NEW APPROACH IN THE DEVELOPMENT OF ELEVATOR GROUP CONTROL ALGORITHMS

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ABSTRACT

Group control algorithms are designed in order to increase the transport capability of elevator groups and to improve various factors such as waiting time of passengers. During the past ten years a significant improvement of performance has been gained owing to the development of technology, hardware and software. However, the objectives of the optimization (for instance minimization of waiting time) are still not clearly defined and remain ambiguous. It cannot be assured that the system optimizes exactly what is expected.

The paper describes our approach which consists first a better definition of objectives (factors related to passengers are projected in the factor space), secondly the design of an evaluation module and finally the integration of the evaluation module into a target system.

1. INTRODUCTION

The function of an elevator group control is to coordinate the movement of elevators in a group with the aim of serving the calls of users waiting at floors (hall calls), and the stop requests of passengers already in a car (car calls). A few basic rules determine the way in which hall calls can be served, such as, a car should not reverse direction until all car calls for the direction in which it is currently traveling have been served.

Thus the task of group control consists of designating which elevator or elevators are to respond to a hall call that has been registered. In the terminology currently in use, this is referred to as assigning a call to an elevator (call assignment).

In a conventional elevator control, the assignment of a call only becomes effective when the elevator begins to slow down to stop at floor; it is permitted to de-allocate a call to an elevator in order to re-allocate it to another one if the elevator control considers this preferable.

The complexity of the problem arises from the very short time available for making decisions, consisting of only one or a few seconds according to the strategy applied, and from the high number of assignment possibilities.

If in an elevator group comprising of n elevators the number of hall calls registered is p, then there are n^p call assignment possibilities, i.e. n^p possible solutions. In a typical elevator group comprising six elevators serving twenty floors, and assuming that a hall call has been registered on half of the floors, then there will already be 6^{10} potential solutions, or more than sixty million.

The task of the elevator control is to decide which out of all these possible solutions is the one most suitable for achieving a specific objective.

The objectives are defined on the basis of the optimization of certain factors. The most important factors are those relating to passengers: these include the waiting time at the floor, the duration of the ride, the number of intermediate stops, the fill-up rate of the car, etc. There are other factors that can be taken into consideration too, such as energy consumption, for example.

How much emphasis is placed on each of these factors primarily depends on the density of the traffic, which is determined by the number of passengers arriving per minute at each floor, consequently by the type of installation (office block, commercial building, apartment block, etc.).

2. CURRENT APPROACH

In order to cope with the complexities we have outlined above call assignment strategies had to be defined and technical solutions for the control in real time of elevator groups had to be developed.

ANALYSIS OF THE SITUATION

The task of the development engineers has primarily consisted of observing and characterizing the various possible situations, i.e. in particular the relative position of cars and calls, and the loading of cars.

A further highly important characteristic with regard to call assignment is the nature of the traffic concerned. It is characterized by the passenger flow. There are three basic traffic categories: 1/ up-peak traffic, where passengers depart from one floor, usually the ground floor, and distribute themselves over the higher floors; 2/ interfloor traffic, where passengers move indiscriminately between one floor and another, and 3/ downpeak traffic, where passengers depart from the upper floors and converge towards one floor, usually the ground floor.

DRAWING UP RULES

The second task of the development engineers was to compile simple rules on the basis of a given situation, of the declared objectives, and which can assure the smooth operation of the elevator group.

If, for example, the objectives are 1/ to make the transport capacity as high as possible, and 2/ to minimize the waiting time for passengers, it will be necessary to seek a rapid turn-around of the cars. For in this manner, the increased frequency of travel to the floors assures shorter waiting times and the speed of travel implies a higher transport capacity.

