FUZZY LOGIC-BASED ELEVATOR GROUP CONTROL SYSTEM FOR ENERGY OPTIMIZATION PURPOSE

Joaquín R. FERNÁNDEZ V.
Engineering Organization Group, University of Seville
Seville, Spain

Pablo CORTÉS
Engineering Organization Group, University of Seville
Seville, Spain

And

Pablo APARICIO
Engineering Organization Group, University of Seville
Seville, Spain

ABSTRACT

The High-rise buildings with their consequent considerable number of elevators represent a major logistic problem concerning saving space and time for the sake of an efficient performance due to economic reasons. Complex Elevator Group Control Systems are developed in order to manage properly the lifts. In this context dispatching issue is one of critical importance and every system must accomplish it considering two main aspects: magnitude of calculation (solving time) and managing of uncertainty. In this paper a novel Elevator Group Control System is proposed for dispatching landing calls using Fuzzy Logic so Energy consumption is minimize. Fuzzy Logic can handle sufficiently lack of information and takes just few instants to obtain a solution good enough.

Keywords: Sustainable Development, Logistic, Energy Optimization, Artificial Intelligence, Elevator, Lift, Fuzzy Logic.

1. INTRODUCTION

The Elevator group control systems (EGCS) manage multiple decks in a building in order to efficiently transport passengers. Performance of EGCS is measured through different parameters like average waiting time, percentage of waits longer than 60sec and power consumption [1], [2], [3] and [4].

A snapshot elevator dispatching problem has been shown to be NP-Hard [5]. In fact, in a building with *n* number of lifts where *k* floors demand decks the number of solutions to be considered is n^k so complexity of problem becomes huge in modern skyscrapers and other high-raise buildings in general. In this sense, once certain grade of optimization is reached, it is impossible to satisfy every criteria at the same time so the EGCS is designed to satisfy each one at determined levels depending on tenant´s preferences.

An EGCS mainly consists of hall call buttons situated at every floor, car calls buttons inside each deck and a group controller. In normal system the amount of uncertainty is considerable, as usually neither the quantity of passengers behind a hall call nor the exact destination until they press the car button inside deck is known [6].

Apart from complexity and data shortage the system has also to handle with possible future calls.

The more general problem assumes the following hypothesis in the elevator system performance. Each hall call is attended by only one cabin. The maximum number of passengers being transported in the cabin is bounded by its capacity. The lifts can stop at a floor only if it exists a hall call or a cabin call in that floor. The cabin calls are sequentially served in accordance with the lift trip direction. A lift carrying passengers cannot change the trip direction.

Usually, the controller implements dispatch rules that make use of an IF-ELSE logical commands set. Among these dispatch rules, a simple lift group supervisory control system, suitable for groups of two or three in not very high rise buildings, is simulated in the computer-aided design suite Lift Simulation and Design (LSD), implemented at University of Manchester Institute of Science and Technology (UMIST), under the designation of the THV algorithm. This algorithm collects the most common rules in duplex or triplex algorithms. The THV algorithm assigns the hall call to the nearest lift in the adequate trip direction.

As a result of complexity, modern heuristic has to be employed in order to solve the problem. Reinforcement Learning algorithms [7] have shown an accurate behaviour. It consists of a semi-Markovian process and uses an agent-team where each agent controls one lift. Under these conditions two architectures are used: a parallel architecture where the agents share the network (Parallel Reinforcement Learning, RL_p) and a decentralised architecture where each agent have its own network (Decentralized Reinforcement Learning, RL_d).

Usual artificial intelligence like genetic algorithms [8] or taboo search show acceptable results, but their time expensiveness employed reaching final solution makes them not efficient solutions worthy enough. Other techniques like neural networks need too much training time to work properly, sometimes are difficult to implement and show not desirable results at all when adapting to fast unforeseen variations. Other methodologies like ant colony optimization [9] shows fast performance but tedious implementation. On the other hand fuzzy logic combines both fast performance and cheap implementation.

