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Concept design and derivation of the round trip time for a general two-dimensional elevator traffic system

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ABSTRACT

A two dimensional elevator traffic system that moves on the façade of large buildings is presented in this paper. The building is assumed to have N floors and M rooms on every floor (effectively M vertical shafts), leading to $N \cdot M$ rooms in total. The elevator cars can move freely both horizontally and vertically.

In each trip, the elevator car only picks up passengers heading to two of the M vertical shafts, denoted as shafts a and b. Such an arrangement provides three advantages: it reduces the number of stops in a round trip thus reducing the value of the round trip time (increasing the handling capacity); the number of turn-round operations between horizontal and vertical directions are limited to four operations in each round trip (thus saving a lot of time); and it reduces the probability of conflicts between the different cars in the group.

The paper discusses the use of a double skin façade as a network of shafts for the two-dimensional elevator system. A detailed set of formulae is then derived for the round trip time and its components. This is followed by a verification example for a large building, whereby the round trip time is evaluated using the derived equations and verified against the values obtained using the Monte Carlo simulation method.

The methodology presented could be used in order to size a generic two-dimensional elevator traffic system to meet higher user requirements for the future.

1. Introduction

A set of previous publications presented the concept of a two-dimensional elevator traffic system [1–3]. They presented a simplified arrangement that comprised a rectangular two-dimensional arrangement. The arrangement assumed rope-less self-propelled elevator cars using linear motor permanent magnet technology [4–9].

Conventionally, there is one elevator car moving within each hoistway, which is inefficient from a transportation traffic point of view, as easily indicated by a railway system. On a rail, there are multiple trains moving on different sections of the rail. The idea of having more cars to serve one hoistway is not new. By using more cars. The handling capacity of one hoistway could be increased as more passengers can be handled at the same time but the motion control tends to be more complicated. Although a double-decker elevator can be considered as a form of a two-car system, it is merely doubling the size of one elevator car as both cars always need to move together at the same time, one on top of the other. The disadvantage is that the average travel time of passengers is increased because passengers need to wait for a while during a stop initiated by passengers not in the same deck. In order to tackle such a problem, previous research employed artificial intelligence in order to optimize the waiting time and travel time [10–12]. The first system with two independent cars in one hoistway was actually implemented by ThyssenKrupp in 2002, called the TWIN™, and the detailed control system was studied in [13–15]. Up to that point, all developments focused solely on the vertical movement of the elevator cars. The concept of sideways movement of elevator cars was first proposed by Otis in 1996, in a system called Odyssey™ [16]. Recently, several configurations of multi-car systems involving both horizontal and vertical movement of elevator cars were proposed [17] in which two types were mentioned, namely the circulation or loop typed and the non-circulation typed. The loop typed resembles what ThyssenKrupp announced in 2014, the MULTI™ system. The authors of this article started to study 2-dimensional elevator system in 2009 [3] where elevator cars are free to move in the vertical and horizontal hoistways.

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In conventional elevator traffic systems, the kinematics and the traffic analysis are addressed separately. However, in two dimensional traffic systems (as well as the TWIN™ systems that employ two elevator cars running in the same hoistway), these two items become inextricably linked. This close relationship between the kinematics and the traffic design of two dimensional systems is contained in [18].

This paper further develops the concept of two dimensional elevator systems by assuming that the elevator cars move on the external façade of the building, both horizontally and vertically (in a manner similar to the one in which the rook piece moves on a chessboard). Under such an arrangement, the external windows on the façade serve two purposes, where they provide the means for the external view and act as landing doors. Once a passenger disembarks from the elevator car, he/she can go directly into the destination room. Alternatively the elevator car can deliver the passengers to the corridor just outside each room.

The elevator cars can thus freely move both horizontally and vertically in response to the overall elevator group controller's commands. However, the elevator cars require time in order to change direction, referred to as a *turn-round* time in the authors' research. This is very similar to trains moving on railways, when they have to change from one rail road to another. This time delay will affect the overall journey time, and it is preferable to minimize the number of turn-rounds in each round trip.

So, although it is possible in theory to make the elevator car move in zig-zag *steps* along the façade of the building, this is not preferred due to loss of time during the turn-rounds and increased congestion within the paths (i.e., higher risk of conflict between the different elevator cars).

