Timing Considerations and Kinematics Parameters of Elevator Group Control Systems

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ABSTRACT

In this paper we concentrate on some important timing characteristics of Elevator Group Control (**EGC**) systems. The main discussion and calculations should be considered as a further development of Three Passages (**TP**) concept, already presented in our previous papers. To achieve better global performance of **EGC** system, especially to reduce hall call waiting time, calculation methodology of car kinematics is presented. The importance of detailed kinematics considerations is demonstrated with data taken from real high-speed **EGC** system, existent in 63-floor building - Seoul, Korea.

1. INTRODUCTION

In order to satisfy increasing demand of high rise building elevator systems, so called *Elevator Group Control* (**EGC**) algorithms were developed. The aim of **EGC** is to satisfy multiple optimization objectives considering all elevator cars as a unite system. Typically **EGC** elevator systems possess hundreds of Boolean and numerical input variables (button insertions, sensor reactions, car speeds, car directions, acceleration of each car, etc). The implementation of **EGC** is additionally troubled by the multi-objective optimization criteria. Often optimization objectives, such as fastness, energy saving, big handling capacity, safety, flexibility, low cost, etc. are mutually contradicting and require different values of tuning system parameters. Looking for optimal solutions of such criteria, the most difficult problem to solve, is *to assign* proper elevator cars to serve proper hall calls. We name such decision and calculation process a *car-call assignment*. Generally, the right or wrong decisions strongly influence global system performance. Our main concern is to explore which parameters strongly affect the right logical decisions.

Due to properties mentioned above, and due to the random nature of passenger demands, the only practical way to explore to **EGC**'s nature was found to be computer simulation.

Commonly **EGC** control problems and respective *traffic pattern* recondition problems are solved by neural networks, fuzzy logic approaches, combinatorial fuzzy-neural logic solutions, reinforcement learning methods, etc. Typically the methodologies dealing with elevator problems are heuristic.

Although many sophisticated methods were used to design **EGC** systems, usually there is insufficient data in the literature for repeating given simulation. Despite the fact that **EGC** practically is needed in high rise buildings, often given examples are for **EGC** systems having small number of floors (from 12 to 25). Typically designers accept so called *single floor flight time* without specifying the exact meaning of that parameter (A.T.P So et al. 1999), (W.L.Chan et all 1996). There are some researches, where speed areas of the system are mentioned (Barney 1977), and their approach shows **EGC** nature more realistically.

In this paper we step on recently proposed *Three Passages* (**TP**) approach of **EGC** (Y.C.Cho et al. 1999). Referring to proposed concept, all hall calls and car calls are classified in three groups. We explore the hidden difficulties related to that classification. Although we discuss the car kinematics, our concern is different than that presented in (Molz H. 1991). While such researches are concentrated on satisfying criteria about smooth traveling, we concentrate on the impact of velocity-related logical decisions on global system performance.

Our paper is structured as follows. In Section 2, implementation problems of **TP** concept in **EGC** are discussed and the need of kinematics calculation is shown. In Section 3, calculation of speed area table is presented. In Section 4 we employ presented methodology to find speed areas of high rise **EGC** system. We conclude our work in Section 5.

2. THREE PASSAGES CONCEPT AND IMPLEMENTATION CHALLENGES

Recently so called *Three Passages* (**TP**) approach of **EGC** was suggested (Y.C.Cho et al. 1999) and it is currently developed as a robust and universal **EGC** solution. Rather than using artificial intelligence methods, we relay on detailed knowledge of separate system parameters.

