TITLE: APPLICATION OF THE EXPERT SYSTEM TO ELEVATOR GROUP-SUPERVISORY CONTROL

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TOPIC: Case Study: Engineering

ABSTRACT: In this paper, the new elevator group-supervisory control method to which the expert system and the fuzzy rule are applied will be suggested. This method determines the optimum car to answer a hall call by using the knowledge bases, the production rule and the fuzzy rule, extracted from the knowledge of experts in the elevator group-supervisory control. It has been verified through simulation that the new method can bring about considerable improvement, reducing the average waiting time by 15-20%, the rate of long waits (not less than 60 seconds) 30-40% in comparison with the conventional method in which a fixed evaluation function is used.

Furthermore, the knowledge-based systems suitable to the online and real-time control for the implementation of this new method on 32-bit microcomputers will be suggested. The result of the simulation has demonstrated that the suggested knowledge-based systems satisfy the required response time 100-150 msec in the group-supervisory control system with an immediate prediction function.

The new group-supervisory control system which incorporates the method suggested is scheduled to be commercialized for real operation in the first half of 1989.

STATUS: Development

DOMAIN: Control (online, real-time)

LANGUAGE: C and assembly languages

EFFORT: Eight person-years
Application of the Expert System to Elevator Group-Supervisory Control

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ABSTRACT

In this paper, the new elevator group-supervisory control method to which the expert system and the fuzzy rule are applied will be suggested. This method determines the optimum car to answer a hall call by using the knowledge bases, the production rule and the fuzzy rule, extracted from the knowledge of experts in the elevator group-supervisory control. It has been verified through simulation that the new method can bring about considerable improvement, reducing the average waiting time by 15-20%, the rate of long waits (not less than 60 seconds) 30-40% in comparison with the conventional method in which a fixed evaluation function is used. Furthermore, the knowledge-based systems suitable to the online and real-time control for the implementation of this new method on 32-bit micro-computers will be suggested. The result of the simulation has demonstrated that the suggested knowledge-based systems satisfy the required response time 100-150 msec in the group-supervisory control system with an immediate prediction function. The new group-supervisory control system which incorporates the method suggested is scheduled to be commercialized for real operation in the first half of 1989.

I. INTRODUCTION

With the advancement of intelligent computerized buildings in recent years, demands for the elevator group-supervisory control with more sophisticated and diversified functions than before have increased. The main function of the elevator group-supervisory control is to determine which elevator is the optimum one in the group to answer the hall call for shortening the waiting time as a whole. In many cases, however, functions relating to comfortableness, safety and economy are also desired in addition to the main function.

A "Call Assignment Method" which aims to determine an elevator to answer for each hall call has been adopted to most of the group-supervisory control systems at present. In this method, the car selected for an assigned car is decided by the evaluation function which includes the waiting time as an element.

It has been realized lately that besides utilizing specific evaluation functions, the experts knowledge and experiential rules, which have not been used because they make the evaluation functions extremely complicated, need to be incorporated in the group-supervisory control system in order to further improve the control performance. The experts here mean engineers who have been engaged in design, development and maintenance of elevators under the group-supervisory control for long years.

This paper suggests a new elevator group-supervisory control method where the group-supervisory control is basically exercised by means of a knowledge-based system housing the knowledge and experiential rules of experts in group-supervisory control.

First of all, Chapter II describes the system configuration, functions and performance evaluation standards of the elevator group-supervisory control system and clarifies the target where the expert system will be introduced. In Chapter III, an outline of major group-supervisory control methods adopted in the past to achieve the goal of the group-supervisory control and the background which has necessitated the introduction of the expert system will be described. Chapter IV deals with the detail of the group-supervisory control method by means of the knowledge-based systems suggested in this paper. Chapter V demonstrates the effect brought about by the group-supervisory control method based on the knowledge-based systems suggested by using a simulator. In conclusion, Chapter VI shows how the new method suggested will actually be adopted as well as the problems for further discussion.