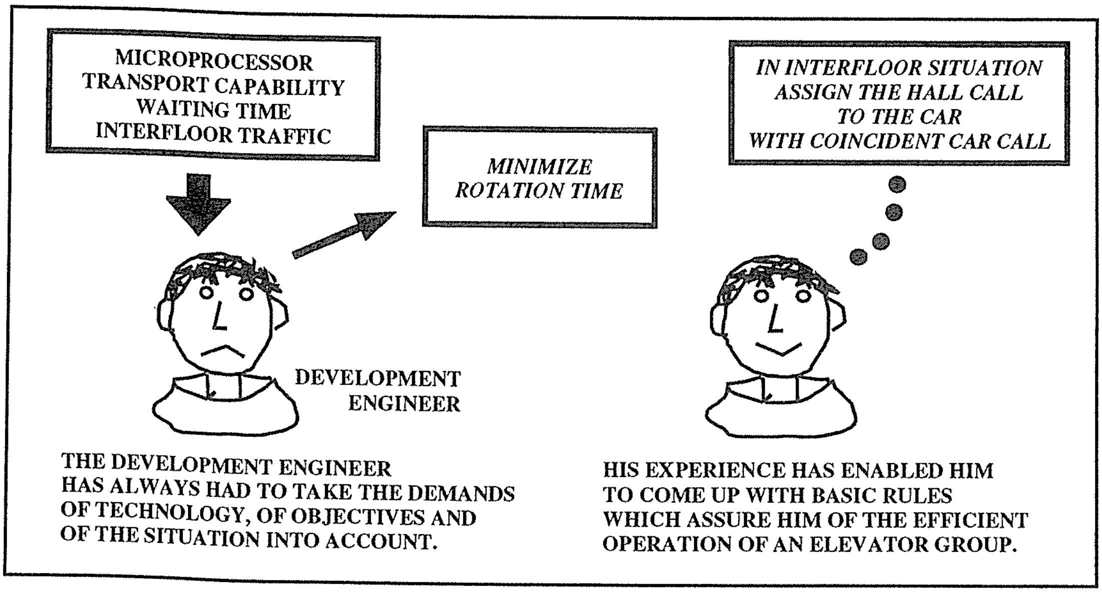


Figure 1 Current approach

In order to reduce the duration of the car turnaround, the number of halts per journey must be minimized, this becomes the objective to be achieved.

How do we accomplish it? It is possible to reduce the number of halts if the cars try to handle the maximum number of passengers exiting (car calls) and entering (hall calls) in only one stop.

The following rule is usually applied (referred to as the coincident call rule): whenever possible, in order to serve hall calls the elevator control designates a car which already has a car call to serve on that floor.

IMPLEMENTATION AND CURRENT TENDENCY

Following the introduction of the first microprocessors in the 1970s, it has become possible to take a greater number of parameters into account than in the past. The rules have thus become more precise and the efficiency of elevator controls has increased.

One of the first methods of implementation, and one which is still very efficient since it has now reached a stage of maturity, was the mathematical formulation of these rules. Using a *cost calculation* it is determined which elevator is *favorite* to serve a hall call. The formula takes into account both the waiting time for the passengers to be served by the car and the travel times of the passengers in the car. The coincident call rule is also applied in this calculation.

The current trend would be to integrate expert systems. An expert system is only applicable if a specialist in the field is available. The latter is obviously the development engineer, and the rules integrated into the expert system are of the same type as in the past.

What is interesting about these techniques arising from the field of artificial intelligence is that they permit a smoother integration of rules, particularly the use of fuzzy rules which permit an imprecision inherent to the nature of the situation.

TRAFFIC DEPENDENCY

These rules, however, suffer from a major drawback - their dependence on the traffic.

Let us consider the case where a period of heavy down-peak traffic clashes with a light interfloor traffic period, this is generally the case at the beginning of the lunch hour or at the end of the day in an office building. Most of the users are heading downwards to the ground floor and generate down-calls. A certain number of passengers need to go from an intermediate floor to a higher floor, and thus generate up-calls.

How should the elevator control serve these calls? What will happen if the upcalls are served with the same priority as the down-calls?

The cars ascending will stop to pick up only a handful of passengers at each floor and will have to serve their car calls before being able to serve those calls of the large number of passengers wishing to descend. If there is a notable disproportion between ascending and descending passengers, the situation can quickly become intolerable; the cars will become incapable of dealing with the volume of passengers wishing to descend.

In order to come to terms with this problem, the following rule, for example, can be introduced: in a situation of down-peak traffic, it is preferable to curtail the response to up-calls. In practice this means restricting the serving of up-calls so as to serve more than one passenger per stop.

This example demonstrates that without changing the objective (optimization of transport capacity and waiting time), it is necessary to apply different rules according to the nature of the traffic.

As a result, the pre-requisites for efficient operation of the elevator control are the precise identification of the traffic in order to determine the rules to be applied. But this identification is difficult to achieve, 1/ during transitions in the nature of traffic as described in the example above, and 2/ in conditions of specific traffic such as a sudden increase at one or more intermediate floors (floor-peak), e.g. at the end of a conference.

