Intellevator: An Intelligent Elevator System Proactive in Traffic Control for Time-Efficiency Improvement

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ABSTRACT Elevator functioning as a vertical transport facility remains stand-alone and incapable of accessing the fine-grained traffic information. It significantly restricts the flexibility and efficiency of vertical transporting. In particular, while in peak-time, the limited elevator physical capacity with the momentary traffic increment gives rise to the vertical traffic bottleneck problem in large-scale buildings. The problem further results in the long waiting, dissatisfaction, frustration of passengers. In this paper, we present our proposal named Intellevator: an intelligent elevator system that enables the passively functioning elevator system be proactive and intelligent in traffic control for optimizing the transport efficiency. The proposal is an end-to-end architecture that composed of three aspects: Internet of things (IoT)-enabling technology on a conventional elevator; an agent server to enhance elevator computational capability and a novel user interface for delivering system intelligence to end-users. The proposal was experimented on a conventional elevator in a built smart-building environment. Numerical simulation results have demonstrated the system efficiency improvement. In addition, the system usability and user experience have been evaluated by a user study as well.

INDEX TERMS Elevator, Internet of Things, traffic control, adaptive computing, user interface.

I. INTRODUCTION
Elevator, functioning as a vertical transporting device, remains stand-alone from the communication infrastructure in the building and is required to be more easily accessible [1]. According to Smarter Buildings Study [2], the investigation of 6,486 office workers in 16 U.S. cities revealed that the total amount of over 92 years was wasted on waiting for elevators in 2009. Similarly, Future Design [3] revealed that nearly 80 percentage of subjects (totally 1030) have indicated that the waiting time of elevators is excessively long and need to be shortened.

In particular, while under the peak time, the momentary increment of traffic load always rises the vertical traffic congestion problem. Whereas, the internal optimization on the controller has been making the limited efficiency improvement. On the other hand, Multi-car elevator (MCE) systems also have been deployed in the large-scale commercial buildings. A few of them were set as: several cabins go to the odd-numbered floors, and the others go to the even-numbered floors; or a part of the cabins go to the lower floors and the others go to the higher ones for solving the traffic bottleneck congestion problem. However, while under the peak-time, quite a few of passengers prefer taking a ride on the elevator cabin which just arrived and they relatively careless about whether their destinations are directly reachable or not. Because compared to the long waiting time with too much uncertainty, the time and effort for climbing one or two floors are negligible.

At the same time, Internet of Things (IoT) [4] and Artificial Intelligence (AI) [5] techniques have brought a promising paradigm. With the rapid development of IoT, plenty of devices inside buildings, such as the heating, ventilating and air-conditioning (HVAC) system and light have become accessible through the wireless network. It facilitates the building to integrate the heterogeneous devices and further utilize artificial intelligence to acquire deep knowledge of the monitored environment, finally to deliver the autonomous and intelligence to end-users, that could increase users’ time efficiency, productivity and ease their daily life.

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Consequently, a more rational and intelligent elevator system could be taken into account. This paper presents our proposal of an intelligent elevator system - Intellevator for improving the intelligence and the time-efficiency by proactive traffic control. As illustrated in Fig 1, the proposal is composed by three components: (1). IoT-enabling hardware development for empowering the conventional elevator; (2). an agent server for improving the computational capability of elevator, that enables the traffic flow to be fine-grained tracked, predicted and dynamically controlled for optimizing the time-efficiency; (3). a novel user interface that was designed to receive the fine-grained traffic information, as well as to present the system intelligence to passengers. Each of them is indispensable, essential for making the proposal to be applicable.

Unlike numerous previous studies that formulated the elevator problem as a controller-centric algorithm problem, this proposal-Intellevator is practicable and has been experimented on a conventional elevator. The efficiency improvement of Intellevator has been quantitatively validated by simulations. Additionally, a user study with 22 participants attended was conducted for assessing the system usability, user experience, and so on. The results showed that Intellevator achieved positive system usability and user experience. Hence, the primary contributions and novelties of this work can be summarized as follows:

- A practical hardware development for empowering the conventional elevator to be IoT-enable has been introduced.
- A proposal which reinforces a traditional elevator system to be proactive and intelligent in dynamical traffic control for the time efficiency improvement has been proposed.
- To the best of our knowledge (so far), our proposal of Intellevator is the first to enable a conventional elevator system to be proactive in traffic control via managing the user interface in real-time while suffered the peak-pattern congestion bottleneck. As a result, Intelllevator is capable to be proactive in traffic management and finally optimize the time-efficiency of transporting. For which, this sort of research viewpoint, approach and experiment have been lacked for long a while.