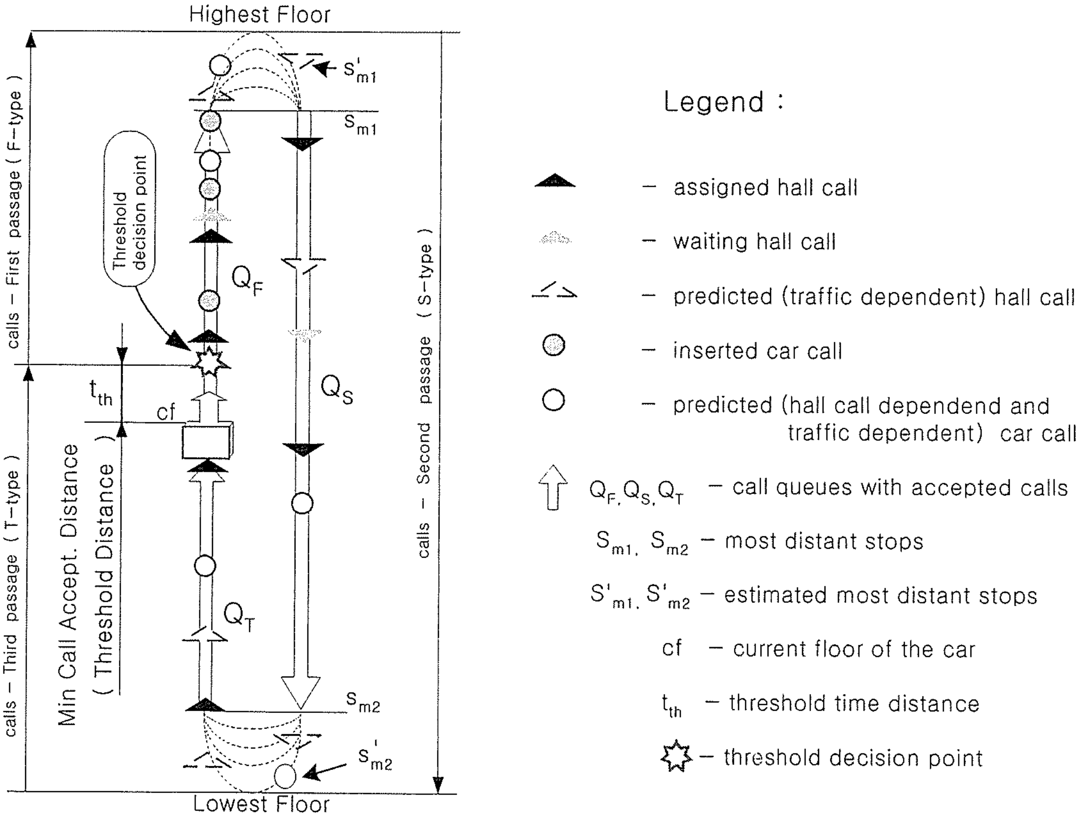


Figure 1. Three Passages Concept - Important parameters

Although that hall calls and car calls are memorized in the controller after entering, it is not clear immediately which set of entered hall calls is going to be served by given car. Latter, following **EGC** assign algorithm, each hall call becomes *assigned* to respective car. As can be seen in the Figure 1., the car calls and assigned hall calls have the same impact on the most distant points of car trajectories ($\mathbf{s}_{m1}, \mathbf{s}_{m2}$). However, there are important differences between car calls and assigned hall calls. Any car call is *accepted* unconditionally whenever it is invoked, while any hall call is *assigned* to particular car after calculation process. Under some conditions, hall calls can be *reassigned*, i.e. *released* and assigned again to different or to the same car. In the contrary, car calls can not be rejected and cannot change the car owner. Referring to the current floor of each car, we classify each hall or car call into three groups. The first group, named **F**-type calls (**F**irst passage calls), are calls supposed to be served without changing car direction, or if the car direction is zero (the car is *idle*). Respectively, calls expected to be served after changing of the direction once, are named **S**-type (**S**econd passage calls). The calls expected to get serving after second changing of car direction, are named **T**-type (**T**hird passage calls) respectively. Described three groups are dynamic and can be changed during any subsequent calculation. We use *time distances* between system cars and entered hall calls to decide which groups of calls and cars are closer among them self's. For the seek of good performance, it is important to predict the time which any car needs on the way travelling before serving any eventual call. As important global criteria, the *hall call waiting time* depends on *traveling related* random parameters, and *serving time related* random parameters. Each car-call time distance is predicted with uncertainty bounded by three types of difficulties (Y.C.Cho et al. 1999):

- trajectory prediction difficulties
- serving time prediction difficulties
- difficulties due to wrong controller decisions.