The elevator system research is quite recent and has followed the technology development. The late eighties and the nineties decade can be considered as the start point of the industrial investigation, especially in USA and Japan [10], [11] and [12]. After that the research experimented the impulse of the largest multinational companies[13], [14], [15] and [16]. By the end of the nineties the research in vertical transportation was a reality and the collaborations among the private companies and the research centres were reinforced, some examples are the Systems Analysis Laboratory in the Helsinki University of Technology with the KONE Corporation [17], the Konrad-Zuse-Zentrum für Informationstechnik of Berlin [18] or the Seville University with MACPUARSA [19].

Actually with the upstarting of sustainable development, energy consumption issue is becoming one of the most import features in technology. Total percentage of electricity bill wasted by the group of elevators in a building goes from 2% to 8% [20], so total amount of power is considerably. However it has not been a common researched issue. [21] Proposed a fuzzy model where diverse criteria are used as the Hall Call Waiting Time for the *i*th-lift ($HCWT_i$), the maximum Hall Call Waiting Time ($maxHCWT_i$), the capacity of coverability for next calls for the *i*th-lift (CV_i), and the minimum distance between new calls and the last calls allocated Gathering Degree (GD_i). [22] Design a combination that integrated bi-objetive genetic algorithm and the control of its performance due to a PI controller, however the design must known before functioning information about its possible waiting time results.

2. ENERGETIC CONSUMPTION IN AN ELEVATOR SYSTEM

Nowadays with the fell into disuse of hydraulic elevator, all the lifts allocated to buildings could be represented as counterweigh plus cabin and ropes system. Normally the design is made for being in equilibrium every time the deck load is equals to half of the maximum load allowed. As shown in following illustration:

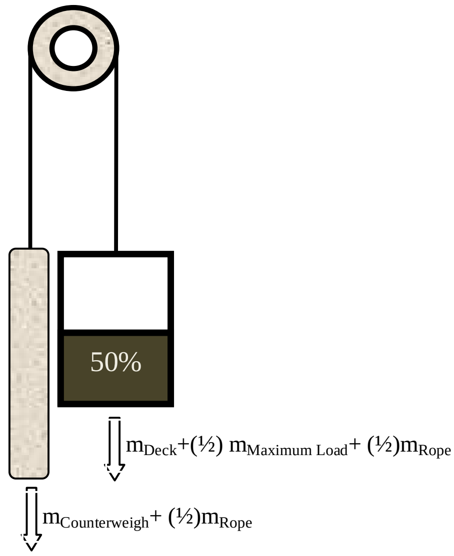

Illustration 1. Balanced elevator system.

When a cabin move towards a height h_2 from a height h_1, his potential energy changes, and as a result so does the whole potential energy of the system:

$$\Delta E = mg\,(h_2-h_1)= mg\Delta h \qquad (1)$$

Where *m* represents the static balance of the system and mass of ropes could be depreciated respect those others elements:

$$m = m_{Deck} + m_{Load} - m_{Counterweigh}=m_{Load} - (½)m_{Maximum\ Load} \qquad (2)$$

From previous descriptions it could be concluded that elevator systems do not employed energy at every movement. In fact, when an elevator move downwards with less load than half the maximum allowed or upwards with more load than half the maximum allowed, the hoisting system wastes energy. But vice versa, every time the deck move downwards with more load than half the maximum allowed or upwards with less load than half the maximum allowed, the hoisting system gain energy.

Actual brake employs resistors that can recuperate the energy gain, however due to mechanical friction reasons not all the energy could be restored. In this scenario, energy system consumption depends strongly on efficient dispatching.

3. ENERGY ASPECTS

From previous section, following deductions are made concerning certain energy aspects:

Useless stop avoidance

Whenever dispatching, it is typical to consider average waiting time of passengers to avoid useless stops in the sense that there is no space available at all for all the passengers behind the landing call so another stop will have to be made in the future to collect passengers lefting, making at the end two stop instead just one. But strictly from a purely energy point of view, two stops instead one could be profitable. It just depends on the snap situation.

Unpredictable future

Without hall call allocation panels situated on every floor, it is impossible to know the destination for each passenger before they enter the cabin. However it is possible to estimate the average people letting the deck at each floor attending to the number of car calls produced and the total weigh inside cabin. Moreover, it is also possible to estimate the average people behind a landing call based on recent history. Employing both methods the EGCS is able to estimate the total amount of passengers along the trip and its consequent energy implications.