Regarding the user acceptance of Intellevator, we collected a few of valuable feedbacks via the user study that could be the references for further improvement on elevator system development.

II. PROBLEM DEFINITION

A. ELEVATOR LACKS THE CAPABILITY OF ACCESSING THE FINE-GRAINED TRAFFIC INFORMATION

Generally, a conventional elevator control system consists of directional landing-call buttons that are situated at each floor, and destination call buttons inside the cabin and a controller [1]. As illustrated in Fig 2, when a passenger wants to use the elevator, he/she should first initiate the directional-landing call (upward or downward) to notify his/her vertical moving direction and then keep waiting. After elevator arrived, the passenger takes a ride on the elevator cabin and presses the floor button to further notify the elevator his/her destination.

This situation rises the problem that the quantity of passengers waiting outside the elevator and the information of their exact destinations is unknown for elevator system at the moment when passenger initiated the directional-landing request. As a result, the fundamental problem that the fine-grained traffic OD (origin and destination of each passenger) information is inaccessible for elevator system remains.

B. LONG WAITING TIME WITH TOO MUCH UNCERTAINTY FOR PASSENGERS

On the other hand, for passengers, the long-waiting time with too much uncertainty of elevator’s moving also results in the negative user experience on their elevator using. Additionally, both the low transport efficiency and negative passenger experience are inseparably associated with the architecture of elevator system. The incoherent and insufficient traffic information being accessed which was caused by the existing elevator system architecture with the traditional user interface, has greatly restricted the efficiency and intelligence of vertical transporting.
III. RELATED WORK

Elevator control and management have become a major application field for utilizing artificial intelligence approaches [6]. A variety of prior studies have been conducted to enhance the efficiency of elevator, by optimizing multiple relevant criterias, e.g., the average time a passenger waits (AWT), the average time passenger takes ride on the cabin (ATT), the percentage of long waiting time of calls (LWT%), energy consumption, and so on.

These works have primarily contributed in two aspects: mathematical optimization of elevator’s controller [7], [8], and data-sensing to minimize uncertainty for scheduling [9], [10]. A few of proposals which focused on algorithm-based optimization, such as fuzzy logic [11], [12], genetic algorithm [13]–[15], reinforcement learning [17], neural networks [16], and hybrid methods [18]–[20] have been introduced. However, these previous works primarily concentrated on the internal optimization of elevator controllers and ended up with simulations. The absence of real experiments makes them lack the evidence of practicality and compatibility for the deployment in real situation.

Meanwhile, a few of studies have been carried out to access more data of passenger side by applying sensor technologies. Dedicated external hardware development has enabled the function of the destination floor being pre-input. For instance, elevator systems where the destination floor could be pre-input by deploying the equipment of an additional button panel outside the elevator have been proposed by [19], [22], [23]. Kwon et al. [10] utilized three types of sensors: RFID, camera and floor sensors to detect passengers at the specific places. If potential passenger was detected in the places, then a reservation call would be automatically generated on the elevator for reducing the passengers’ waiting time. Hangli et al. presented an approach that enabled passengers to register the elevator landing-call remotely based on the location-aware platform in smart building for reducing the passengers’ waiting time [21]. Suzuki et al. proposed that the optimally assigned elevator cabin number could be presented at the ID-card authorized gate for optimizing passengers’ waiting time of elevator [24].

To summarize, the development of single aspect of sensing technologies, hardware updates, complex algorithms as such related works proposed, is not sufficient in efficiency and intelligence improvement of elevator systems. Owing to Internet of Things (IoT) and Artificial Intelligence (AI) technology, tracking on the fine-grained traffic and being dynamically self-adaptive in optimization of traffic control are considered to be rational and expectedly desirable. However, as a facility offers user-oriented service, deciding how to design the user interface, whether the user needed the content, or whether the decision provided was reliable and assistive or not, then following an user-centered improvement process are quite crucial for ensuring the better user experience on the elevator using. Nevertheless, the research conducted from these research views has lacked for a long time.

IV. PROPOSAL–INTELLEVATOR

We propose Intellevator that based on IoT-enabling development, agent server as well as a new user interface design, for optimizing the transporting efficiency by fine-grained tracking and proactively controlling on the traffic. In addition, Intellevator was also proposed to further improve the system usability and user experience of passengers.