II. PROBLEM DEFINITION

The Elevator Group-Supervisory Control System

Configuration of the elevator group-supervisory control system is shown in Fig.1. In general, the elevator group-supervisory control system consists of multiple elevators (usually 3 to 8 elevators), car controllers for each elevator and one group controller. An elevator hall is furnished with equipments such as hall buttons, hall lanterns and chimes. Micro-computers (8-bit or 16-bit) are mounted on the group controller and individual car controllers. The control programs are mainly written in the assembly language.

As soon as a hall button in the elevator hall is pressed, a group controller registers the hall call, selects and assigns the optimum
Evaluation Criteria of System Performance

Evaluation items and evaluation standards given below are generally used to evaluate the performance of the group-supervisory control having the above-mentioned functions.

1) Waiting time:
   Usually, the total amount of time required for a car to arrive after a hall call is registered represents the waiting time and the system performance is evaluated by the average waiting time, the rate of long waits and the distribution of waiting times. In general, service is judged good if the average waiting time does not exceed 20 seconds and the rate of long waits (not less than 60 seconds) is 3% or less.

2) Accuracy of prediction:
   If the car not predicted to be assigned answers the car call (the call registered by the destination button in the car) and arrives before the car that has been predicted to be assigned, it is called the prediction error. The prediction errors displease passengers waiting in the hall. The rate of prediction errors is generally judged good if it does not exceed 5%.

Other important purposes of the group-supervisory control are the reduction of boarding time (the time required for a car to arrive at the destination floor after a passenger gets in the car), energy-saving (to control elevators not to make wasteful movements while securing satisfactory service) and improvement of convenience and comfortableness.

The group-supervisory control has various purposes as mentioned above. Many evaluation items conflict with each other. For instance, reduction of prediction errors must be sacrificed to some extent for shortening the waiting time, and also, shortening of waiting time must be sacrificed to some extent for the sake of energy-saving. From this point of view, the elevator group-supervisory control can be regarded as a problem dealing with optimization involving multiple purposes.

III PREVIOUS APPROACHES

As stated in the earlier chapters, the main purpose of the elevator group-supervisory system is having one of the cars in the group answer a hall call efficiently.

One of the important subjects is to deconcentrate and properly dispatch cars in the group throughout the multiple floors so that any hall call can be answered quickly. Especially when the traffic is heavy, cars tend to travel in groups, which is generally called "bunching." It is known that once the bunching occurs, satisfactory service cannot be provided for some period of time.

As approaches to this subject, the "Scheduling Method," the "Demand Zoning Method," and other types of methods have been introduced. In the "Scheduling Method," cars are dispatched at specific intervals from both terminal floors of the building and operated to shuttle between the both terminal floors answering calls on the way like buses. In the "Demand Zoning Method," several hall calls are grouped for each zone and one car is assigned to each zone to answer hall calls within the respective zones. Furthermore, the "Call Assignment Method" in which a car is assigned to a hall call to answer making the best use of the operation capability of computers, especially the capability of numerical operation, has been commonly employed since it became possible to mount digital computers on the group controller owing to the advancement of computer technology. Most of the group-supervisory control systems which currently exist have adopted the method for the selection of an assigned car based on their own evaluation functions. In this chapter, the basic idea and the problems of this method will be explained further in detail.

Call Assignment Method

An outline of the procedure for selecting an assigned car in the "Call Assignment Method" having the "immediate prediction function" is as follows.

1) Inputting the traffic condition:
   After a hall button is pressed in a specific hall, the hall call is registered, and at the same time, the operation state of each car at the point of time is inputted from each car controller.

2) Predictive operations:
   Predicted values of the following items based on the inputted traffic condition are calculated:
   - the time required for each car to arrive at each hall,
   - the number of passengers getting on and off each car at each hall, etc.

3) Determining an assigned car:
   An appropriate car to be assigned is selected based on the results obtained from the predictive operations and the assignment command and prediction command are inputted to each car controller.