Adjoining of landing calls

The proximity between landing calls should be a decisive factor to take into account when dispatching. Adjacent landing calls must be assigned to the same or different deck according to the elevator energy state. For example, a cabin that is moving downwards with a total load inferior to half the maximum load allowed should serve a few landing calls in a row to increment its inside weigh for reducing energy waste or even to start generating energy.

Promote loading passenger depending on deck direction

As an alternative to adjoining landing calls consideration, EGCS could promote or not loading passengers on the same deck for the same reason state previously. However in an attempt to not to do this multi-criteria design redundant, promote loading passenger was not consider in favour of serving adjoining landing calls.

Sectoring techniques

When dispatching for time optimization, it is common in periods such as interfloor or downpeak to distribute the elevators among some areas of the building formed by consecutive floors, looking for minimizing the space a deck hast to move to respond a landing call and therefore reducing waiting time.

On the other hand, when dispatching for energy optimization, such a division has no sense at all because could limit energy blooming, as the longest distance to landing call when lift is generating power the better for the sake of energy efficiency.

Energy Considerations about traffic pattern

Classical theory [6] describes four traffic pattern for a typical day in a worker building according on whether the main flow is ascending, descending, both or none of them.

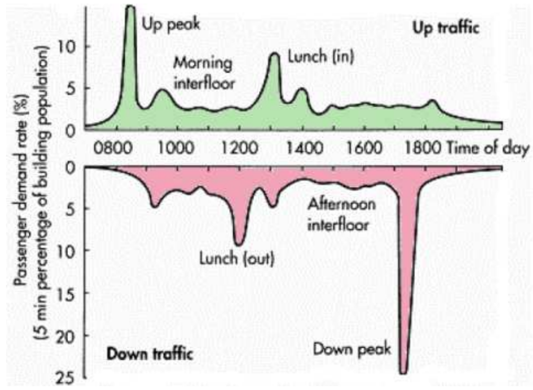

Illustration 2. Traffics patterns occurring along the day in a typical workers building.

As mentioned in the introduction, some intelligent dispatchers make their decision basing on different criteria: average passenger waiting time and the most advanced, energy or percentage of long waits.

Destination or starting floor are usually known in downpeak or uppeak periods respectively, and so occurs in lunchpeak period, (which constitutes a mixture of both) reducing the dispatching options. Besides, the total amount of passengers in these periods is considerable so waiting time is critical. As a consequent of that, it is usually while the interfloor pattern, when the dispatching options are higher and the traffic lighter (so waiting time problem has not the size as in others periods), when the EGCS is able to dispatch landing calls taking the energy issue more into account than other factors.

4. FUZZY LOGIC-BASED ALGORITHM FOR ENERGY CONSUMPTION OPTIMIZATION

Restrictions

The proposed energy dispatching method follows two simple restrictions:

- Collective Rule: Elevators are not allowed to gather passengers that want to travel in the different way the lift is moving due to psychological human constraints.

- A landing call must be always allocated to a lift.

NOTE: A lift is able to have allocated more than one landing call or even none at all.

Working Principle

In a facility with n number of lifts and p number of landing calls, the algorithm evaluates nxp fuzzy procedures so allocates landing calls in an optimized order to the intended best lift among all the possibilities according to three estimated criteria: possible absolute energy, possible relative energy and possible adjacent energy:

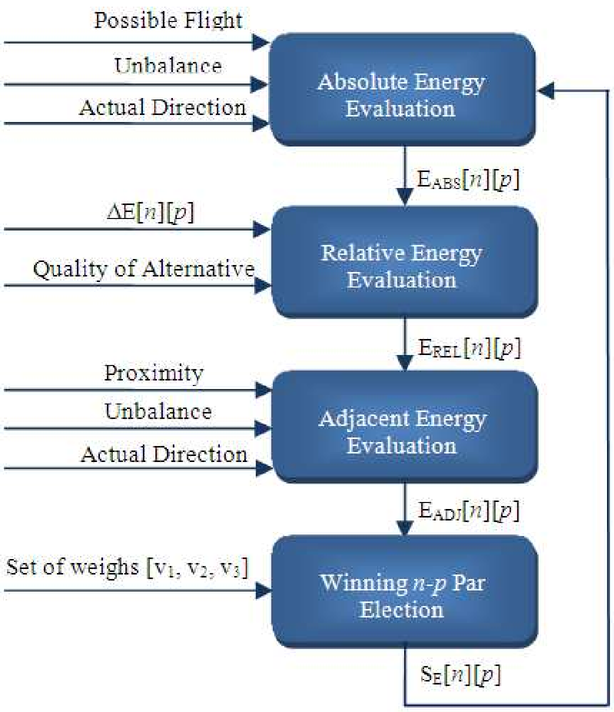

Illustration 3: Flow-chart showing the four basic steps of the saving energy consumption algorithm.

Absolute energy evaluation (E_{ABS}[*n*][*p*]): The absolute energy evaluation estimates the total amount of power wasted by the cabin *n* if it would attend the landing call p. As it is defined depends on:

- The *possible flight* made by the deck.
- The *unbalanced* weigh respect to the equilibrium balance state.
- The *actual direction* of the cabin (which at the same time depends on the car calls and landing calls already assigned to deck).

Absolute evaluation acts as a measure of the objective energy employed in the action without considering the snapshot problem conditions.

Relative energy evaluation (E_{REL}[*n*][*p*]): Relative energy evaluation makes a quality comparison between the total amount of power wasted by the cabin *n* if it would attend the landing call *p* (E_{ABS}[*n*][*p*]) and the energy wasted by the rest of *n-1* deck possibilities for attending the concrete landing call *p*. As it is defined depends on:

- ΔE[n][p]: It measures in number of average deviations the difference between the absolute energy of the *n-p* par decision and the average of the whole set of *n* possibilities for attending landing call *p*:

$$\Delta E[n][p] = \frac{E_{ABS}[n][p] - \bar{E}_{ABS}[n]\left[p_{fixed}\right]}{S[n]\left[p_{fixed}\right]} \tag{3}$$

Where S[n][p_{fixed}] is the average deviation and E_{ABS}[n][p_{fixed}] the energy average consumption for all the possible assignation for a fixed landing call *p*.

- The *quality of the best alternative* to cabin *n* for attending the concrete landing call *p*:

$$Quality\_Best\_Alternative = \frac{E_{ABS}[n]\left[p_{fixed}\right] - E'_{ABS}[n]\left[p_{fixed}\right]}{best\left(E_{ABS}[n]\left[p_{fixed}\right]\right)} \tag{4}$$

Where E'_{ABS}[n][p_{fixed}] is the best alternative to E_{ABS}[n][p_{fixed}] for a fixed landing call p.

Relative evaluation acts as a measure of environmental situation, allowing to establish decisions about the fitness of the *n* possibilities attending a concrete landing call *p*.

Adjacent energy evaluation (E_{ADJ}[*n*][*p*]): The adjacent energy evaluation estimates if a landing call *p* should be served to a cabin *n* accordingly to landing calls already assigned to cabin *n*. As it is defined depends on:

- The *proximity* of the landing call p considered to the nearest landing call already assigned to cabin n.
- The *unbalance* weigh respect to the equilibrium balance state.
- The *actual direction* of the cabin (which at the same time depends on the car calls and landing calls already assigned to deck).

Adjacent estimation contributes whether to assign group of nearby landing calls to the same deck as far as energetic saving was described in previous section 3. This valuation combined with the relative one acts as a measure of the snapshot problem situation.

Final energetic evaluation: Once the three parameters are calculated, the final figure representing the energetic fitness of each possibility is obtained through the set of weighs [v_1, v_2, v_3]:

$$S_E[n][p] = v_1 E_{ABS}[n][p] + v_2 E_{REL}[n][p] + v_3 E_{ADJ}[n][p] \tag{5}$$

FUZZY ENGINE

Each one of the triple energetic evaluation represents a fuzzy procedure (fuzzification, inference and defuzzification).

Input data: Consist of basic information.

- Mass load of each deck (Kg) measured through installed weighs on the deck floor.
- Actual direction of each deck (upward, downwards or stationary).
- Position of every cabin and landing floor (m above reference).

- Registry of the Car calls.

