical Office Traffic, Strakosch[2]

According to Barney and dos Santos[1], conventional design procedure is to determine the performance of lift systems for the morning up peak traffic situation. This is consistent with the authors' experience from reviewing consultants' and manufacturers' calculations. The common approach is probably because:

- the up peak traffic condition is relatively simple to analyse
- it is widely accepted that, if a lift system can cope efficiently with the morning up peak, then it will cope with other periods in the day
- most traffic flow design recommendations are for up peak handling capacity

CIBSE Guide D[5] suggests the following up peak traffic flows for design purposes:

Building Type	*Arrival rate (%)*	*Building Type*	*Arrival rate (%)*
Hotel	10-15	Flats	5-7
Hospital	8-10	School	15-25
Office (multiple tenancy)	11-15 regular, 17 prestige	Office (single tenancy)	15 regular, 17-25 prestige

Table 1 CIBSE Guide D Guidance On Peak Arrival Rates

Strakosch[2] places most emphasis on the incoming up peak traffic, but also proposes two-way and outgoing traffic criteria. BS 5655 Part 6[6] offers only up peak design criteria.

2.2 Published Lift Traffic Surveys

Detailed lift traffic surveys carried out by researchers, consultants and manufacturers are rarely published. One exception is *A survey of passenger traffic in two office buildings*[7] published by BRE in 1974. Results are summarised in Table 2.

Building	*Traffic period*	*Peak 5 min % building population using lifts*
Southbridge House	morning up peak evening down peak	12.2% 8%
Sanctuary Buildings	morning up peak evening down peak	7.8 6.7%

Table 2 Summary Of BRE Traffic Survey Results

The BRE survey also concluded that lunch time traffic amounts to 12% of building population in both buildings, but this includes stair traffic.

3 TRAFFIC SURVEYS

Passenger traffic surveys have been carried out on behalf of the authors at a range of buildings. Results are summarised in Figures 3 to 7 which record the traffic to and from the main terminal floor(s), except for Building E where the predominant traffic flow was inter-floor. Traffic was measured only during peak periods (normally morning, lunch and evening; morning and evening for the hotel).

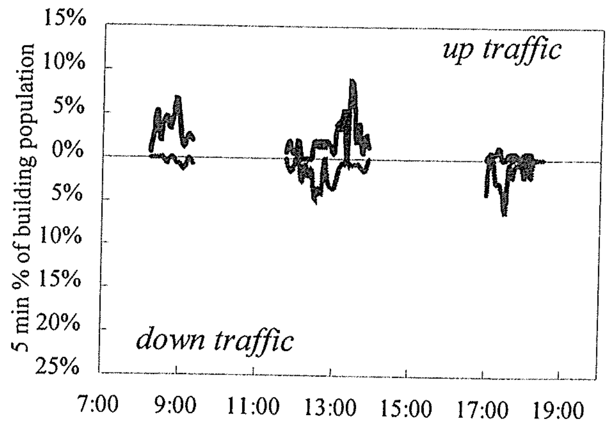

Figure 3 Building A Traffic Survey Results For Single Tenancy Office, Engineering

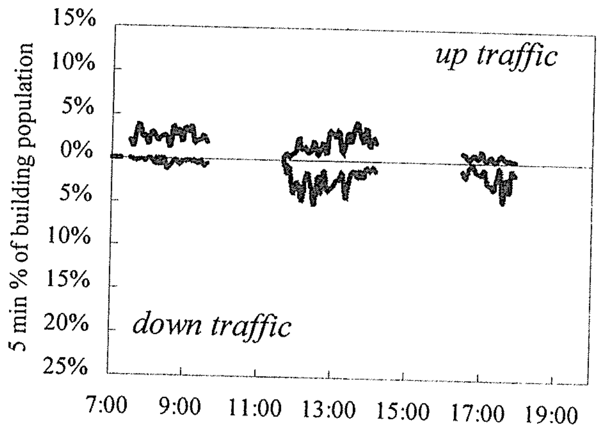

Figure 4 Building B Traffic Survey Results For Single Tenancy Office, Banking/Dealers (results based on nominal population of 1 person/10m^2 as actual occupancy not available)

