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An Integrated Solution to Enable Safe Evacuation of Tall Buildings | 高层建筑紧急疏散的系统集成解决方法

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Abstract | 摘要

Implementing real-time, efficient, and intelligent tall building egresses that ensure human safety in cases of emergencies can be extremely difficult. Most current egress strategies are pre-designed and based solely on the usage of stairs; therefore, it is desirable to have an egress system which could utilize elevators and also provide clear guidance. In this paper, we propose a real-time system that has the capability to monitor fire and smoke sensor statuses in the building, dispatch elevators automatically for egress and ingress, and also allow for first responders to push different and dynamic egress routes based on people locations to avoid congestion. Our proposed real-time, intelligent egress system is the first of its kind – an integrated solution that combines different building systems and sensors to work together and guide people to optimal routes for efficient evacuation. Our proposed egress system also allows first responders to view and manage the building systems' statuses remotely.

Keywords: Egress, Elevator Evacuation, Integration

高层建筑早已成为世界城市中的一道风景。在紧急情况中，为这些建筑进行实时、高效和智能的疏散以保证人员安全非常困难。现有的疏散策略多为预先确定的并只利用楼梯，具有如下局限：1）楼梯的有限容量不足以进行快速人员疏散和消防救援人员进入；2）没有清晰的导航指引人员利用正确的逃生出口和避免人员拥堵等风险。因此，一个能够利用电梯进行疏散并提供清晰导航的疏散系统是理想的。在本文中，我们提出了一个能够监控建筑中火灾/烟雾传感器状态，自动派遣电梯进行疏散和救援，并允许救援人员根据人员位置提出不同的和动态的疏散线路以避免拥堵的实时系统。我们提出的实时智能疏散系统是第一个整合火灾报警系统、电梯系统、监控摄像和人员室内定位等建筑系统和传感器，以指引人员利用最优逃生线路进行有效疏散的集成解决方案。我们提出的疏散系统还可以使救援人员远程观看和管理建筑系统的状态。这样的系统将有助于提升紧急状况中高层建筑乘员的整体安全水平。

关键词：紧急疏散、电梯疏散、系统集成

Introduction

Egress systems, including effective and efficient evacuation and guidance services in cases of fires and other emergencies in high-rise buildings, are crucial to the society due high social and financial consequences. For example, the fire at the Shanghai Jing'an Teachers Apartment in 2010 caused 58 deaths and injured 71 people. In 2009, the fire at the China Center Television Tower's wing building caused one death and injured seven people, and also caused more than RMB1600 million economic losses. Increased population density, taller buildings, and complicated internal building structures cause evacuation (egress) and rescue (ingress) under emergency conditions which are longer to perform and more dangerous.

According to 2014 CTBUH research (Oldfield, 2014), intelligent egresses with elevator usages are ranked as one of the top five topics under the category of research and development for Vertical Transportation and

简介

高层建筑在火灾及其他紧急情况下的紧急疏散系统（包括有效和高效的疏散和导航方案），对于现代社会无论从人文还是经济上都非常重要且有重大的影响。举例而言，2010年的上海静安寺教师公寓大火造成了58人死亡，71人受伤；2009年的北京中央电视台大楼的副楼大火造成1人死亡，7人受伤，同时还造成了人民币1600多万元的经济损失。越来越密集的人员，越来越高的建筑，以及越来越复杂的建筑内部结构都导致高层建筑的疏散和救援需要更长的时间，以及更加危险。

根据CTBUH 2014年的研究报告(Oldfield, 2014)，在垂直交通和紧急疏散分类中，使用电梯的智能疏散被认为是未来高层建筑排名前五的主要研究发展方向之一。在智能疏散方面，排名靠前的研究课题包括实时的紧急疏散管理策略及其技术，具体而言比如人流统计，人员疏散路径规划以及指引等方向。

Evacuation for future high-rise buildings. For intelligent egresses, the top priority research topics include real-time evacuation management strategies and technologies, such as people flow, occupant navigation, and way finding.

In terms of real-world egress cases, elevators play critical roles in evacuation. For example:

In the New York City World Trade Center (WTC) 9/11 disaster, elevators played a critical role in WTC Tower 2 evacuation (NIST, 2008). In Tower 2, 18 percent of the survivors were saved using elevators. Without elevators, more than 3,000 people would have remained in WTC Tower 2 when it collapsed, with over 2,000 trapped above the 78th floor.

For the Burj Khalifa (with 162 floors and a height of 828 meters), a simulation study of the total evacuation time from using stairs alone versus using a combination of stairs and elevators was performed. In this simulation, there is an estimated 45 percent reduction in total evacuation time (from 160 to 90 minutes) when using both the stairs and elevators. A similar study was performed for the Taipei 101 tower (508 meters), with an estimated 53 percent reduction in the total evacuation time (CTBUH, 2010).

In case of fire, the two sightseeing elevators (products of Otis Elevators) in the Shanghai World Financial Center (492 meters) are modified to stop at each of the refuge floors to act as shuttle cars and be used for occupant egress. Compared to egress without elevators, the reduction in total egress time with elevators as shuttle cars is estimated to be on the order of 25 percent (Bukowski, 2007).