OBSERVATION AND SELECTION OF THE OBJECTIVES

In the process we have just described for drawing up rules, a fundamental transformation takes place with regard to the nature of the objectives. The initial objectives make way for a collection of rules involving certain factors to be optimized (e.g. assignment of a call to a car which minimizes the waiting time), and rules which recommend how calls should be served (e.g. restricted serving of up-calls).

It should be noted that the rules thus obtained are more "precise" than the initial objectives. Does the objective of *minimizing the waiting time* have to interpreted as minimizing 1/ the average waiting time or 2/ the maximum waiting time, or perhaps 3/ the probability of long wait? The machine, of course, cannot ask itself such questions when applying a rule.

Defined in this way, the rules concerning the factors to be optimized are thus insufficient to ensure good results on their own. We cannot enter into too much detail here, since this would require a more detailed analysis of the rules to be applied in a particular elevator control. We would simply like to ask two questions: can we really be sure that the system is optimized according to our expectations? And is it possible to modify the optimization objectives in a sure and simple manner?

3. NEW APPROACH

It seemed to us that the current approach, which places an emphasis on the way in which the problem of optimization is solved, rather than on the finality of the optimization itself, arose primarily from the development of elevator controls, and not from objective reasons.

We asked ourselves therefore whether it would not be possible to integrate a module into the elevator control kernel which contains the precise definitions of our objectives, and if we could construct a shell around this module which would determine call assignments according to the given objectives.

This implies that adaptation to traffic would occur naturally and smoothly, since the final decision would be taken by the module containing the objectives. If the need were to arise, any modification of the objectives could also be carried out simply and securely.

EVALUATION MODULE

We have termed the module in which the objectives are defined the *evaluation module,* since its role is to evaluate a possible solution for the assignment of calls, or an elevator control, or even the performance of an installation. It has to draw up an evaluation of given precise and objective data.

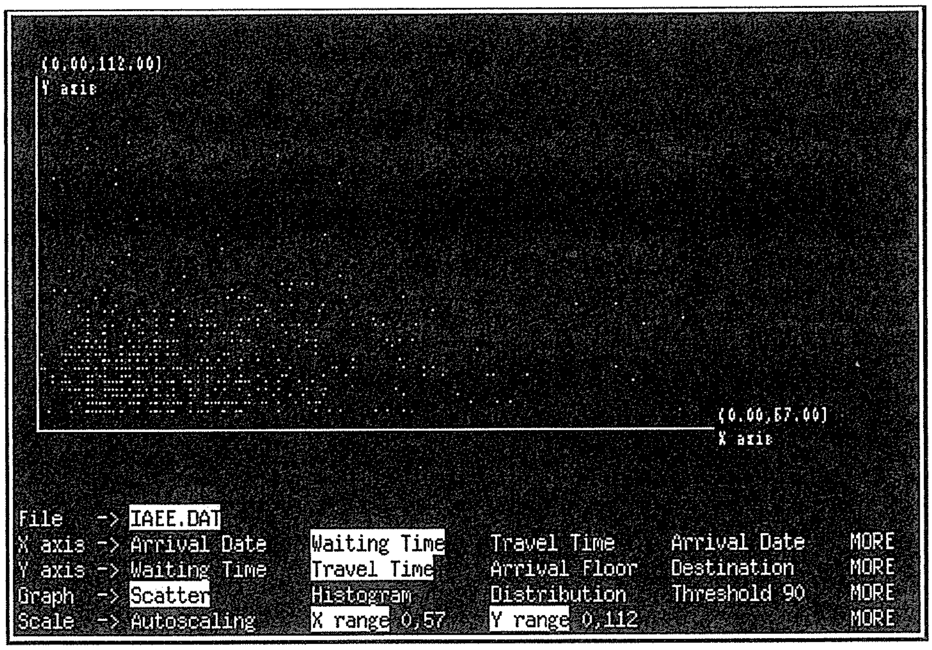
The design of the evaluation module must be done in two steps: 1/ the information required for the evaluation must be defined, 2/ the evaluation function has to be specified.

FACTORS

What is the data required for such an evaluation? Let us return to the previous example of waiting time. The objective of "minimizing waiting time" can be interpreted in a number of ways depending on whether passengers are considered in their entirety (e.g. average waiting time value) or whether certain exceptional passengers are taken into account (e.g. maximum waiting time value). In fact, the evaluation is the result of a compromise between these two perspectives.