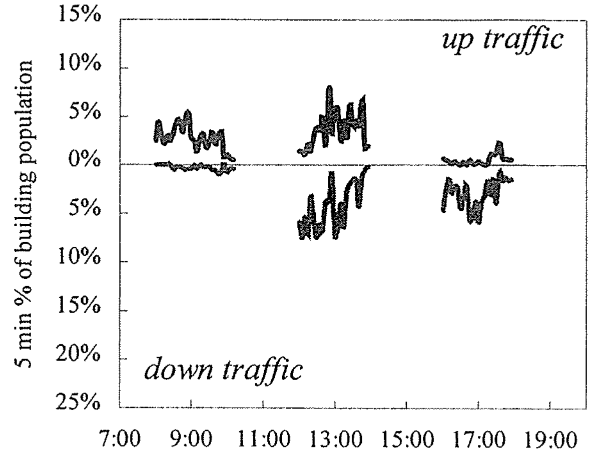

Figure 5 Building C Traffic Survey Results For Single Tenancy Office, General

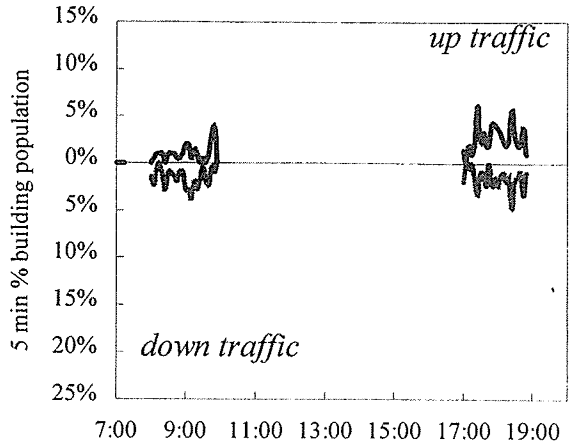

Figure 6 Building D Traffic Survey Results For Prestigious Traditional Hotel

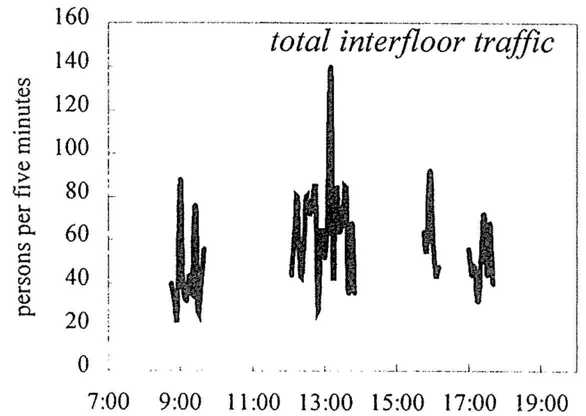

Figure 7 Building E Traffic Survey Results For Major High Rise Hospital
(results not shown as % as only one of two passenger lift banks available for survey)

4 DISCUSSION

The traffic survey results suggest that the morning traffic peaks are less marked in buildings than they were when traditional up peak design criteria were formulated. In work-related buildings occupied during the day, the busiest period appears to be over the lunch period. Lunch traffic is a combination of up and down peak traffic to the main terminals, but often includes an element of inter-floor traffic. This inter-floor traffic is especially significant in buildings with restaurants, meeting rooms, etc. It can be shown that, if the same total handling capacity is assumed, people wait longer for a lift at lunch time than they do during a morning up peak. This is because the combination of passengers travelling up and down the building results in more stops per round trip. Consequently, the authors suggest that future design criteria for traffic analysis should use the lunch peak as a primary design criterion. It would be dangerous to disregard established up peak design criteria without a wider study of building traffic flow peaks. Thus the remainder of this paper discusses means of representing and collecting traffic data so that, in due course, updated design criteria can be formulated for a wide range of buildings.

5 REPRESENTING LIFT TRAFFIC FLOWS

Traditionally lift traffic flows have been defined in terms of the percentage of the building population transported upwards and downwards in five minutes, as used in Figures 1-6. For more complex flows such as lunch peaks we need a more comprehensive way of describing lift traffic. Peters presented an approach in his paper on *General Analysis Lift Calculations*[3] that allows us to describe traffic flow completely. Two terms are required:

μ_i the passenger arrival rate at floor i (defined for each floor at which passengers may arrive

d_{ij} the probability of the destination floor of passengers from floor i being the jth floor (defined for all possible i and j)

Using these terms, a simple up peak traffic flow in an office block could be represented as in Figure 8. And a more complex traffic flow could be represented as in Figure 9.