On the other hand, in December 2015, a fire occurred in a 63-floor residential building in Dubai, causing at least 60 people to be hurt by many crushing injuries during egress, and also a heart attack, according to officials. A news report (DailyMail, 2015) read that, "People were shoving each other down the stairs and climbing over each other" and also, "One Briton was forced to carry his disabled mother on his back." This fire event in Dubai shows that high-rise building evacuation is challenging, and it is difficult to evacuate people safely and efficiently without access to intelligent egresses and the usage of elevators.

Existing Enabling Elevator and Fire Systems

Egresses with elevators in buildings has been studied since the beginning of the 1930s, but the 9/11 WTC event pushed researchers and engineers to make full use of occupant elevators in a systematic way for more effective and reliable egresses (Kinateder, 2014). Now, the traditional concept that occupant elevators cannot be used during any emergency has been overcome to some extent. In their 2009 editions, both the International Building Code and NFPA Building Construction and Safety Code (NFPA 5000) permit the use of occupant elevators meeting certain requirements to be designated for self-evacuation in fires. The International Building Code (ICC, 2012) has defined the rules for egress involving the use of Occupant Evacuation Elevators (OEEs). Buildings over 420 feet are required to have an extra exit stairway unless the building has occupant evacuation elevators. ISO/TR 25743 studied the use of evacuation elevators and ISO/TR 18870 proposed requirements on elevators used to assist in building evacuation. The American Society for Mechanical Engineers (ASME) committee that is responsible for elevator code also investigated the feasibility of the use of occupant elevators during egress, and developed the occupant evacuation operation (OEO) protocols for occupant elevators. In a recent CTBUH paper (Stranieni, 2014), the current status of egresses with occupant elevators was reviewed and an objective-based approach was proposed to enhance egress efficiency compared to the cases where only stairways and OEO are used.

As for intelligent egress products, one of United Technologies Corporation (UTC)'s Business Units, Gulf Security Technology (GST) has developed the intelligent egress system (IES) with components of egress sign indicators, egress control panels, lighting systems, and also emergency power systems (Figure 1) along with fire detection and alarm systems. These systems are now targeted at high-rise buildings or large-scale areas for emergency evacuation purposes.

As described above, intelligent egress has become an active topic for high-rise buildings from real-world lifesaving needs,

对于真实世界的情况而言，电梯在紧急疏散中发挥了重要作用。例如：

在纽约世界贸易中心911事件中，电梯在二号大楼的救援任务中发挥了关键作用（NIST，2008）。二号大楼中18%的生还者是利用电梯逃生的。如果没有使用电梯，当大楼倒塌时，还会有超过3000人滞留在二楼大楼里面，其中有超过2000人被困在78楼以上。

对于哈利法塔（高度828米，有162层楼），CTBUH 2010年的研究报告进行了只使用楼梯进行紧急疏散和结合使用电梯与楼梯进行紧急疏散的实验仿真比较。在仿真中，结合使用电梯与楼梯可以节约大概45%的疏散时间（从160分钟降低到90分钟）。同样的研究也在台北的101大楼（508米高）做了仿真实验，仿真中疏散时间可以节约53%。

上海的环球金融中心（492米高）的两台观光电梯（奥的斯电梯）在紧急疏散的情况下可以作为一种固定路线的穿梭救援电梯在每一个避难层停留。相比不使用电梯，使用这种类型的穿梭救援电梯大约可以节约25%的紧急疏散时间（Bukowski，2007）。

另一方面，在2015年12月，迪拜的一座63楼高的高层住宅大楼发生火灾。大火造成至少六十人受伤，其中很多是疏散时拥挤造成的伤害。官方的消息还声称有一个人突发心脏病。根据新闻消息(DailyMail, 2015)，“人们在楼梯里面下楼的时候互相推挤其他人，甚至爬过其他人”，“一个英国人被迫抱着他残疾的母亲下楼”。在迪拜发生的这场大火显示高层建筑的救援是一个非常困难有挑战的任务。如果没有智能疏散系统以及电梯的使用，从高层建筑里面高效以及安全的疏散的人群将会非常困难。

现有的启动电梯与安防系统

自从1930年，电梯就被研究用于疏散，但是9/11世界贸易中心恐怖袭击推动了科研人员和工程师系统地研究如何充分

Figure 1. Introduction of UTC's GST's Fire Alarm System (Source: UTRC)
图1. 联合技术公司海湾安防技术有限公司火灾报警系统简介（来源：联合技术研究中心）

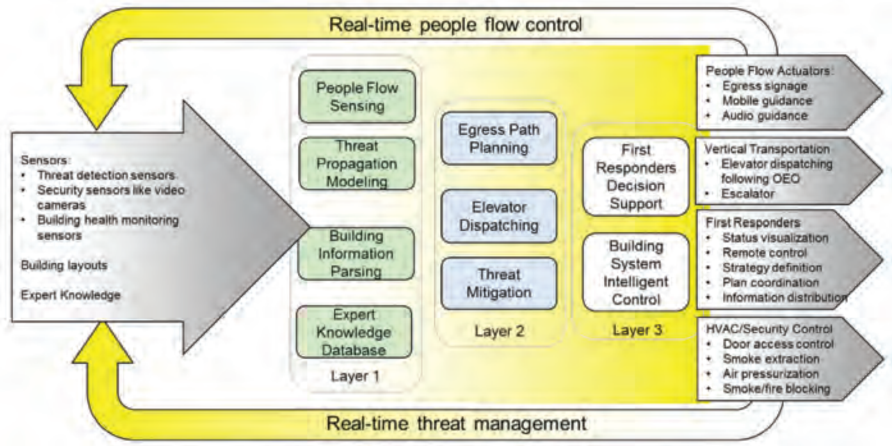

Figure 2. Proposed intelligent egress system architecture (Source: UTRC)
图2. 智能疏散系统架构提案（来源：联合技术研究中心）

international code, and also industry product perspectives. In this paper, UTC presents its recent research results to provide more insight on the development of integrated building technology for intelligent egresses. This paper also tries to increase the awareness of egress problems and the OEO code for the high-rise building industry, and hopes to set the stage to encourage more people to join in the research and development of new technologies for intelligent egress technology solutions.