As illustrated in Fig. 3, only the destination input was required and it could be pre-input before the passenger taking a ride on the elevator cabin. Meanwhile, if the elevator was in the proactive mode for traffic control, other advice might be provided on the interface for the passengers. The key challenge of Intellevator might be broken down into the sub-components listed as follows:

A. IOT-ENABLELING DEVELOPMENT ON A CONVENTIONAL ELEVATOR

Essentially, IoT-enabling development lays the foundation for enabling elevator system to context-aware in the external environment. Generally, a conventional elevator controller which was shown in Fig 4 (A), consists of input from the landing-call buttons and destination call buttons; further, the position monitor for capturing the output of elevator status, i.e., the current position or the moving direction [25].

IoT-enabling development for a conventional elevator was proposed as illustrated in Fig 4 (B). We utilized a signal input device to generate the signals which from the landing-call button; a signal output device to capture the signals which presenting the current position of the elevator. The input and output signals are processed on an external CPU (central processing unit). Application programming interface (API) was designed on the agent server for the other devices to communicate with the elevator through the local area network.

B. USER INTERFACE DESIGN

Leveraging on the IoT-enabled development and the designed user interface enables the elevator system and its approaching traffic flow could be associated and fine-grained tracked in real-time. Fundamentally, it further enables the new user interface be developed, which not only satisfies the basic functionality of receiving the transport requests from
passengers, but also designed to be dynamically-changing and self-adaptive for efficiency optimization. The detail advantages of the new user interface are listed as follows:

Providing more referable information. The user interface dynamically visualizes the overall contents of elevator moving, including the waiting time for elevator arrival, the elevator’s moving direction and position, etc.

Tracking on the fine-grained traffic. The user interface enables that only the destination was required to be pre-input prior to passengers’ riding on the elevator cabin. It makes the traffic flow be fine-grained (origin floor and destination floor of each passenger) tracked for further transport efficiency optimization.

Making proactive control on the traffic. Tracking and predicting on the fine-grained traffic make it possible for Intellevator to further proactive-control on the traffic flow for efficiency enhancement. Accordingly, the user interfaces on some targeted floors would be managed to be unusable under its self-adaption for solving the bottleneck congestion. Instead, the advice of taking a ride at the neighbour floor with showing the merit of reduced waiting time and travel time would be presented.

C. AGENT SERVER FOR DATA-DRIVEN ADAPTION

Hence, a data-driven adaptive computing mechanism was executed on the agent server, in which a peak-pattern detector for detecting peak pattern, a traffic data store for predicting traffic flow and a Markov Decision Processor (MDP) for dynamically decision-making were proposed. Fig 5 describes the overall architecture of how the traffic being tracked and computed depending on the actual situations.

1) TRAFFIC DATA STORE

The traffic data store monitors the fine-grained traffic information from all the floors in real-time. As Fig 6 shows, the traffic \( (T_{od}) \) was structured as a m-by-m 2 dimensional matrix in which: \( t_{od} \) is treated as the traffic specified by the origin \( (o) \) and destination \( (d) \). In addition, the elements where \( d > o \) represent the upward traffic. Conversely, the elements in which \( d < o \) represent the downward traffic. This data structure enables the traffic being fine-grained monitored and computed for further optimization.

Thus, based on the above data structure, the dynamic traffic flow at i-th floor in a certain duration also was fine-grained structured by the vectors: \( \lambda_i = (\lambda_{ien}, \lambda_{iex}) \), where \( \lambda_{ien} \) was noted as the traffic arrival rate for entering the floor, formulated in the equation 1; \( \lambda_{iex} \) was noted as the traffic arrival rate for existing the floor, which is formulated in the equation 2.

\[
\lambda_{ien} = \frac{\sum_{d=0}^{m} t_{ld}}{\sum_{o=0}^{m} \sum_{d=0}^{m} t_{od}} \quad (1)
\]

\[
\lambda_{iex} = \frac{\sum_{o=0}^{m} t_{oi}}{\sum_{o=0}^{m} \sum_{d=0}^{m} t_{od}} \quad (2)
\]