4th floor	▲ 25%
3rd floor	▲ 25%
2nd floor	▲ 25%
1st floor	▲ 25%
Ground	■ 20 p/5m

Figure 8

4th Floor	▲ 20%	▲ 20%	▲ 20%	▲ 0%	■ 40 p/5m
3rd Floor	▲ 20%	▲ 20%	▲ 20%	■ 40 p/5m	▼ 0%
2nd Floor	▲ 30%	▲ 30%	■ 30 p/5m	▼ 33%	▼ 33%
1st Floor	▲ 30%	■ 60 p/5m	▼ 30%	▼ 33%	▼ 33
Ground	■ 20 p/5m	▼ 30%	▼ 30%	▼ 33%	▼ 33%

Figure 9

Key
■ Arrival rate in persons per five minutes
↓ Destination probability as %

Future design criteria should enable the designer to estimate peak traffic flows in these terms from a knowledge of the office building population, number of hotel rooms, etc. dependant on the building type. The lift performance can then be assessed analytically, or by simulation.

6 CARRYING OUT LIFT SURVEYS

6.1 Alternative Survey Techniques

The are a number of alternative approaches to collecting data on lift passenger traffic patterns. Those considered by the authors are discussed in the following subsections. Other and new technologies may yield alternative approaches.

6.2 Manual Surveys Using Observers

In manual surveys observers count passengers in and out of the lifts. Manual surveys are normally based on one of two approaches:

i. survey from the main terminal(s), where observers count passengers in and out of the lifts as they arrive/depart from the main terminal floor(s). Traffic between other floors is assumed to be negligible. Survey results given in Figures 3 to 6 where collected using this approach.

ii. the in-car survey, where observers are situated in the lift car, and count the passengers in and out at every floor the lift stops at. Survey results given in Figure 7 were collected using this approach.

Manual surveys are discussed in detail in [1] and [8]. The new generation of cheap, miniature video cameras (used with a video recorder) can be used to make observation unobtrusive; the recorded video is played back off site for counting.

The survey techniques do not allow us to describe traffic flow completely as:

i. only measures arrival rate at the main terminal floor(s) and requires assumptions to be made about arrival rates and destinations probabilities on other floors. These assumptions are generally based on the building floor populations.

ii. measures arrival rates at all floors, so provides superior data to (i). Overall destinations probabilities (averaged over all arrival floors) can be approximated from the count of passengers as they leave the lift. Collecting data to enable traffic to be described completely is impractical for the human observer unless traffic is light - to achieve a full data set of destination probabilities, the observer would have to track every passenger, e.g. passenger 53 entered the lift at floor 3 and alighted at floor 6; passenger 54 entered the lift at floor 4 and alighted at floor 10, etc.

6.3 Control System And Traffic Analyser Surveys

6.3.1 Conventional Systems

Traffic analysers are linked to the lift control system, and record the time every landing and car call is made and cleared. They analyse this data and provide a range of performance results and graphs. Modern control systems incorporate similar functionality.

A range of traffic and performance measures can be determined, for example:

- average response time to landing calls by time of day
- distribution of response times
- distribution of car calls by floor

Traffic analysers give a good indication of a lift system's performance, but very limited information about the actual passenger traffic flow. This is because they have no means of determining the number of people transported on each trip, e.g. a landing call at floor five and corresponding car call to floor seven could equally be a single person, or a group of people travelling together. The use of accurate weighing devices would provide a guide to passenger load. But ambiguities occur if people are loading and unloading at the same floor, e.g. five people loading and three people unloading would provide the same weight differential as two people loading.

Therefore, on its own, traffic analyser data does not give us the information we require.

6.3.2 Inverse S-P Method

Al-Sharif suggested a means of interpreting data that is available to traffic analysers. The Inverse S-P method[9] applies conventional up peak traffic analysis formulae "backwards" to estimate the number of passengers using a lift from the number of car calls and lift movements. The Inverse S-P method is effective, yet applies only to up and down peak traffic.