The most significant point in the course of procedures given above is how to find out an appropriate assigned car. It can be regarded as a problem to select one from among N alternates (N is
In the conventional methods, service of the whole group is numerically evaluated by calculating the value of the designated evaluation function \( J(e) \) based on the results of predictive operations on the assumption that car \( i \) (1 ≤ i ≤ N) is assigned. In general expressions, this can be expressed as expressions (1) and (2): 

\[
J(e) = \text{Min} \{ J(1), J(2), \ldots, J(N) \}
\]

\[
J(i) = f(x_{ik}, y_{ik}, z_{ik}, x_{ik}^{*}, y_{ik}^{*}, z_{ik}^{*}, \ldots)
\]

where:
- \( e \): assigned car,
- \( J(i) \): evaluation value of car \( i \),
- \( x_{ik} \): predicted waiting time of hall call \( k \) when car \( i \) is assigned to the latest hall call,
- \( y_{ik} \): probability of prediction error of hall call \( k \) when car \( i \) is assigned to the latest hall call,
- \( z_{ik} \): probability of a full car passing without stopping in reply to hall call \( k \) when car \( i \) is assigned to the latest hall,
- \( x_{ik}^{*}, y_{ik}^{*}, z_{ik}^{*} \): predicted waiting time, probability of prediction error and probability of a full car passing without stopping in reply to hall call \( k \) when car \( i \) is not assigned to the latest hall call.

The evaluation items \( x_{ik}, y_{ik} \) and \( z_{ik} \) given above are calculated from the results of predictive operations and other data.

One of the evaluation functions (1) of the expression (2) is as follows. The irritation of the passenger due to long waits in a hall or the prediction error is evaluated quantitatively as follows. The irritation of the passenger due to long waits in a hall the prediction error is evaluated quantitatively as follows.

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neck and develop the new method.

The first approach is a mathematical analysis of the optimum elevator operation. At first, we developed a method to generate traffic in a building on a computer based on past data and mathematically analyze to find the optimum operation of an elevator group for the traffic generated [4]. This is an analysis method where the S.A. (Simulated Annealing) Method, a valid solution to a problem of large-scale combination, is used. It has become possible to analyze and find out the optimum operation in terms of various evaluation points such as minimization of the average waiting time, the maximum waiting time and the average service completion time. Various traffic conditions were analyzed by using this method. Next, the result of the optimum operation and the result of operation under the conventional method were compared by means of a group-supervisory control simulator described below to extract differences. Then, problems of the conventional method were examined.

The second approach is to organize knowledge and to examine through the group-supervisory control simulator. We organized the extracted problems and the knowledge of experts in the group-supervisory control about improvement plans of such problems, and then, arranged the production rules and the fuzzy rules relating to an assignment method to obtain the optimum operation. Validity of the rules was verified by using the group-supervisory control simulator mentioned later.

Linguistic expressions of thus extracted rules are shown below as examples. Expressions (3) and (4) represent the production rule and expression (5) represents the fuzzy rule.

\[
(P\text{-RULE } j) \quad \text{IF (There is a hall call (x) which was bypassed by its assigned car.)} \quad \text{THEN (Give priority to the hall call (x).)}
\]

\[
(P\text{-RULE } k) \quad \text{IF (There is a hall call (x) which has priority.)} \quad \text{AND (There is a car (y) which is assigned to the hall call (x).)} \quad \text{THEN (Forbid the car (y) to be assigned to new hall calls.)}
\]

\[
(P\text{-RULE } n) \quad \text{IF (A new hall call (x) in the high-zone is registered.)} \quad \text{AND (The number of cars which are ascending to the high-zone is large.)} \quad \text{AND (The number of free cars is small.)} \quad \text{THEN (Select one assigned car from among the candidates.)}
\]

\[
(P\text{-RULE } m) \quad \text{AND (Select cars (z) except free cars in the group as candidates.)}
\]