2) PEAK-PATTERN DETECTOR

The peak-pattern detector was designed for detecting the real-time traffic pattern based on the fine-grained monitored arrival rate \( (\lambda_f) \) of the lobby floor \( (f_L) \), where \( 0 < L < m \). The patterns were defined depending on whether the main flow significantly descends toward the lobby floor (down peak), or ascends from the lobby floor (up peak). The following formulations describe the detail: known the threshold value of the traffic arrival rate \( (A') \), comparing the real-time monitored overall arrival rate \( (A) \) at the lobby floor, to determine the peak pattern. The traffic pattern definition could be
formulated as the equation 3 shows:

\[ TP = \begin{cases} 
\text{UpPeak} & \lambda_{\text{en}} > \Lambda' \\
\text{DownPeak} & \lambda_{\text{ex}} > \Lambda'' 
\end{cases} \quad (3) \]

By doing so, the peak-pattern was detected if the elevators were switching to or from the same floor (UpPeak or DownPeak), which means they were switching to a floor that was more congested. If the peak-pattern was not detected, the agent server would switch the elevator server to be proactive in traffic control by taking actions on the user interface for improving the overall time efficiency.

3) MARKOV DECISION PROCESS

Markov Decision Process (MDP) was utilized for modeling the decision-making in situations where the agent needs to make proactive control by computing on the traffic input and executing actions sequentially. In this proposal, the MDP consists of the 3-tuple \((S, A, R_a)\).

a: STATE

The state \( s_i = 0 \cup 1 \), describes the status of the user interface at the floor, where they were noted as: 1 means the user interface is normally open for passengers to make request of going up or down. 0 means the user interface is closed in a time phase for optimizing on the traffic flow control, with the advice being presented.

b: ACTION

The action \( a \in 0 \cup 1 \) were defined as the equation follows:

\[ a_i = \begin{cases} 
1 & \text{if } f_i = f_{\text{target}} \\
0 & \text{otherwise} 
\end{cases} \quad (4) \]

where \( a_i = 1 \) means to switch the current state \((s)\) to be closed if the floor was targeted; \(0\): keep the current state as normally open.

c: REWARD AND FORMULATION

The reward function \((R_a)\) determines the reward value after executing action \(a\) to switch the state on the interface at the i-th floor. To simplify the policy of decision-making, two parameters were used as constraints: \(\Delta t\): each decision corresponds to the time interval \((\Delta t)\). Accordingly, the time interval of decision-making was structured as \((\ldots, (k-1)\Delta t, k\Delta t, \ldots)\); \(\Delta f\): the floor numbers for grouping. Thus, the floors of building was split into: \((0, \Delta f], (\Delta f, 2\Delta f], \ldots\) for managing the traffic flow within sub floor-groups.

Fig 7 shows the details of Markov Decision Process applied in this proposal. As formulated in the equation 5, the core process for optimization in performing state-action-reward \((R_i)\) calculation is determining whether the i-th floor \((f_i)\) to be targeted \((f_{\text{target}})\) or not is depending on the approaching traffic flow \((F(\lambda_i))\) would be the maximum or not within the floor window \((\Delta f)\) and the time interval \((\Delta t)\).

\[
\arg \max \int_{f_i}^{f_i + \Delta f} R_i = \arg \max \int_{f_i}^{f_i + \Delta f} PC_i \\
= \arg \max \int_{t_0}^{t_0 + \Delta t} \int_{f_i}^{f_i + \Delta f} F(\lambda_i)d\Delta t \quad (5)
\]

V. EXPERIMENT

Intellover was experimented on a real elevator system in our research building, which consists of five floors, including B2F, B1F, 1F, 2F, 3F. The building was constructed as a smart environment in that devices such as light, and the HVAC system inside could be accessed by the wireless network. The elevator system inside is conventional with the parameters shown in Table 1. It was produced by HITACHI Co., Ltd. As the heights of the floors is 5 m and the elevator moves by the uniform speed of 60 m/min, the elevator’s moving time between two floors was fixed to a constant value of 5 seconds.

| Parameter      | Value         |
|----------------|---------------|
| Series Number  | P-11-C060     |
| Capacity       | 11            |
| Weight         | 750           |
| Width of Door  | 140 × 135     |
| Motor Power    | 4.6           |
| Uniform Speed  | 60            |

As shown in Fig 8 (a), the external CPU was operated on the T-Engine Reference Board, i.e., the U00B0021-02-CPU board.\(^1\) The SN-4008-STT input terminal block\(^2\) and SN-4016-RT output terminal block\(^3\) for making the input to or output from the elevator controller, respectively. The SN-4008-STT was used for capturing the signals showing elevator’s position. The SN-4016-RT was used for submitting the signals to elevator’s controller which representing the ones from the directional buttons. The output and input signals connected to these two terminal blocks are listed in Table 2.