We stop our attention on very high buildings, where the prediction of the trajectory becomes cumbersome task. Referring to (Toshiaki Ishii 1994), the fastest elevator in the world (in Japan) possesses peak velocity 12.5 m/s, having problems with rope-vibrations, air resistance, cable weight, etc. Obviously in such **EGC** system exact prediction of the speed profile is impossible and uncertainty should be accepted. Our aim is to demonstrate the significance of profile prediction uncertainty.

3. SPEED AREAS AND THRESHOLD PARAMETERS

The purpose of this chapter is to give explicit calculation procedure for obtaining *speed area table* of car kinematics. By "speed area" we mean integer which value is increased/decreased by one, crossing so called *threshold point*. The area is increased when the car is accelerating, and decreasing when decelerating. The minimal area is one, and maximal number of areas depends on car kinematics parameters. The important parameters are given in *Table 1 Speed Area Parameters* as a general reference. They are supposed to be implemented in **EGC** controller. On the contrary to the often-suggested simple concepts with constant parameters, we consider kinematics parameters as **functions** $parameter := \mathrm{Fun}(speed\_area)$. Generated speed table, in this chapter is used for such purpose in **EGC**.

Annotation notes:

We denote non-scalar objects (vectors or matrices) with bold letters, and scalars with small regular letters. In general, we denote vectors with small bold and matrices with big bold ones. Usually we specify the domain of used variable or its dimension only during first its usage. All *timing parameters* are denoted by $\mathbf{t}_{\mathbf{index}}^{\mathbf{domain}}$, or t_{index} and all *displacement parameters* by $\mathbf{d}_{\mathbf{index}}^{\mathbf{domain}}$, d_{index}. We are using $\lceil value \rceil$ to denotes "*closest integer* $\geq$ *value*", and $\mathbf{v}_1 .* \mathbf{v}_1$ to represent *element-by-element* multiplication between non-scalar operands.

Kinematics Calculation Procedure for Obtaining Speed Area Table

We begin our calculations using well-known dependencies of kinematics of a particle eqns(1). The variable v denotes *current velocity* of a single car at given instant of interest. Respectively v_o is the initial velocity. For each separate elevator car we take in consideration its threshold decision points (See Figure.2). All dependencies are seen as relations between threshold points and either initial velocity $v_o = 0$ or final velocity $v_{end} = 0$. Threshold points denote the last decision instant at which given stop (due to car call or hall call) can be considered as a next and feasible. Since our objective is the decision for feasibility or not, without loose of generality, from car acceleration profile we take only points of interest joining them with straight lines. If used profile and timing data are realistic, the achieved results are supposed to be realistic to. In Figure 2 the real shape of car acceleration is shown with dashed lines. It is clear, that besides such profiles there are important calculations. We do not reject the need of profile or jerk calculations, they just are beyond the scope of this paper.