Proposed Architecture for Integrated Solution

Nowadays, high-rise buildings typically have two exit stairways as the primary egress routines for use under emergencies; however, the egress capacity of the stairways largely depends on their widths. Consequently, the egress capacity with only stairways is constant and thus the required egress time will be unacceptably long for high-rise buildings with a large number of floors and occupants. Furthermore, mobility impaired occupants may experience severe difficulties using exit stairways during egresses, including not being able to traverse the stairways at all (Kinateder, 2014). Capacity is further reduced when firefighters have to use exit stairways for ingresses, causing considerable congestion. All of these facts demonstrate that only using stairways may greatly limit the egress efficiency and reliability.

In addition, considering the tragic loss of life in the 2001 terrorist attack of the WTC, a large amount of effort has been focused on the design of efficient egress systems to evacuate occupants from high-rise buildings, especially for occupants who cannot use exit stairways by themselves. In addition, a coordination control between fire and smoke alarm systems and the egress guidance system is not considered in current solutions. The location where fire occurs can be sensed from the fire alarm system, while existing egress guidance systems can only use pre-determined egress routines, unable adapt to real-time fire and smoke statuses or occupant flow information. Besides, to understand the whole emergency situation in the building, first responders need a reliable tool to observe where the fire occurs, how occupants are evacuating, and the movement of every elevator. Such information is critical for them to make often life-saving decisions for efficient egresses and ingresses.

Based on previous discussions and prior work (Stranieni, 2014), UTC proposes the following system architecture to address the technology challenges for intelligent egress operation (Figure 2).

Firstly sensor data, building layout information, and expert knowledge are input to the intelligent egress operation system. In this system, we define three-layer architecture as below:

The first layer has modules such as people flow sensing, threat propagation modeling, building information parsing, and a human expert knowledge module to process and analyze input information.

Processed information from the first layer modules, such as people location, threat propagation trends, building layout, and equipment statuses, are passed to the egress path-planning, elevator-dispatching, and threat-mitigation modules to form the second layer of the system and to create actionable egress operations.

With the actions defined, the third layer modules will act like actuators to take actions such as providing decision support for first responders or controlling building equipment.

Finally, output is generated to achieve intelligent egress operation.

利用乘客电梯进行更有效和更可靠的疏散（Kinateder，2014）。现在，乘客电梯不能在任何紧急情况下使用的传统观念已经在一定程度上被克服了。2009年版本的国际建筑规范和NFPA建筑施工和安全规范（NFPA 5000）都允许人员在火灾中使用符合一定要求的乘客电梯自行撤离。2012年版本的国际建筑规范为用于疏散的乘客电梯（OEE）定义了一系列的规范。高度超过420英尺的建筑物必须拥有一个额外的楼梯出口，除非该建筑安装了乘客疏散电梯。由国际标准化组织定义的ISO/TR 25743研究了如何使用电梯逃生，ISO/TR 18870对用于帮助逃生的电梯提出了要求。美国机械工程师协会（ASME）负责电梯规范的委员会也研究了人员使用电梯疏散的可行性，并且为乘客电梯制定了人员撤离操作（OEO）的协议。在最近的世界高层都市建筑学会（CTBUH）上，Stranieni回顾了使用乘客电梯疏散的现状，并提出了一个基于目标的逃生方法（Stranieni，2014）。相比于只使用楼梯和OEO的情况，该方法可以提高疏散的效率。

关于智能疏散产品，联合技术公司（UTC）旗下的海湾安防技术有限公司（GST）已经开发了智能逃生系统（IES）。如图一所示，该系统由疏散指示牌，疏散控制面板，照明系统，紧急电力系统以及火灾探测和报警系统组成（图1）。目前，这套系统定位于高层建筑或大规模区域的紧急疏散。

如上所述，考虑到世界范围内高层建筑救生的需求，国际相关规范的制定以及实际的工业产品，高层建筑智能逃生已经成为一个活跃的课题。在本文中，联合技术公司展示了集成建筑技术的发展应用于智能逃生系统的最新研究成果。本文还试图加强高层建筑行业对于疏散问题以及人员撤离操作规范的认识，并且鼓励更多的人加入智能疏散解决方案和新技术的研究和开发。

提出集成解决方案的架构

如今，在紧急情况下高层建筑通常拥有两个逃生楼梯作为主要逃生路径。不过，楼梯的疏散能力在很大程度上取决于它们的宽度。因此，仅使用楼梯作为逃生路径的疏散能力是固定的，从而拥有大量楼层和人员的高层建筑所需的逃生时间会难以接受的长。此外，行动不便的人员在紧急情况下使用楼梯逃生可能会遇到严重的困难，甚至根本无法使用楼梯逃生（Kinateder，2014）。当消防队员不得不使用逃生楼梯进入建筑实施救援时，楼梯的疏散能力会进一步降低从而造成楼梯的拥挤。所有这些事实表明，只使用楼梯逃生会很大程度地限制逃生的效率和可靠性。

New Technologies Developed to Enable Safe Egress

In order to implement the proposed architecture above, the egress system needs to collect different kinds of real-time sensor data, such as fire and people location, to provide optimal paths for evacuation and to send control commands to building systems. Furthermore, in order to aid building owners and first responders in understanding the emergency status and make quick decisions, the egress system should have a user-friendly interface. Several technologies developed to achieve these goals are presented below.