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\(^1\)T-Engine Reference Board (U00B0021-02-CPU) was certified by T-engine Forum as Target Board for T-Kernel 2.0 with ARM 11 Core 500MHz (http://www.t-engine4u.com/en/).

\(^2\)SN-4008-STT is an 8 point NPN input terminal block provided by ONTEC COMPANY, LTD., was used for receiving the signals from elevator controller (https://www.ontec.co.jp/).

\(^3\)SN-4016-RT is a 16 point NPN output terminal block provided by ONTEC COMPANY, LTD., was used for submitting signals to the elevator controller (https://www.ontec.co.jp/).
REST-ful API also has been developed for communicating with the elevator. The API for query is structured by two endpoints: (position, sensed time), for a real example shown as (3, 2019-1-30 09:37:03). In addition, the control API was structured by two endpoints as well: elevator_id and value of destination floor.

In addition, the novel user interface was deployed on a tablet of Nexus 7, with a display size of 7 inches and operating on the Android 6.0. As showed in Fig 8 (C), the user interface offers a single screen for dynamically visualizing the overall contents, including the waiting time for elevator arrival, the elevator’s dynamical moving, the number of the passenger waiting outside the elevator as well as riding on the elevator (marked with 1⃝, 2⃝, 5⃝, 6⃝, respectively), and so on. As the example shows, the buttons of destination floors (in the area 4⃝) were managed to be unusable under its self-adaption. The advice of taking a ride at the neighbour floor with showing the merit of how much waiting time and travel time could be reduced (marked as 3⃝) was presented.

VI. EVALUATION

To validate the efficiency and effectiveness of this proposal, first of all, we tested the system performance improvement by simulations. Subsequently, we also conducted a user study to evaluate the effectiveness of Intellevator, by providing a real end-to-end usage on our proposal.

A. SIMULATION

In the simulation, the traffic flow was generated, managed and transported in iteration. In each round, the simulator records the waiting time, travel time, passenger count in order to computes the average or maximum value for evaluation.

1) TRAFFIC PATTERNS

- Up-peak (U): Known the current up-peak pattern in which the origins are centralized at the lobby floor while the destinations are distributed, to merge the destinations of the traffic flow based on the following methods;
- Down-peak (D): Known the current down-peak pattern in which the destinations are centralized at the lobby floor, while the origins are decentralized, to merge the origins of the traffic flow based on the following methods.

2) COMPARED METHODS

To quantitatively evaluate the effectiveness of our proposal, a comparison was drawn between our approach and the following baseline methods, with the parameter tuned for all methods.

- Passive transport method (PT) is the method widely applied on the traditional elevator system, by which the elevator system is passive in reaction to all the transport requirement (all are transported from origins to destinations).
- Fixed rule method for managing the traffic (FR) represents a deterministic method for the traffic management. In this evaluation, the lowest floor was taken as the target floor to merge the traffic load within the floor group.
- Dynamical targeting-optimization method for managing the traffic (DT) is a hybrid method proposed by our proposal that real-time predicts the traffic distribution and dynamically targets the floor within the deterministic periodic time and floor group for optimizing the traffic distribution.

Apart from the above base line methods, we also consider the peak-time fluctuation with arrival rates (a + λ) varying
TABLE 3. Performance of different methods on the evaluation (in seconds).

| Traffic Pattern | Method | AWT | ATT | LL | MWT | MTT |
|-----------------|--------|-----|-----|----|-----|-----|
| Up Peak         | PT     | 33.97 (0.53) | 92.81 (1.42) | 0  | 75.18 | 51.43 |
|                 | FR     | 27.74 (0.16) | 63.70 (0.17) | 3600 (0.0) | 59.77 | 36.02 |
|                 | DT     | 27.76 (0.17) | 68.75 (0.73) | 3482 (42.3) | 59.76 | 36.89 |
|                 | PT+λ  | 28.84 (0.30) | 101.93 (3.3) | 0  | 75.83 | 52.08 |
|                 | FR+λ  | 21.72 (0.20) | 67.81 (1.47) | 3826 (127.2) | 60.25 | 36.50 |
|                 | DT+λ  | 21.66 (0.15) | 67.43 (0.33) | 2443 (21.0) | 60.41 | 36.66 |
| Down Peak       | PT     | 48.80 (0.11) | 94.84 (0.62) | 0  | 75.22 | 51.47 |
|                 | FR     | 42.91 (0.17) | 64.28 (0.21) | 3600 (0.0) | 59.81 | 36.09 |
|                 | DT     | 42.77 (0.12) | 65.10 (0.20) | 3524 (36.4) | 53.97 | 36.06 |
|                 | PT+λ  | 42.67 (0.89) | 98.00 (3.10) | 0  | 68.90 | 45.15 |
|                 | FR+λ  | 30.48 (0.43) | 66.80 (1.37) | 3770 (88.5) | 48.08 | 24.25 |
|                 | DT+λ  | 30.36 (0.51) | 66.41 (1.92) | 2424 (14.7) | 48.18 | 24.43 |