Table 1 Speed Area Parameters

Par.	Units	Meaning
n_a	aresas	- number of speed areas of the car
v_m	$[m/s]$	- contract (maximal) car speed
d_{FF}	$[m]$	- distance from one floor to another
k_1	$[m/s^2]$	- constant car acceleration
k_2	$[m/s^2]$	- constant car deceleration
d_{zVm}	$[m]$	- displacement accelerating from speed *zero* to v_m with k_1
d_{VmZ}	$[m]$	- displacement decelerating from v_m to speed *zero* with k_2
t_{zVm}	$[s]$	- time to accelerate from speed *zero* to v_m
t_{VmZ}	$[s]$	- time to decelerate from v_m to speed *zero*
d_{zLth}	$[m]$	- distance from *zero speed point* to the last threshold point
d_{th}	$[m]$	- distances from *zero speed point* to each threshold point
$\mathbf{v}_{\mathbf{th}}^{1\times \mathbf{n}_a}$	$[m/s]$	- speeds at threshold points
$\mathbf{t}_{\mathbf{th}}^{1\times \mathbf{n}_a}$	$[s]$	- times from *zero speed point* to each threshold point
$\mathbf{t}_{\mathbf{st}}^{1\times \mathbf{n}_a}$	$[s]$	- times from each threshold point to *zero speed point*
$\mathbf{t}_{\mathbf{w}}^{1\times \mathbf{n}_a}$	$[s]$	- time windows from each threshold points to the next one
$\mathbf{t}_{\mathbf{flg}}^{1\times \mathbf{n}_a}$	$[s]$	- flight times prom departure *zero speed point* to the landing floors
$\mathbf{d}_{\mathbf{st}}^{1\times \mathbf{n}_a}$	$[m]$	- stopping distances from each threshold point to *zero*
$\mathbf{f}_{\mathbf{stp}}^{1\times \mathbf{n}_a}$	floors	- floor differences between threshold points and landing floors

We assume that the control of elevator motor is proper. However, it is possible to accept wrong positions of the speed threshold points, due to safety reasons for example. In this way, the decision error whether some call is **F**-type or **T**-type, is going to increase the value of average hall call waiting time.

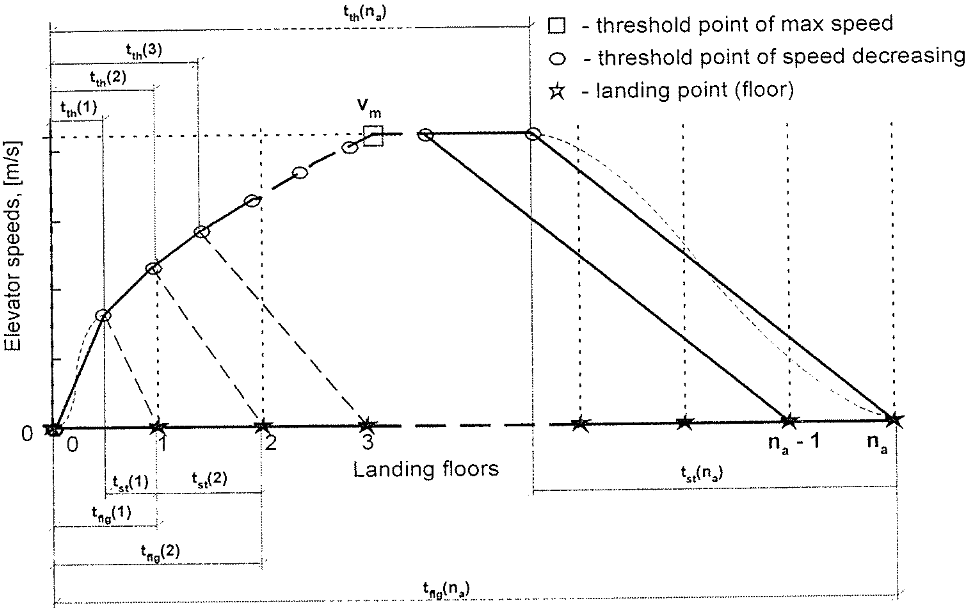


Figure 2 Illustration of Speed Area Timing Parameters

$$
\begin{aligned}
v &= v_0 + kt = kt \\
v^2 &= v_0{}^2 + 2kd = 2kd \\
d &= v_0 t + \frac{1}{2}kt^2 = \frac{1}{2}kt^2 \\
d &= \frac{1}{2}(v_0 + v)t = \frac{1}{2}vt
\end{aligned}
\tag{1}
$$