BIM, Building 3-D Visualization, and Remote Control

According to interviews with first responders, it will be convenient for them to observe information, such as fire and people location and elevator statuses in a 3-D building layout before entering a building for rescue. Building Information Models (BIM) can be used to visualize building layouts in 3-D. BIM are digital representations of physical and functional characteristics of buildings. Normally, BIM files are hard for first responders to view and understand if they don't have professional CAD tools. UTC has developed a software tool that parses building structure information out of the BIM, visualizes it in 3-D, and then connects building equipment to visualize system statuses on top of building structures, and also enables egress remote control functions to support first responders for egress decision making.

Figure 3 shows one of UTC's results for building 3-D visualization (Figure 3). The fire alarm, occupancy, elevator statuses, and egress signs can be shown in this 3-D layout. Users, such as building owners and first responders, can use this 3-D visualization tool to quickly understand the emergency status and make better-informed decisions. This tool also allows users to draw and change egress paths and remotely control egress systems such as the directions of egress signage.

Indoor Localization and Mobile Guidance

Indoor people localization is extremely important for egresses. With indoor localization, the egress system can know the location of people and whether congestion will occur. Based on people location and risk information (such as fire location), the egress system can generate an optimal path to guide

此外，考虑到在2001年世界贸易中心恐怖袭击事件中惨痛的人员损失，大量的精力已经集中在为高层建筑设计有效的逃生系统以进行人员疏散，尤其是为不能自已使用逃生楼梯的人员。另外，目前的解决方案没有考虑火灾和烟雾报警系统与逃生导航系统之间的协调控制。虽然火灾报警系统可以检测火灾发生的位置，但是现有的逃生导航系统只能使用预先确定的逃生路径，无法适应实时的火灾和烟雾状态或人员的流量信息。同时，为了了解整个建筑物的紧急情况，建筑物的第一反应者需要一个可靠的工具观察火灾发生的位置，人员逃生的情况以及每个电梯的运行。这些信息对做出有效的生命攸关的逃生和救援决策是至关重要的。

基于之前的讨论和研究（Stranieni，2014），联合技术公司提出系统架构用于解决智能疏散操作的技术挑战（图2）。

第一手的传感器数据，建筑布局信息，以及专家知识被输入到智能疏散操作系统。在这个系统中，我们定义如下的三层结构：

系统的第一层拥有不同的模块，比如人员流动检测模块，威胁传播建模模块，建筑信息解析模块，以及处理和分析输入信息的人类专家知识模块。

从第一层模块处理后的人员位置，威胁传播的趋势，建筑的布局，设备的状态等信息被传递给疏散路径规划模块，电梯调度模块和威胁缓解模块。这些模块组成了框架的第二层并产生可实施的逃生操作。

基于第二层定义的动作，逃生系统第三层的模块类似于致动器一样采取动作，比如为消防救援人员提供决策支持，或者控制建筑的设备。

最后，系统生成并输出智能疏散操作。

为保证疏散安全所开发的新技术

为了实现上文所提出的架构，疏散系统需要采集不同的实时传感器数据，比如火情和被困人员的位置。疏散系统还需要提供最优逃生路径来疏散被困人员，并向建筑系统发送控制指令。另外，为了帮助建筑所有者和消防救援人员了解灾情信息并及时做出决策，疏散系统需要具备友好、易于理解的用户界面。下面章节将介绍在疏散系统中所开发的新技术。

BIM、楼宇三维显示以及远程控制

在对消防救援人员的采访中，他们提到在进入建筑物前，如果能够获得以三维建筑布局显示的信息，比如火情和人员位置、电梯状态，则会对救援带来极大的帮助。建筑信息模型（BIM）是一种用来显示三维建筑布局及其他信息的方法。它能以数字方式表示建筑物的物理和功能特性。一般来说，如果没有专业的CAD软件，消防救援人员很难根据BIM文件直观地理解建筑信息。联合技术公司已经开发了一套软件平台用以从BIM文件中提取建筑结构信息，将其以三维方式显示，并连接建筑物中的设备并将它们的状态叠加显示在建筑结构上。这个平台还可以启用远程控制以支持救援人员进行疏散决策。

图三显示了联合技术公司开发的建筑物三维显示的一个案例（图3）。火灾报警、人员分布、电梯状态以及疏散指示信息都可以显示在这个三维平台上。建筑物所有者和救援人员等用户可以利用这个三维显示工具快速了解灾情信息并及时做出知情的决策。用户也可以利用这个软件平台来规划或改变疏散路径以及对疏散系统进行远程控制，比如控制疏散指示牌的方向等等。