3) EVALUATION METRICS
The performances of the above methods were assessed using the following metrics:
- AWT: average waiting time that passengers spent on waiting for elevator arrival.
- ATT: average travel time that passengers spent on taking ride on the elevator.
- LL: the overall amount of labor effort caused by traffic managing, which is calculated as the product of the affected passenger count and the corresponding floor numbers for walking. The unit was defined as the labor effort for one person to walk between two floors.
- MWT: the maximum waiting time during the simulation.
- MTT: the maximum travel time during the simulation.

4) SIMULATION PARAMETER SETTING
Various dynamics from elevator environment was approximated for decision-making. We started the simulation by setting the parameter defined in Table 4.

TABLE 4. Elevator environment settings.

| Parameter                        | Value         |
|----------------------------------|---------------|
| Time interval (Δt) for making decision | 300 seconds   |
| Floor window (Δf) for grouping    | 3             |
| Floor numbers (N)                | 20            |
| Average floor population (p_{Ci}) | 200           |
| Building population (P)          | 200*(N-1)     |
| Cabin capacity of persons (C)    | 15            |
| Cabin numbers (CN)               | N / 5         |
| Elevator moving time (t_{m})     | 5 s           |
| Elevator boarding time (t_{b})   | 5 s + 0.2*α   |
| Overall average arrival rate in lobby floor (Ł) | P / 2 hours |
| Average arrival rate in the i-th floor (Ł_i) | p_{ci} / 1 hour |

B. RESULT OF THE SIMULATION
We ran 20 times on each scenario and took the average. The overall simulation result was listed in Table 3.

The result of time-efficiency is shown in Fig 9. In general, FR and DT methods achieved better performance in both AWT and ATT than the ones of PT method, regardless of the traffic pattern. Furthermore, there is little significant difference in the performance of waiting time reduction between the FR and DT method.

Particularly, compared to the methods of FR and DT, the methods of FR+λ and DT+λ showing that traffic control under peak-fluctuation could save more time-consuming on waiting. The results quantitatively show that while the traffic peak fluctuated, the method of proactively control on the traffic achieved significant performance improvement.

Fig 10 shows the result of labor effort cost of the simulations. First of all, PT method that is passive to undertake transport task, required no labor effort cost. Since the FR method was defined by a fixed rule that always merging the traffic to the lowest floors, it resulted in that both FR and FR+λ require the largest amount of labor effort regardless of the traffic pattern. DT method which takes into account the traffic prediction in real-time, shows the most desirable performance as the less labor-effort loss cost needed compared with the FR method.

among all the floors for simulating the realistic scenarios. The offset on the peak time of each floor is randomly set.

FIGURE 9. Figures show the simulation results of time-efficiency.
We also conducted a user study for evaluating the system usability as well as the user experience of Intellevator. A total of 22 participants (P1-P22) including 5 females and 18 males, were recruited in person for the user study. The average age of the participants was 25.64. Further, 55% of them use elevators more than 5 times weekly, 27% use elevator 3–4 times weekly, and the remainder use elevator 1–2 times weekly.

Comparative tasks were performed in the user study. The tasks were designed into two versions: using the Intellevator and using the existing elevator system. To ensure the equal experiences for each participant, the initial floor where elevator came from was set at the same in both the two versions of tasks. While using Intellevator, the participants were asked to follow the advice if it was provided, i.e., walking to other neighbor floors to take a ride.

After the comparative tasks completed, the participants were asked to fill a questionnaire that was designed to subjectively evaluate our proposal. The questionnaire consisted of the system usability scale (SUS) [26], the NASA-task load index [27] and the user experience questionnaire (UEQ) [29]. The user preference of following the advice also was observed by the filling problems. The average duration of the whole user study per participant was about 80 minutes, including the introduction, comparative tasks and duration of the whole user study per participant was about also was observed by the filling problems. The average (UEQ) [29]. The user preference of following the advice indeed. However, it causes a large amount of labor effort loss of passengers. On the other hand, DT method computes the optimal floor based on the real-time traffic prediction requires minimal labor effort. Accordingly, in respect of the trade-off on time-saving and labor-effort loss, DT method shows the comprehensively best performance.