6.3.3 Estimation Of Complete Traffic Flow

Peters reported having derived a method for extrapolating (complete) traffic flow from control systems data in[10]. The development of this method has been halted after successful preliminary tests as further work is impractical without taking data directly from lift system controllers. Manufacturers have proved unable or unwilling to provide access to the necessary data for research purposes. The proposed method is outlined as follows:

- The passenger arrival rate, μ_i, is a function of [the average time between a lift leaving floor i travelling up and the up landing call being pressed by the next passengers arriving at the landing station] and [the average time between a lift leaving floor i travelling down and the down landing call being pressed by the next passengers arriving at the landing station].

- This function can be derived by applying the assumption that the arrival of passengers at a lift landing is reasonably modelled by a Poisson process. (This assumption has been previously been applied in lift traffic analysis[1][3].)

- Destination probabilities can be estimated by analysis of car calls registered as the lift leaves each landing. Not every passenger will register a car call (as other passengers will have pressed the button first). But over time the relative frequency of unregistered car calls being pressed will provide a good indication of the average destination probabilities from each floor.

Figure 10 records some results from the preliminary tests where control system data was collected "manually" by observation.

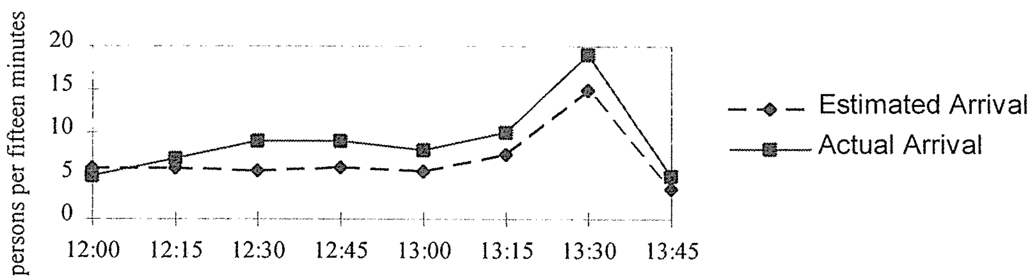

Figure 10 Poisson Based Estimate Of Traffic Flow

6.4 Computer Vision

Researchers[11][12] have applied image processing techniques to video pictures of lift lobbies to determine the number of people waiting for the lifts. This lobby count aids the control system by enabling it to prioritise calls from busy floors.

A spin off from the lobby count system developed at Brunel University was a prototype "traffic surveyor" to count the passengers as they loaded and alighted the lifts. The system applies similar image processing techniques to the lobby count system, but compares each video frame in sequence to track people across the scene. If people join or leave the scene from the areas defined as the lift doors, they are counted as having loaded or alighted the lifts. In tests the system was found to be 80-85% accurate, errors being due mainly to a tendency to miss-track people from one image to the next.

This Brunel University research project has now concluded, so no further development is envisaged. But image processing is an active research area and improved pedestrian tracking systems are likely to be developed in the future, probably initially for security applications. In due course, we are likely to be able to purchase general purpose pedestrian tracking systems that will provide us with the basis for complete measurements of traffic flow.

6.5 Infra-Red

Infra-red technology is widely applied, particularly in the security industry. Traffic surveys using photocells or infra-red beams were suggested in [13][14]. The approach requires a minimum of two horizontal beams to count people passing through the detection field in single file. The sequence of beam states enables direction to be determined. If people are walking side by side, horizontal beams will detect only a single person. This can be overcome by mounting beams vertically - a system believed to be using this approach is installed in a London department store monitoring escalator traffic.

Initial lab and site tests suggest that, although system logic can be fooled, in practice the overall counting accuracy of infra-red counting systems is high. The infra-red detectors effectively replace observers in manual surveys, so the data collected does not describe traffic flow completely (as in 6.2 ii we can only calculate average destination probabilities). But infra- red technology is available and relatively inexpensive to implement.

6.6 Written Surveys

Written surveys, where people record the times of lift trips on a form, have been found to be unreliable[7]; this was confirmed from the results of a written survey at Building A (Figure 3). This is probably due to a tendency for people to record their arrival and departure times as the fixed working hours of a company.