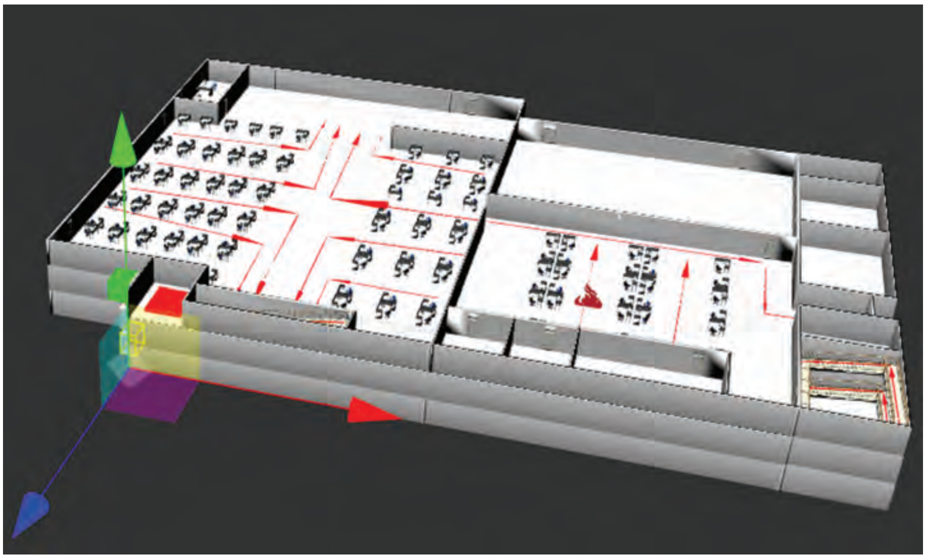

Figure 3. Building information 3-D visualization tool (Source: UTRC)
图3：建筑信息三维显示工具（来源：联合技术研究中心）

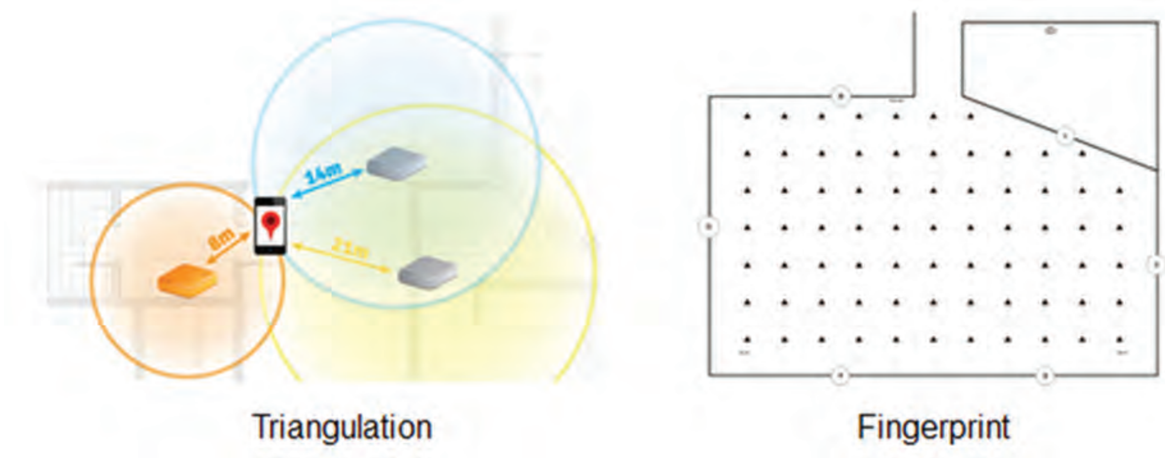

Figure 4. Two types of localization approaches (Source: UTRC)
图4. 两种定位算法（来源：联合技术研究中心）

people located in different areas of a building, which can be life-saving for people in an unfamiliar tower.

There are two basic approaches for people localization: triangulation and fingerprint (Figure 4). The triangulation approach is quite straightforward. It determines location based on distances to the three nearest sensors. In comparison, the fingerprint approach needs to create a signal map based on RSSI (Return Signal Strength Indicator) data from installed sensors (or background measurements) in an area during commissioning. Then during real-time localization, mobile devices can receive live RSSI signals from nearby sensors and match them with the signal map to determine current location.

In UTC's POC implementation, UTC used iBeacon as the sensor to localize people, and developed both triangulation and fingerprint approaches. iBeacon is one of the available sensor solutions for indoor localization. Other approaches, like a WIFI based solution, can also be applied, especially for large spaces that do not need to install many iBeacon sensors (Stojanović, 2014).

Based on people localization, mobile guidance applications can be developed. UTC created an egress application that can be installed and run on mobile phones. The application collects nearby iBeacon sensor data, obtains a customized egress path from the path planning server, and then shows all the information through a graphical user interface (Figure 5).