Firstly we calculate the times and displacements needed to either reach maximal speed and to decelerate from maximal speed to speed *zero*.

$$
\begin{aligned}
t_{zVm} &= \frac{v_m}{k_1}, \quad d_{zVm} = \frac{1}{2}v_m t_{zVm} \\
t_{VmZ} &= \frac{v_m}{k_2}, \quad d_{VmZ} = \frac{1}{2}v_m t_{VmZ}
\end{aligned}
\tag{2}
$$

Knowing the distance floor-to-floor, we can obtain the maximal number of floors needed to fully accelerate and decelerate.

$$
n_a = \left\lceil \frac{d_{zVm} + d_{VmZ}}{d_{FF}} \right\rceil + 1 \tag{3}
$$

Using the dependencies from eqns(1), by simple manipulation we obtain the threshold times at which decisions should be taken. Usually this important set of parameters is not shown explicitly in the literature. Practically, only at that instants, the decision to stop or not is taken. Estimating correctly that parameter can be useful in two ways. One, when real control is performed, to predict the time duration when the processor is free for other activities. Or in other, when simulating, to implement *event driven* simulation instead of *time driven* one.

$$\mathbf{t}_{\mathrm{th}}{}^{1\times(\mathrm{n_a}-2)} = \sqrt{\frac{2d_{FF}\,[1,2,\cdots,(\mathrm{n_a}-2)]}{k_1\left(1+\dfrac{k_1}{k_2}\right)}} \tag{4}$$

The speed at first instant of consideration is *zero*, as well as at last should be v_m:

$$\mathbf{v}_{\mathrm{th}}{}^{1\times\mathrm{n_a}} = [0 \;\vdots\; k_1\mathbf{t}_{\mathrm{th}} \;\vdots\; v_m] \tag{6}$$

The distance to last threshold point guarantees reaching of maximal speed.

$$d_{zLth} = n_a\, d_{FF} - d_{VmZ} \tag{7}$$

Once again, using the dependencies from eqns(1), the displacements to threshold points are achieved and the time for last two speed areas is calculated.

$$\mathbf{d}_{\mathrm{th}}{}^{1\times\mathrm{n_a}} := \left[\frac{1}{2}k_1\mathbf{t}_{\mathrm{th}}{}^2 \;\vdots\; d_{zLth} \;\vdots\; d_{zLth}+d_{FF}\right] \tag{7}$$

$$\begin{aligned} t_{tmp} &= t_{zVm} + \frac{(d_{zLth}-d_{zVm})}{v_m} \\ \mathbf{t}_{\mathrm{th}}{}^{1\times\mathrm{n_a}} &:= \left[\mathbf{t}_{\mathrm{th}} \;\vdots\; t_{tmp} \;\vdots\; t_{tmp}+\frac{d_{FF}}{v_m}\right] \end{aligned} \tag{8}$$

To calculate the stopping times and displacements, all non-zero threshold speeds are needed.

$$\begin{aligned} &\mathbf{v}_{\mathrm{tmp}} := [\mathbf{v}_{\mathrm{th}}(2), \mathbf{v}_{\mathrm{th}}(3), \cdots, \mathbf{v}_{\mathrm{th}}(n_a) \;\vdots\; v_m] \\ &\mathbf{t}_{\mathrm{st}}{}^{1\times\mathrm{n_a}} = \frac{\mathbf{v}_{\mathrm{tmp}}}{k_2}, \qquad \mathbf{d}_{\mathrm{st}}{}^{1\times\mathrm{n_a}} = \frac{1}{2}\mathbf{v}_{\mathrm{tmp}} \,.\!*\, \mathbf{t}_{\mathrm{st}} \end{aligned} \tag{9}$$

Finally, we obtain the value of flight times floor-to-floor, and we calculate the values of time jumping $\mathbf{f}_{\mathrm{w}}$ among all threshold points.