6.7 Security Systems

Various security systems are applied to control access in buildings, some of which are integrated with the lift systems. Systems that use swipe cards to call the lift, or a key pads to control access to specific floors, do not yield useful traffic flow data. Where they are installed, systems that identify passengers individually as they arrived and depart lift lobbies will enable traffic flow to be monitored completely.

7 OTHER ISSUES

7.1 Use Of Stairs

In planning lift installations, some designers make allowance for the use of stairs. The authors' survey experience suggests:

- the number of people using the stairs in lieu of the lifts drops off sharply as the journey travel increases
- people are less likely to walk up than down
- an attractive staircase sited adjacent to the lifts is far more likely to be used than a back staircase

In the Building C (Figure 5) survey, use of the staircase was virtually nil in spite of the lifts being heavily loaded and long passenger waiting times; the main staircase was an unattractive fire escape sited well away from the lift lobby. Figure 11 shows the associated stair usage for the BRE[7] and Building A (Figure 3) surveys.

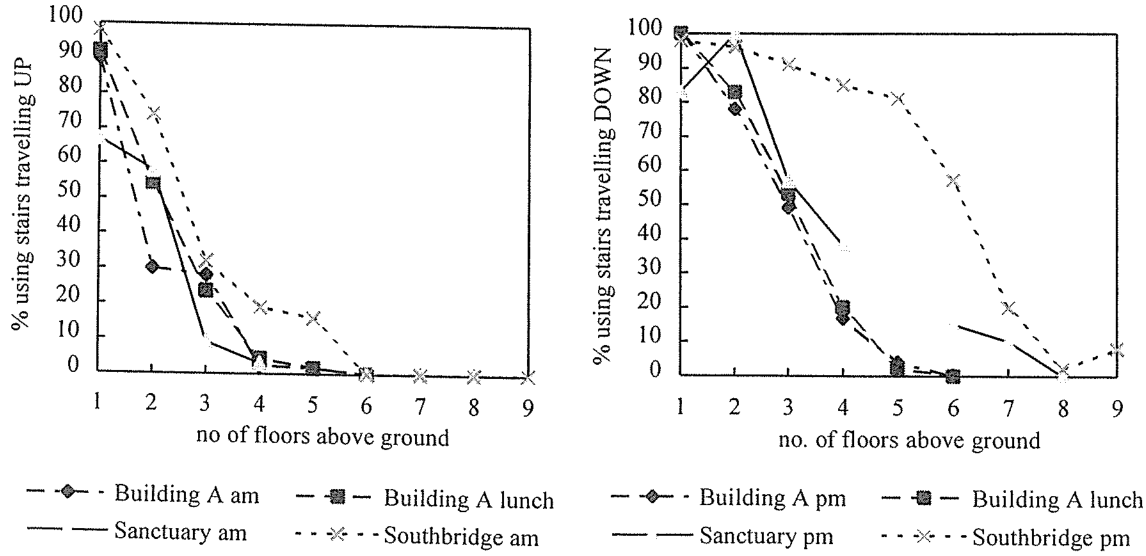

Figure 11 Example Stair Usage For Up And Down Travel

In lift traffic surveys we need to assess stair usage, otherwise generalised recommendations will be inappropriate to:

- high rise buildings where the relative use of stairs is far less significant
- buildings where stair access is poor

7.2 Occupancy

If the results of traffic surveys are to be applied in the design of other buildings, it is important that traffic is recorded relative to the actual building population - plotting survey results of a partly occupied building relative to nominal building population can suggest misleadingly low traffic flows.

8 CONCLUSIONS

It is important for lift designers to have a good understanding of lift traffic flows. Most lift installations are designed on the basis that the morning up peak is the most onerous traffic condition for lifts, yet traffic surveys suggest that the lunch period is more often the busiest period.

In planning new lift installations, it would be dangerous to disregard conventional up peak design criteria completely without a wide study of other traffic flow peaks. But in many cases designs applying up peak traffic analysis are inappropriate.

A range of surveying techniques has been reviewed as a means of establishing passenger traffic flows. The authors continue to collect data, and encourage others to publish their results so that improved design criteria can be established. Survey techniques are improving - currently the authors favour the infra-red system as the best available technology. Improved knowledge of traffic flows will also aid control system design.

ACKNOWLEDGEMENTS

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