Video Analytics

In addition to indoor localization, which enables personalized guidance during egress, video surveillance provides another way for the egress system to monitor people flow and occupancy. For egresses with elevators, controlling the elevator efficiently reduces evacuation time. In the implemented egress Proof of Concept demonstration, a multi-camera video analytics system was developed to estimate the crowd level in each elevator lobby. Based on crowd information, elevators can be controlled automatically to achieve high efficiency. For example, the egress system can send commands to control the elevator

室内人员定位与移动指示系统

室内人员定位对于智能疏散是极其重要的一项技术。在该技术的帮助下，智能疏散系统可以获得人员的实时位置并且推断拥塞是否将要发生。基于人员位置和风险信息（例如火灾位置等），智能逃生系统可以针对不同位置的人员生成最优的逃生路径来引导合理的疏散。当人员处于不熟悉的建筑时，这种优化导航可以发挥巨大的作用。

在联合技术公司的POC实现中，联合技术公司使用iBeacon作为传感器来实现人员定位，并且同时开发了三角定位法和指纹法（图4）。基于iBeacon的室内人员定位是目前可获得的解决方案之一。其他方法，例如基于WIFI的方法也可被应用，尤其对于不需要部署过多iBeacon传感器的大面积空间（Stojanović，2014）。

基于人员定位，可以开发移动指示应用。联合技术公司开发了一款可在移动电话上安装和运行的逃生应用。如图五所示，这款手机应用收集附近的iBeacon传感器数据，从逃生路线服务器取得一条定制的疏散路线，并将所有信息通过一个图形用户界面进行展示（图5）。

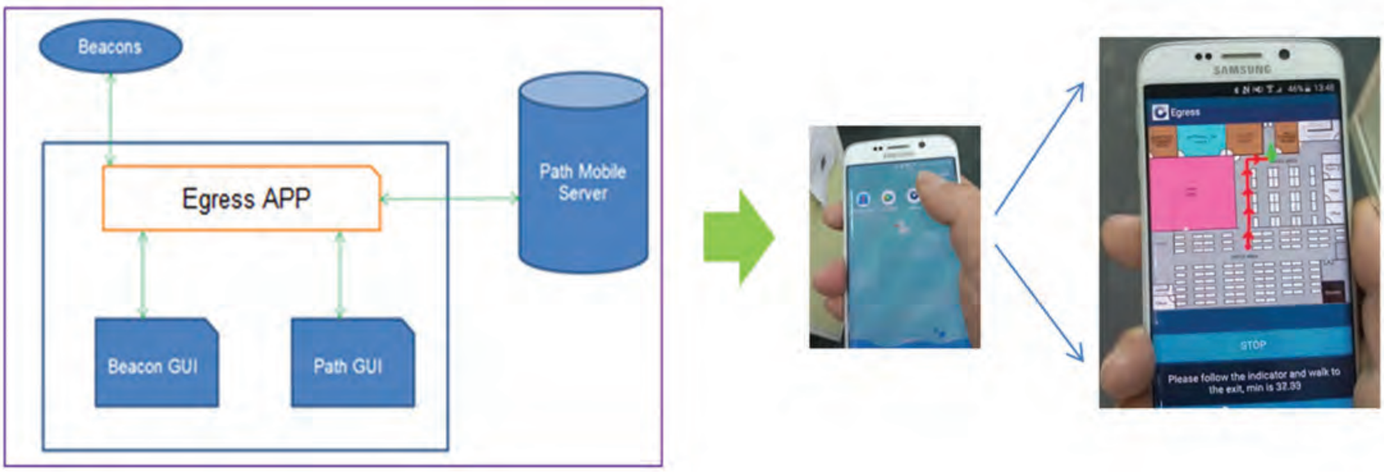

Figure 5. Mobile guidance system based on indoor localization (Source: UTRC)
图5. 基于室内人员定位的移动指示系统（来源：联合技术研究中心）

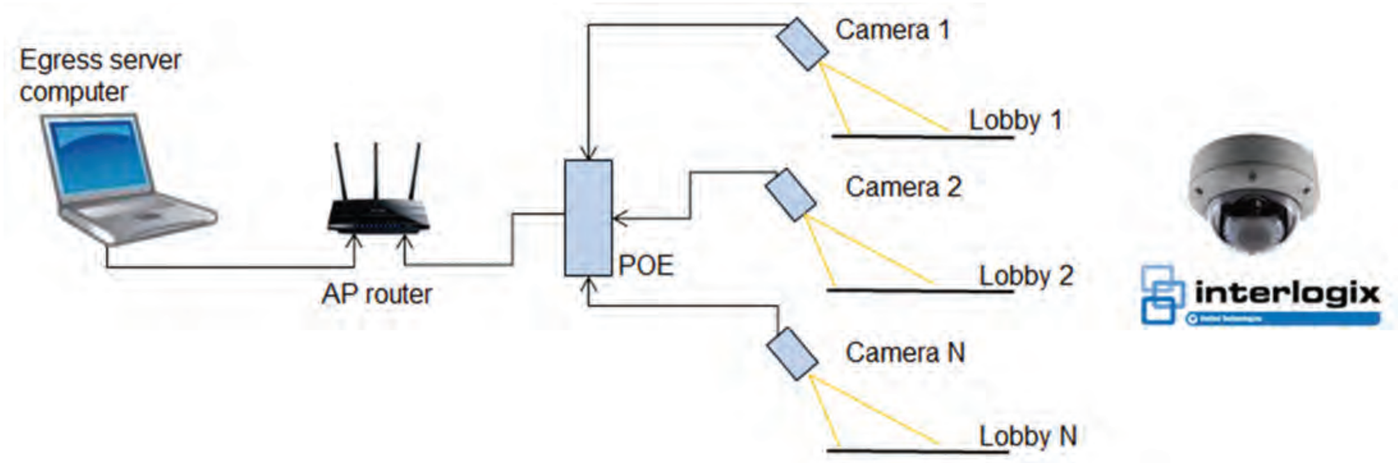

Figure 6. Multi-camera surveillance system for POC (Source: UTRC)
图6. 概念验证演示中的多摄像机监控系统（来源：联合技术研究中心）