Linguistic variables: As shown in illustration 3 before, not all linguistic variables but some form part of a determined criteria calculus. Although besides, some of them contribute to more than one calculus.

- Possible flight.
- Unbalance.
- ∆E[n][p].
- Quality of the best alternative.
- Proximity.

Fuzzification: Fuzzification of linguistics variables are carried out through typical membership functions.

Fuzzy inference: Each energy evaluation is deduced from de fuzzy variables according to a set of logic rules. As example, next table shows logic rules constituting the deduction about quality of absolute energy for a concrete *n-p* par ($E_{ABS}[n][p]$).

Table1. Logic Rules for absolute energy criteria.

	PF_{VS}		PF_S		PF_A		PF_L		PF_{VL}	
U_E	R_1	↑G / B↓	R_6	↑G / B↓	R_{11}	↑VG / VB↓	R_{16}	↑VG / VB↓	R_{21}	↑VG / VB↓
U_{NE}	R_2	↑A / A↓	R_7	↑G / B↓	R_{12}	↑G / B↓	R_{17}	↑VG / VB↓	R_{22}	↑VG / VB↓
U_{EQ}	R_3	↑G / G↓	R_8	↑G / G↓	R_{13}	↑A / A↓	R_{18}	↑A / A↓	R_{23}	↑B / B↓
U_{NF}	R_4	↑A / A↓	R_9	↑B / G↓	R_{14}	↑B / G↓	R_{19}	↑VB / VG↓	R_{24}	↑VB / VG↓
U_F	R_5	↑B / G↓	R_{10}	↑B / G↓	R_{15}	↑VB / VG↓	R_{20}	↑VB / VG↓	R_{25}	↑VB / VG↓

PF: Possible Flight
U: Unbalance

VG: Very Good
G: Good
A: Average
B: Bad
VB: Very Bad

VL: Very Large
L: Large
A: Average
S: Short
VS: Very Short

E: Empty
NE: Near Empty
EQ: Equilibrium
NF: Near Full
F:Full

Defuzzifcation: Is carried out through sigmoid function to obtain a unique valour between zero and one.

5. RESULTS

Elevator systems are designed mainly according barneys classical theory [6] in the meaning that a system the can handle the logistic transport during uppeak, is also able to transport efficiently passengers during the rest of periods. Overcoat, this gives a large extra handling capacity during interfloor interval, and as shown in previous section, allow the dispatcher to focus exclusively on energy matter. In this aspect the fuzzy based elevator group control design is completely able to dispatch efficiently the landing calls.

Simulation trough ELEVATE software has been carried out. The example building has 15 floors and 6 elevators with a total population of 1200 workers equal distributed along the facility.

Most of actual companies use a dispatch algorithm call "nearest call", which is self-descript, it dispatches the landing call to the near lift following the collective principle. In this sense while during light interfloor traffic (around 2 POP is moving between random floors), the following average results were obtained:

Table3. Simulation result showing the performance of the EFLGCS

	EFLEGCS	NC Alg.	Difference	% Imprve
Power	-226,5 Kw	29,5 Kw	-197 Kw	668%
AWT	18.3 seg	9.2 seg	9.1 seg	-98.9%
ATT	20.8 seg	22 seg	1.2 seg	-5.45%
ATD	39.1 seg	31 seg	8.1 seg	-26,12%

AWT: Average Waiting Time
ATT: Average Transit Time
ATD: Average Time to Destination

EFLEGCS: Energy Elevator Group Control System

NC Alg.: Nearest Call Alg.

The results are conclusive, the total amount of energy wasted in the movement of the elevator can be extremely decreased even producing gaining to the system for a concrete period of time with a slightly cost of total waiting time (ATD). However due to the classical design theories already exposed and the recommendations of CIBSE guide [20] the most important time figure AWT is still more than acceptable, and so are the others time figures.

6. CONCLUSIONS

In this paper a novel Fuzzy Logic Elevator Group Controller has been presented. It has been concluded that its self-sufficiency for working during light and medium traffic periods such as during the interfloor pattern. Through simulation and comparison with a classical dispatcher the energy profit has been numerical calculated: the results show desirable performance, beating broadly the other dispatcher in energy issue and maintaining a more than acceptable mark as far as waiting time is concerned.

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