**Knowledge Representations**

In this method, the production rule is described in the following form.

\[
\text{IF (definite conditions) THEN (procedure for execution)}
\]

The fuzzy rule representing knowledge involving ambiguous expressions is described as below.

\[
(P\text{-RULE } n) \quad \text{IF ((condition-n1) OR (condition-n2))} \quad \text{AND (condition-n3)} \quad \text{THEN (procedure-n1)} \quad \text{AND (procedure-n2)}
\]

To be concrete, the second and the third conditions of the rule (P-RULE rm) in expression (5), for example, are described as shown below.

\[
(m\text{-function (p-hall, GT, al, bl)}) \quad (m\text{-function (n-h-zone, GT, a2, b2)}) \quad (m\text{-function (n-free, LT, a3, b3)})
\]

Each condition is prescribed as a "fuzzy set" by the membership function. The m-function (o, type, a, b) representing the membership function is so simple that a triangular or straight-inclined form as shown Fig. 4 is employed. V is variable, type is the type of membership function, and a and b respectively represent the center and the width of membership function.

The C-language is used as a programming language and each rule is defined as a function respectively. Also, it is possible to include conventional type programs written in the C-language or in the assembly language such as programs for numerical operations which are unique to the elevator control in the condition and conclusion parts of the rule. This feature facilitates connection of the programs that have been used in the conventional group-supervisory systems to this system.

**Control Algorithms Based on Rule Base**

The inference engine for production rule draws a forward chaining inference from the production rule. The control algorithm is shown in Fig.5. Several useful ideas to further improve efficiency, such as configuration corresponding to the hierarchy of rule groups, simplified conflict resolution and a function to limit
Fig. 5. Control algorithm of PREX

The control algorithm based on the fuzzy rule (rule selector and rule executor) is shown in Fig. 6. The rule selector shown in Fig. 6 conducts initial processing to judge certainty first. Here, in order to exclude irrelevant rules from the operations of certainty value, a flag, pass-flag(1) - pass-flag(M), which corresponds to M rules is set depending on if the rule belongs to the previously specified rule groups. Next, the certainty values of the designated rules are calculated in order and a rule with the highest certainty value among them is selected. At this time, certainty value of each rule is calculated by carrying out Min. and Max. operations corresponding to the certainty value of each condition and concatenation words AND and OR.

For instance, suppose that the condition part of (F-RULE n) is

\[ (\text{condition-}n1) \text{ OR (condition-}n2) \]

AND (condition-n3).

If the certainty values of respective conditions are Cn1, Cn2 and Cn3, the certainty value of (F-RULE n) Cn is calculated as expression (8).

\[ Cn = \text{Min} [\text{Max} (Cn1, Cn2), Cn3] \]  

(8)

Thus, once a rule which has the highest certainty value is selected by the rule selector, the rule executor carries out the procedure for execution described in the conclusion part of the selected rule in consecutive order.
tion), which is 0.9 in case of 10th floor. Shown in Fig. 9(b) is the certainty value in terms of the second condition (car concentration), which is 0.8. Fig. 9(c) represents the certainty value in terms of the third condition (the number of free cars), indicating 0.9. From the above results, the certainty value of the whole rule turns out to be 0.8 if calculated by using expressions (7) and (8). If the certainty value of this rule is higher than the other rules, then, according to this rule, car Nos. 1 and 3 are selected as candidates for assignment and car No. 3 which shows the best evaluation value is selected as the final assigned car.

Movement diagrams obtained when passengers B-I are generated at random after car assignment under the conditions of Fig. 7(a) are shown in Fig. 7(b) and (c). Fig. 7(d) and (e) show the waiting time of each one of passengers B-I. As we find from the movement diagrams in Fig. 7(b) and (c), three cars are concentrated in the high-zone after car assignment to the down-hall call on the 10th floor in the conventional method (b) while such situation is not taking place in the new method (c). Furthermore, as we recognize from the waiting time of each passenger shown in Fig. 7(d) and (e), the waiting time of passenger A on the 10th floor is a little longer in the new method (c) in comparison with the conventional method (d). However, the waiting times of other passengers B-I are shorter, and the waiting time of passengers A-I as a whole turns out to be shortened.