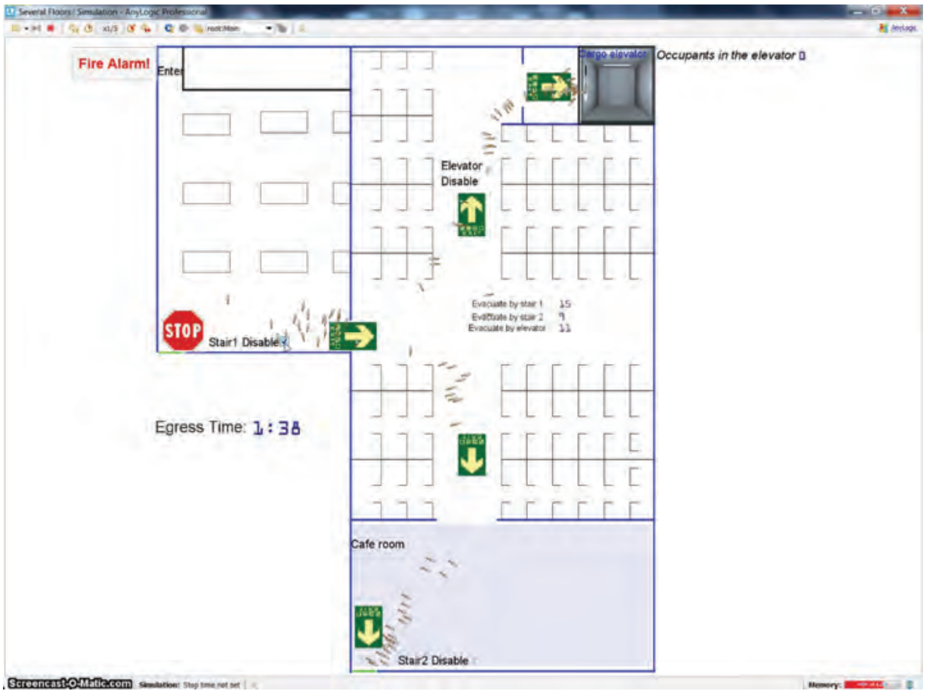

Figure 7. People flow and egress strategy simulation with Anylogic (Source: UTRC)
图7. 基于AnyLogic的人员流动与疏散策略仿真（来源：联合技术研究中心）

to "go" when no waiting occupants are detected in the elevator lobby.

As shown in Figure 6, the egress server computer can acquire video stream from each camera through PoE (Power over Ethernet) and an Access Point (AP) router, and run a multi-camera video analytics program to estimate the occupancy in each elevator lobby (Figure 6). Three-level crowd information – no people, light crowd, and heavy crowd – was defined and automatically estimated in the current system. Similar video analytics programs are already used in commercial HVAC and elevator scheduling applications (Romano, 2015).

People Flow and Egress Strategy Simulation

Normally, it can be difficult to run experiments with human subjects to evaluate egress strategies; therefore, it is necessary to develop a simulation platform that can simulate people flow and test different kinds of egress strategies. UTC developed an egress simulation platform based on the software AnyLogic (Khaled, 2012). In this software platform (Figure 7), social force models are used to simulate people movement and their interactions with each other and with walls, corridors, stairs, and elevators. Later, different kinds of egress strategies including guidance, and the usage of elevators and stairs can be defined. In the simulation, egress time and the number of people evacuated through different strategies can be estimated.

Proof of Concepts for Intelligent Egress

In order to integrate and evaluate the above technologies, UTC is developing multiple Proof of Concepts (POCs); two of

视频分析

在疏散过程中，除了应用室内定位技术进行个人化的疏散导航外，视频监控系统也可以被用来监控人员流动以及人员分布。如果在疏散中使用电梯，有效地控制电梯将减少疏散时间。在已实施的疏散系统概念验证的演示中，我们开发了一个基于多摄像机的视频分析系统用以估计各个电梯等候厅的人员拥挤程度，并根据拥挤程度信息来自动控制电梯以提高效率。比如，如果探测到没有人员在电梯等候厅（也就是所有人都进入了电梯），则疏散系统可以自动控制电梯关门并立即去其他楼层。

如图六所示，疏散服务器可以通过PoE（以太网供电，Power over Ethernet）和一个无线路由器（Acess Point router）来获得各路视频，并且通过运行多摄像机视频分析程序来估计各个电梯等候厅的人员状态（图6）。在当前系统中，定义并可以估计三种拥挤程度：没有人，轻度拥挤和重度拥挤。类似的视频分析程序已经使用于商用的暖通空调系统和电梯调度系统中。