Section 2 will describe the components of the round trip that the elevator will follow in detail. Section 3 discusses the rationale for using the façade of the building as the two-dimensional shaft for the two-dimensional elevator system. The use of the double skin façade (DSF) is discussed in detail in Section 4, outlining its additional critical role in the heating and ventilation of the building. Section 5 outlines the operation of the drive system that propels the elevator cars. In preparation for the derivation of the formula for the round trip time, Section 6 defines the parameters of the traffic analysis of the elevator system. The core of the paper lies in Section 7, in which the formula for the round trip time is derived together with formulae for its components. A number of verification practical examples are presented in Section 8, where the value of the round trip time for the building is compared using calculation and the Monte Carlo simulation method (similar to the process used in [19,20]). Section 9 presents the results of comparing the time to destination under the conventional system compared to the two-dimensional system. Three closing notes are presented in Section 10. Conclusions are drawn in Section 11.

2. Description of the round trip

During the up-peak period, the elevator car is only allowed to dispatch passengers to two vertical hoist-ways denoted as the *a*th vertical hoist-way and the *b*th vertical hoist-way (as shown in Fig. 3). The elevator car will only dispatch passengers to one or more rooms along the *a*th hoist-way, from the ground floor to R_{1a}, R_{2a}, …., at most up to R_{Na} and move horizontally to the *b*th hoist-way and then descend to dispatch passenger at one or more rooms from at most R_{Nb}, $R_{(N-1)b}$, …. R_{1b} down to the ground floor and then back to the main terminal. A typical round trip is described in detail below.

1. Without loss of generality, the elevator car will travel from the main terminal (where passengers board) to the starting base.
2. Following a turn-round procedure, it will then travel along the ground level horizontal shaft (or ground floor) from the starting base to the bottom of the 1st hoist-way (denoted as the *a*th vertical hoist-way).
3. Following a turn-round procedure, the elevator car will travel vertically in the *a*th vertical hoist-way, stopping along the shaft to deliver passengers destined for rooms in the vertical hoist-way.
4. Once all the passengers destined to the *a*th vertical hoist-way have been delivered, the elevator car makes a vertical adjustment journey within the *a*th vertical hoist-way in order to align itself with the highest call registered in the *b*th vertical hoist-way (without opening its doors when it stops).
5. A turn-round procedure will follow and then the elevator car will travel horizontally from the a^{th} vertical hoist-way to the *b*th vertical hoist-way, opening its doors when stopping to allow the passenger(s) heading to this room in the *b*th vertical hoist-way to disembark.
6. A turn-round procedure will follow (although it will not lead to time delay as it can be carried out during the time required for the elevator doors to open, the passenger(s) to disembark and the elevators door to close).
7. The elevator car will then travel downwards in the b^{th} vertical hoist-way and deliver the passengers destined to the rooms in the *b*th vertical hoist-way on the way, until it comes to stop at the ground level (level 0). It is assumed that the ground floor is not occupied by any tenants.
8. A turn-round procedure will follow to prepare for the horizontal journey back to the main entrance or terminal.
9. The elevator will then travel back horizontally to the starting

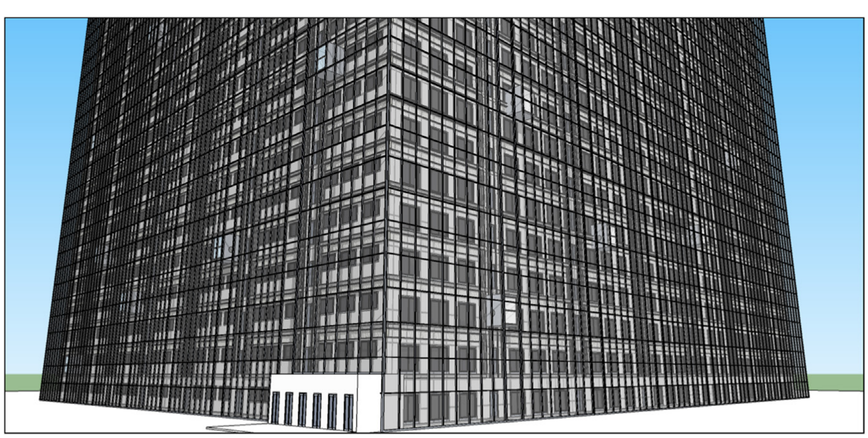

Fig. 1. General overview of the steel framework installed on the building façade (the white block shows the main terminal where passengers board the cars).