C. USER STUDY
1) PARTICIPANTS AND PROCEDURE
We also conducted a user study for evaluating the system usability as well as the user experience of Intellevator. A total of 22 participants (P1-P22) including 5 females and 18 males, were recruited in person for the user study. The average age of the participants was 25.64. Further, 55% of them use elevators more than 5 times weekly, 27% use elevator 3–4 times weekly, and the remainder use elevator 1–2 times weekly.

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D. RESULT OF THE USER STUDY
1) SYSTEM USABILITY
The System Usability Scale (SUS) has been measured for evaluating the participants’ attitudes towards the usability of Intellevator, covering the effectiveness, efficiency and satisfaction [28]. The overall SUS score of Intellevator was on average 75.45 (SD = 11.5). A basis for positioning SUS scores within the grade rankings has revealed: a System Usability Scale (SUS) above 68 could be considered above average and the acceptability is HIGH [28]. Based on this reference, the rated overall SUS score of 75.45 above the average a few shows Intellevator matches user’s satisfaction by a effective and efficient way. The system was evaluated that easy to lean, useful to help them smoothly completed the tasks in the user study.

2) USER EXPERIENCE
We also utilized the user experience questionnaire (UEQ) [29] for measuring the passengers’ experience on Intellevator in a immediate and simple way. 6 factors including attractiveness, perspicuity, efficiency, dependability, stimulation, novelty were analyzed based on the rating system of 26 items scored by 7-point Likert scale.

In total, the user experience was scored at 1.5 (SD = 0.28) on the scale between −3 to 3. Fig 11 interprets the details of user experience result, that was compared with the benchmark of UEQ data analysis tool which provided the data set collected from 9905 persons from 246 studies concerning different products [29]. Obviously, all scales of Intellevator showed an extremely positive evaluation result based on the comparison, that demonstrated Intellevator has the relatively high user experience quality.

According to the objectively rated results of SUS and UEQ, we can state that, Intellevator provided relatively high quality of the system usability and the user experience, that could consequently contribute to a high user acceptance.

3) NASA-TASK LOAD INDEX
The NASA-task load index consists of six dimensions: mental demands, physical demands, effort, temporal demands, performance and frustration, for those each was required individually to evaluate the given tasks.

The result of NASA-TLX has been listed in Table. 5 and depicted in Fig. 12 as well. For the details, regarding to the Overall Work Load, there were no significant differences between using Intellevator and using the existing system, which was 49.1 and 47.9 separately.
TABLE 5. Table shows the subjective ratings on NASA-TLX.

|        | Mental | Physical | Temporal | Effort | Performance | Frustration |
|--------|--------|----------|----------|--------|-------------|-------------|
| Existing | Avg.   | 35.5     | 27.7     | 58.2   | 29.1        | 60.7        |
|         | SD     | 28.7     | 22.24    | 31.26  | 26.62       | 34.51       |
| Intellever | Avg    | 43.2     | 44.1     | 37.7   | 42.7        | 76.1        |
|         | SD     | 21.19    | 27.80    | 24.96  | 26.71       | 21.82       |

FIGURE 12. Figure shows the rating averages of NASA-TLX.

The following analysis could be summarized:

- The decrement of temporal demand showed that unlike the existing elevator system with uncertainty of time-consuming, Intellever that presents the waiting time in real-time and further provides the passenger time-efficient advice for using the elevator, might be helpful for passengers to relieve the time stress.
- Frustration has decreased by 39.1%, showed the Intellever provides more referable contents could assist passengers to obtain more comprehensive knowledge of the elevator using, consequently ease their frustration. In particular, the advice based on the proactive optimization for reducing their waiting time could be considered to be assistive as well.
- The mental demand has increased slightly even if the Intellever provided much more information to retrieve and refer. It might be the reason that the contents were designed to be supportive and beneficial for passengers and there is little significant increment on the mental demand of passengers.
- The increment of the physical demand showed passengers felt more physical effort needed for using the Intellever, for the reason that Intellever sometimes forces them to walk to other neighbor floors for taking a ride if under the peak-pattern optimization.
- The performance has increased by a little showing the participants feel their own performance became important for Intellever system.
- As a result, the dimension of effort primarily including the mental demand, physical demand, increased a little. Concerning the goal of Intellever is to improve the time-efficiency and user experience on the usage of elevator system by proactive control on the traffic, this result was totally in line with expectation. Ultimately, the overall result of NASA-TLX could be summarized that, based on the comparison with the existing elevator system, Intellever reduced passengers temporal demand and eased their frustration.