$$\mathbf{t}_{\mathrm{flg}}{}^{1\times\mathrm{n_a}} = \mathbf{t}_{\mathrm{th}} + \mathbf{t}_{\mathrm{st}} \tag{10}$$

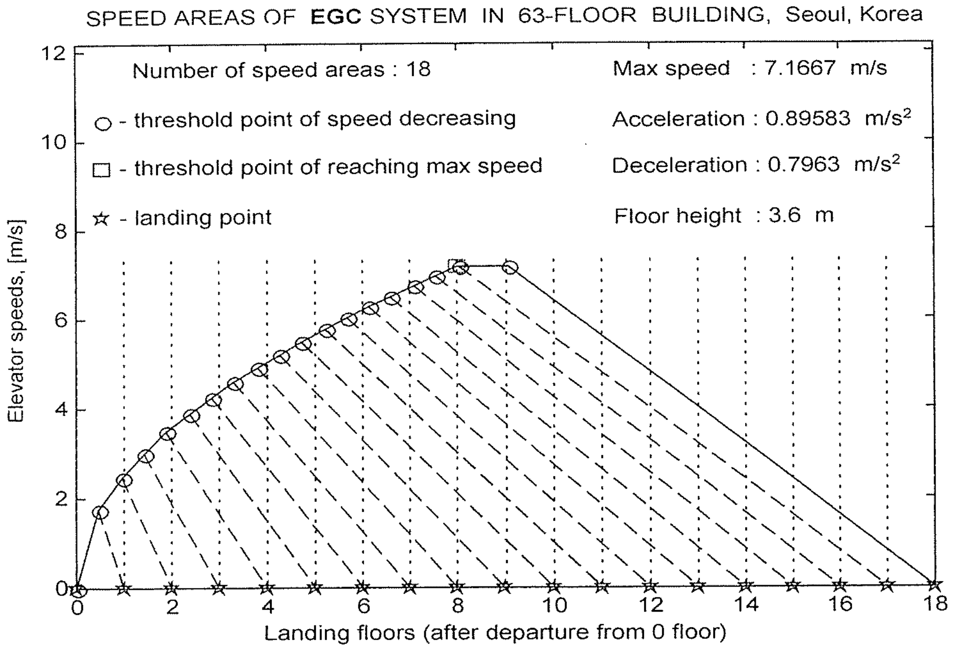
$$\mathbf{t}_{\mathrm{w}}{}^{1\times\mathrm{n_a}} := \mathbf{t}_{\mathrm{th}} - [\;0 \;\vdots\; \mathbf{t}_{\mathrm{th}}(2), \mathbf{t}_{\mathrm{th}}(3), \cdots, \mathbf{t}_{\mathrm{th}}(n_a-1)\;] \tag{11}$$

The list with floor differences $\mathbf{f}_{\mathrm{stp}}$ is needed to decide which of following calls can be accepted as a *next demanding stop* at every threshold instant.

$$\mathbf{f}_{\mathrm{stp}}{}^{1\times\mathrm{n_a}} = \frac{\mathbf{d}_{\mathrm{st}}}{d_{FF}} \tag{12}$$

Additionally, eqn(11) checks the correctness of calculations above. If the calculations were correct $\mathbf{f}_{stp}$ should contain only integers.

4. EXPERIMENT WITH PRESENTED METHODOLOGY



5. CONCULSION

In this paper we have discussed some important timing characteristics of Elevator Group Control (**EGC**). The main issue was to demonstrate the importance of detailed kinematics modeling of elevator car, due to the need to take right control car-call assign decisions. This research step enriches the background of Three Passages Concept (**TP**) presented before.

The calculation methodology of speed kinematics was presented and calculation results were illustrated graphically. It became clear that detailed consideration of speed and acceleration/deceleration profiles and parameters is unavoidable during design of **EGC** for very high rise buildings. The data demonstrated was taken from high-speed elevator in 63-floors building in Seoul, Korea.

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