The evaluation module needs to be able to accept any new objective and to accomplish this compromise it has to be fed with data relating to all users. On the basis of this data, it is possible for the module to draw up general indices such as, for example, an average value; it would be impossible for it to derive individual indices such as, for example, the maximum waiting time value, on the basis of average values.

The waiting time should be regarded not as an optimization objective, but rather as merely one factor associated with a user. It is natural to associate other factors with users, such as the duration of the journey, for example. Thus in order to have a representation of the data necessary for evaluation, representation which is a little abstract but convenient, it can be stated that the passenger is one point in the factor space. The dimension of that space is the number of factors. Figure 2 is the result of a simulation. We have considered only two factors in order to permit this graphic representation.



EACH OF THE POINTS IN THE FIGURE REPRESENTS ONE PASSENGER.

THE X AXIS REPRESENTS THE WAITING TIME, AND THE Y AXIS INDICATES THE TRAVEL TIME

<u>Figure 2 Factor space</u>

This representation serves to record data on the majority of passengers whilst indicating the exceptional cases. It also records data regarding the density of traffic, which is proportional to the number of points.

The pattern recognition of the cluster of points can serve as a basis for evaluation. A neural network would appear particularly suitable for carrying out this task. Once trained, the network adapts itself to all types of installations since the data it has been fed only concerns passengers. The characteristics of the installations, such as the number of floors, the number of elevators and their speeds, are implicit.

Users certainly do not have a uniform perception of time. Although the evaluation function can take this phenomenon into account, it may be preferable to convert the factors obtained, using non-linear pre-processing, into "human" factors indicative of this perception.

Only factors relating to passengers have been taken into account in the previous example, for reasons of simplicity. But in fact, each component of the elevator group can be evaluated. The factors relating to a particular component category are projected into a factor space relating to that category. For example, factors such as energy consumption and number of door openings can be associated with an elevator. The concept of category can also be extended to users. In principle, it is permissible to regard certain types of users as belonging to a particular category (e.g. priority passengers, etc.). The weighting of the various categories should be carried out on the basis of individual specifications according to the needs of the client.

EVALUATION FUNCTION

The situation of the development engineer is now fundamentally different from that in the previous approach (see figures 1 and 3), since technical realization is no longer subject to an *a priori* and fixed definition of optimization objectives. These will become apparent when in the form of an evaluation function.

The development engineer can therefore devote his efforts entirely to the task of design, adopting a simplified evaluation function to begin with. This approach permits an incremental cycle of development, and speedy realization.

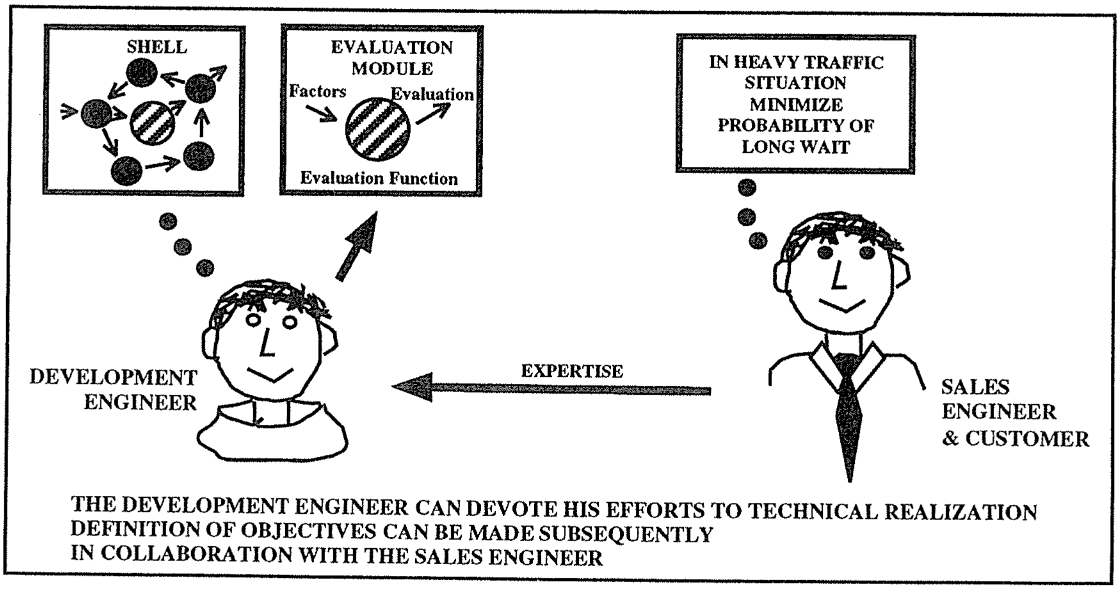


Figure 3 New approach

The second stage of realization of the evaluation module consists of specifying the evaluation function with the aid of a sales engineer, for the latter is particularly well acquainted with the client's special requirements and objectives.