4) USER PREFERENCE FOR TAKING ADVICE

Besides, participants were asked to give answer three questions listed as follows. The questions was designed to quantitatively evaluate participants’ preference and incentives of following the advice which provided by Intellever.

- If an advice presented that walking to upper floor to take a ride, what is the maximum floor number that could be affordable.
- If an advice presented that walking to lower floor to take a ride, what is the maximum floor number that could be affordable.
- How much reduced time could be a incentive for following the advice.

FIGURE 13. User preferences of taking the advice (N = 22).

Regarding to user preferences of taking advice, as shown in Fig 13 (A), we can clearly see that there is an offset on the overlaps of the maximum floor of going downward and going upward, showed as 3 floors and 2 floors separately. It quantitatively revealed that the participants would rather to going downward to take a ride than going upward. Besides, as shown in Fig 13 (B), if the waiting time reduced by more than 60 seconds, almost all the participants would like to follow the advice. Consequently, it can be concluded that if the advice showed walking upward or downward within 2 floors to take a ride on the elevator thus the waiting time could be reduced more than 60 seconds would be acceptable for almost all the participants.

VII. DISCUSSION

A. INCREASED PHYSICAL DEMAND IS NOT A PAIN

It is essential to note that, according to the NASA-TLX result of Intellever, we do not consider the increase in effort and physical demand as a pain. The prevalence of sedentary lifestyles has occurred when human populations start to concentrate in urban areas, and the popularity of physical activity is falling [31]. The physical inactivity further amplified the risk of physical health and the significance of frequent exercise has been recognized by the public [32]. Moreover, relevant research demonstrated that existing technologies and procedures can improve indoor environments that promotes
human health [33]. However, the industries including building developer or elevator manufacturer, do not have the incentive to independently undertake this program because the required effort was considered very interdisciplinary.

The benefits of walking on health management also have been validated by the related research [34]. It is hoped that optimal advice provided by Intellevator which guides the passengers to walk to another floor for taking the elevator could be a considerable by-side product for increasing the frequency of physical exercise, finally could make contributions to improving the physical health of users.

B. USER EXPERIENCE WHILE IN A GROUP
Passenger experience of elevator ought to be viewed in the context of both the individuals and larger populations, and be optimized depending on the actual situations. It is not a single specific technology or component can figure out, but the combination of multiple fields affecting the overall experience of individuals and group. Elevator system facilitates the building to be constructed into high-rise, and further promotes the process of urbanization development. In particular, the proportion of the world’s population lives in urban areas is expected to increase from 55% in 2018 to 68% by 2050 [30]. The challenges that elevator systems face are increasing with the ever-growing height of buildings [6]. At the same time, the passenger experience of elevators is evolving as well. Regarding to the vertical traffic bottleneck in peak time within tall commercial buildings, balancing the passenger experience while in a single or a group for the overall time-efficiency could be concerned.

VIII. CONCLUSION
This paper presented Intellevator: an intelligent elevator system that is proactive in traffic control for the time-efficiency optimization. The proposal is an end-to-end architecture which composed of three aspects: Internet of things (IoT)-enabling technology on a conventional elevator, an agent server to enhance elevator computation capability, and a designed user interface for delivering intelligence to end-users.

Intellevator system has been experimented on a conventional elevator. We evaluated Intellevator quantitatively by simulations. The numerical simulation results validated the efficiency improvement of our proposal. Furthermore, we also conducted a user study for evaluating the system usability, user experience and so on of Intellevator. By drawing comparison with the existing elevator system, it was demonstrated that our proposal owned better system usability and user experience. Additionally, via the user study, we also collected a few of valuable insights of user preference on elevator using, which could be references for further improvement of elevator system.

The global optimization and the sensory richness within smart building provides theoretical probability to detect and reason more context of the elevator environment, finally to control the elevator by more flexible and intelligent methods.

In the near future, we intend to develop the high level intelligence for an elevator by accessing the contexts of the whole smart building framework, including integration with the autonomous robotic mobility platform.

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