Thus, it is recognized that the waiting time can be shortened by making the best use of the experts knowledge involving ambiguous expressions, namely, by making the best use of evaluation of the traffic conditions from this point of time up to the near future (car position, call occurrence, etc.) and the assignment logic which takes such evaluation into account.

Performance Analysis by Group-Supervisory System Simulator

Next we compared the new method consisting of various kinds of rule groups including the above examples with the conventional method through the group-supervisory control simulation in order to quantitatively evaluate improvement in performance of the group-supervisory control by using the method suggested in Chapter IV.

In advance of this, we built a simulator for the group-supervisory control (5) which conducts the entire process from input of rules to verification through simulation on the Engineering Work Station (E.W.S.). Such functions as a function to generate traffic in a building at random based on past data, a function to simulate movement of each car in the same way as actual elevators, a function to simulate the function of the group-supervisory control which carries out register of hall calls, car assignment, etc. and a function to operate and input the results of statistics including the number of hall calls, the waiting times and the prediction errors are implemented on the E.W.S. Furthermore, this simulator has edit functions such as addition, modification and deletion of rules relating to car assignment, etc.

Through this group-supervisory control simulator, we conduct-
ed simulation under diversified conditions. An example of the simulation result is shown in Fig.10. In this example, improvements have been made as follows; the average waiting time was reduced by 15.4%, the rate of long waits (not less than 60 seconds) 36.0%, and the rate of prediction errors 35.5%, compared with the conventional method. However, in the simulation that was carried out after conditions such as the number of cars, that of landing floors and that of passengers were changed, the average waiting time was reduced by 15-20%, the rate of long waits (not less than 60 seconds) 30-40%, and the rate of prediction errors 30-40%.

**Evaluation of Processing Time**

Lastly, in order to verify if the two knowledge-based systems, PREX and FREX, can be applied to the real group-supervisory control system in which online and real-time control is conducted, we manufactured prototypes of PREX and FREX and operated them on a 32-bit micro-computer to measure the processing time. The result is shown in Fig.11, from which we recognize that the required response time 100-150 msec is satisfied on the condition that the number of rules involved in processing is approximately up to 70-100.

As mentioned above, it was found that PREX and FREX are applicable to the real group-supervisory control system if the size of the rule group is limited to the above-mentioned range.

**V. CONCLUSIONS**

In this paper, the new group-supervisory control method which controls selection of cars assigned for hall calls through the rule bases without using a specific evaluation function has been suggested. The idea of this method can be applied to the function to decide the number of cars assigned to a crowded floor, the parking floors where free cars stand by, etc. as well as to the assignment method without the immediate prediction function. Moreover, we suggested the two knowledge-based systems used to implement this group-supervisory control method on micro-computers, namely, PREX and FREX. As a result of examination, we could verify that the application of the expert system to the elevator group-supervisory control system is feasible and that we can expect improvement in performance of the group-supervisory control.

We are currently promoting commercialization of the elevator group-supervisory control system to which the method suggested in this paper is applied. This new group-supervisory control system is scheduled to be operated in multiple buildings in Japan in the first half of 1989. We expect that the same effect will be achieved in the field as well.

The PREX and FREX have the following features;

1) applicable to an online and real-time control system (high-speed processing),
2) able to cope with a rule involving vague expressions (fuzzy rule),
3) operates on a 32-bit micro-computer,
4) can coexist with the conventional types of programs (such as the assembly language, C language, etc.).

There is a possibility that they can be applied to other online and real-time control systems than the elevator group-supervisory control system. We like to deal with applications of the PREX and FREX to other control systems as our future subject.

**REFERENCES**