The application of a conventional or a fuzzy logic expert system can also be envisaged with this approach; the main difference from the former approach is that the expertise resides within the definition of the objectives and not in the means by which they are achieved. The expert is a sales engineer. The application of the expert system is limited to the evaluation module only.

The separation of the definition of the objectives from the remainder of the system allows greater flexibility of configuration. The weighting between the various factors can be specific to a particular client.

4. INTEGRATION

The foundations of artificial intelligence are based on the question: how does a human being tackle to a given problem and what is his approach to seeking a solution? This viewpoint applies precisely to our realization and in particular to the integration of the evaluation module in the target system.

Faced with the problem of call assignment, which is the most natural approach to adopt? Let us suppose that a human operator is instructed to solve the problem: how will he proceed?

From the many possible solutions, the operator will initially identify a "convenient solution" using his intuition, i.e. on the basis of his own experience. Such a solution will not necessarily be the optimal one.

If our operator has a little time to reflect before making his reply, he will consider alternative solutions. « If I opt for this solution, what will be the result? » For each alternative he makes a quick mental simulation, evaluates the likely results, and finally decides whether it can replace the initial solution. Those alternative solutions less likely to improve on the best solution will only be evaluated in the last resort.

For the operator's decision-making procedure, two attitudes play a conflicting role: the speculative attitude, and the cautious attitude. A strategy which would genuinely give rise to good results, yet whose potential for causing some kind of "catastrophe" (i.e. undesirable results) is not minimal, might have been accepted with a speculative attitude, yet will be rejected on the basis of a cautious attitude.

The scenario we have just described occurs again in our implementation. We shall now describe its principal modules (see figure 4).

TREE SEARCHING

The situation of cars and calls is transmitted to a module instructed to manage the potential solutions for call assignment and the evaluations which will be made of these. The module creates a tree, each branch of which corresponds to the designation of an elevator to serve a hall call.

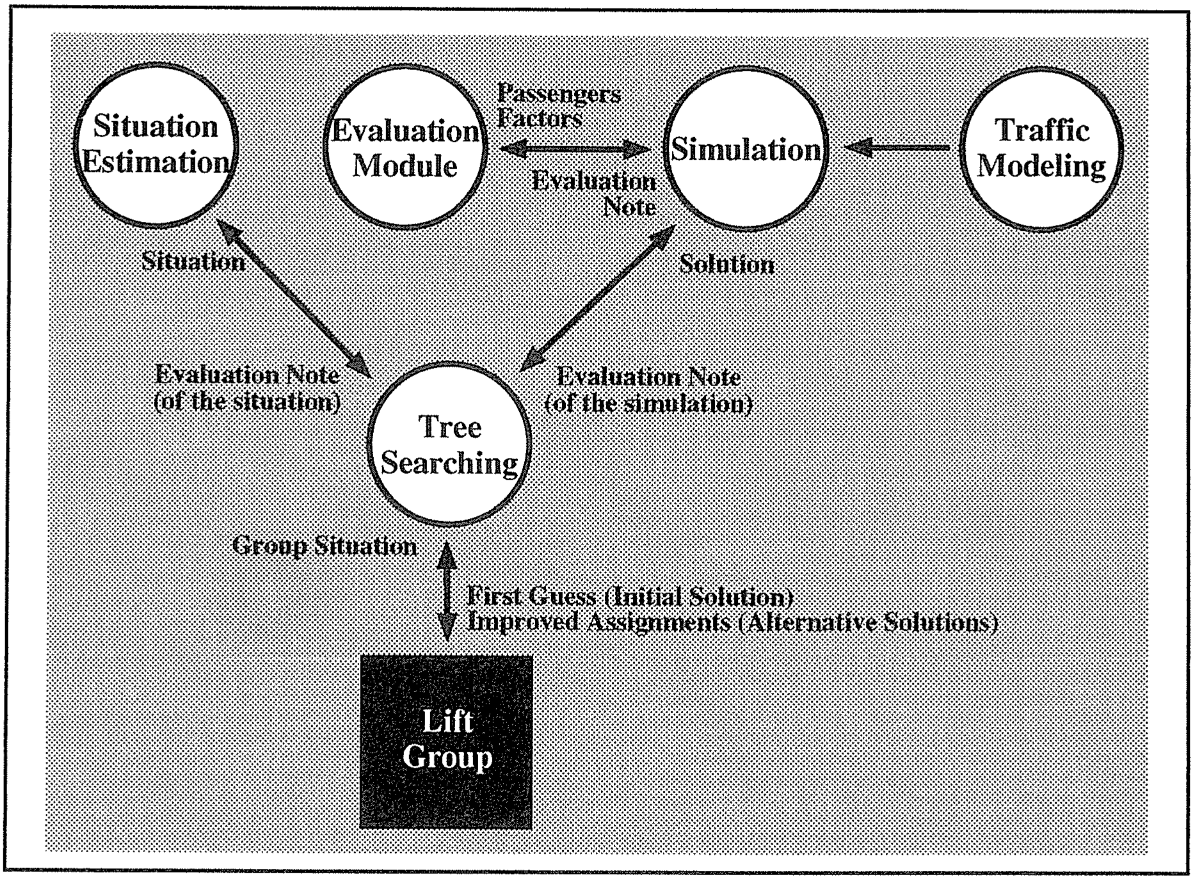


Figure 4 Realization

An initial solution is determined on the basis of a collection of rules drawn up from previous experience (especially the *favorite* rule, see ¶2.). This initial solution is evaluated and serves as a first reference in the search for alternative solutions.

We use a technique called *alpha pruning* in our search for alternative solutions. The search for solutions is continued for a period determined by the relative situations of the cars and the hall calls.

EVALUATION

The solutions are transmitted by the tree searching module described above to the simulation module, whose task is to assess the factors required by the evaluation module. In order to arrive at this result, the simulation module 1/ generates the passengers to whom the factors will be associated, and 2/ simulates the car journeys and the passengers movements. The factors are then transmitted to the evaluation module and are evaluated according to the specified objectives.

The simulation module uses the resources of a traffic modeling module which instantly supplies it with the likely number of passengers waiting at a floor and with estimates regarding their possible destinations.

ASSESSMENT OF THE SITUATION

The evaluation of a solution is moderated by an analysis of the situation derived from the simulation. The solution will be rejected if, for example, it should subsequently cause a grouping together of the cars (referred to as bunching). A situation estimation module supplies this information; this module fulfills the moderating function of the cautious attitude mentioned above.

5. CONCLUSION

Historically speaking, elevator group control algorithms have been designed on the basis of heuristic rules which describe how, according to the traffic situation, cars can serve hall calls. During the past decade, the range of technological means available has expanded enormously. New implementation techniques have been introduced, and as a result the rules have been defined much more precisely. However, two characteristics inherent in this approach limit its subsequent development in our opinion: 1/ the dependence of rules on traffic conditions, and 2/ the non-ambiguous interpretation of the optimization objectives.

The present tendency is to analyze the traffic more precisely in order to allow a better rules selection. We feel that it would be preferable to instigate a change of direction in this field and to tackle the problem by means of a clearer definition of the optimization objectives.

As we have demonstrated, a precise definition of these objectives authorizes their implementation directly in the elevator control system within an evaluation module. This offers several advantages: 1/ the elevator control can adapt itself automatically and with greater flexibility to fluctuations in traffic; 2/ the absence of transformation of the objectives ensures their actual optimization; and 3/ the optimization objectives can easily be modified, which permits response to the specific requirements of the clients. We feel that these results show that this line should be pursued.

BIOGRAPHICAL NOTES

Patrick Chénais obtained his diploma in automation and electrotechnics in 1977. After gaining his first professional experience in four years of research department, he proceeded to study for his doctorate in computer science, specializing in the field of speech recognition, within the framework of a technical collaboration between the University of Toulouse and Renix Electronique (automobile electronics). He received his Doctor of Engineering diploma in 1987, following which he joined Schindler.

Karl Weinberger has been with the Schindler Elevator Corporation since 1977 and is currently Vice Director in charge of the R&D Control Systems Department. He is one of the initiators of the program for the development of elevator group control algorithms based on artificial intelligence and presently manages AI development which is spread across several of the Corporation Development Centers.