人员流动与疏散策略仿真

一般而言，利用有人类被试者参与的实验来评估疏散策略是困难的。因此，有必要开发一种仿真平台来模拟人员的流量并且测试不同的疏散策略。联合技术公司开发了一种基于AnyLogic软件（Khaled，2012）的逃生仿真平台。在这个软件平台（图7）中，社会力模型被用于模拟人员的运动，人员之间以及他们与墙壁，走廊，楼梯和电梯的相互作用。基于此平台，不同种类的疏散策略，包括逃生导航，电梯的使用，以及楼梯的使用可以被定义。在仿真中，不同策略所需要的逃生时间以及所撤离的人员数目可以被估计。

these are described herein to demonstrate the proposed capability. UTC's proposed intelligent egress is a novel approach to improve evacuation effectiveness and efficiency by means of integrated and intelligent systems that exploit real-time information gathered from building sensors. In POC 1, the proposed system works with the following steps (Figure 8):

1. Under normal conditions people are working in their office;

2. A fire occurs at some location in the office;

3. The Fire Alarm System (from UTC's GST) detects smoke and triggers a fire alarm;

4. The Egress Signage Control System (also from UTC's GST) lights egress signs based on pre-configured paths depending on the detected fire position;

5. People follow the egress signs for evacuation, and at the same time they can trigger the mobile application to start an Indoor Localization System. Then, based on their location, a customized egress path will be displayed on the mobile application;

6. Meanwhile, the Elevator Control System (from UTC's Otis elevator) dispatches elevators to the affected floor for evacuation;

7. The Intelligent Video System (from UTC's Interlogix) will monitor people occupancy in the elevator lobby, and once all people have entered the elevator, it will send a "Go" command to the elevator to let it travel to the discharge floor.

For the POC 1 mentioned above, a demonstration was conducted at UTC Climate Controls and Security (CCS) Shanghai Research and Development Center (SRDC)'s engineering building, which has three floors with a total area of ~600m2. Four typical strategies (as mentioned below) were tested at SRDC and evacuation times were recorded:

Strategy 1: No guidance, no elevator, with stair one

Strategy 2: No guidance, with elevator and stair two

Strategy 3: With guidance, with elevator and stair three

Strategy 4: With guidance, with elevator and stair four

Here, in strategies 1 and 2, in order to simulate an unknown environment to the people joining the test (and thereby addressing the possible learning effect in the tests), two stairs were randomly picked and people needed to find the stairs by themselves. In strategies 3 and 4, another two stairs were picked, but guidance was provided for people to find the stairs.

From the testing, strategy 3 has the best performance since people could use both the elevator and the stairs with guidance. Compared to strategy 1, strategy 3 has a reduction of around 40 percent in total egress time. Strategy 4 has similar performance to strategy 3, while with strategy 4, more people

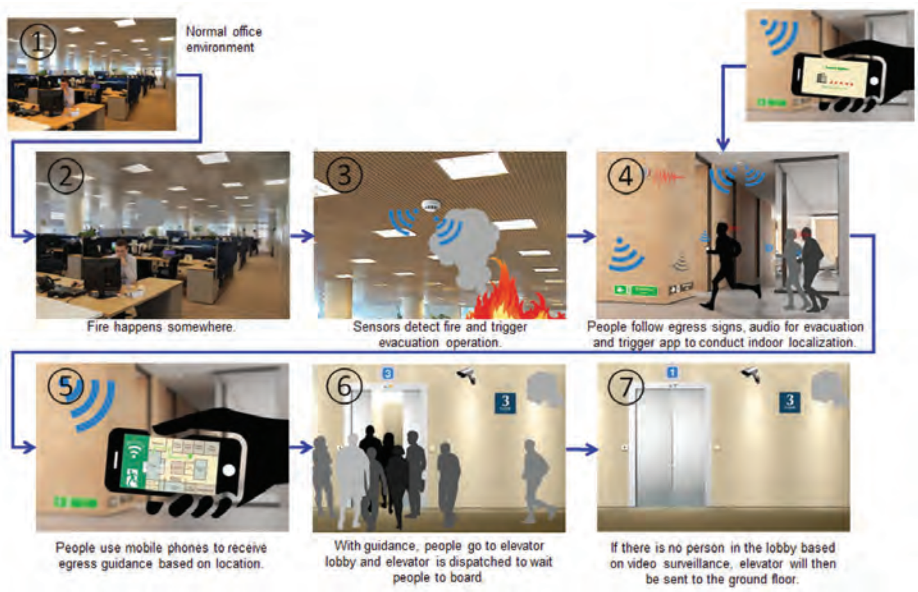

Figure 8. POC 1 concept of operations (Source: UTRC)
图8. POC1操作概念（来源：联合技术研究中心）

智能疏散的概念验证方案

为了集成和测试以上所述的技术，联合技术公司正在研发多个POC（Proof of Concepts，概念验证方案）。本文将详细讨论其中的两个POC来展示本公司所提出方案的可行性。

联合技术公司提出的智能疏散是一个具有创新性的方案，该方案通过集成的、智能的系统利用来自建筑传感器的实时数据，以提高疏散有效性和疏散效率。

在POC1中，联合技术公司提出的系统以如下的步骤工作，具体如（图8）：

1. 在正常情况下，人员在他们的办公室工作；

2. 在办公楼的某一处地点发生火灾；

3. 火灾报警系统（联合技术公司海湾安防技术有限公司产品）检测到烟雾并触发报警系统；

4. 消防指示牌控制系统（联合技术公司海湾安防技术有限公司产品）根据火灾位置并按照预先配置好的路线点亮对应路径上的消防指示牌；

5. 人员按照消防指示牌的方向来进行逃生。同时，他们也可以触发联合技术公司开发的人员定位手机应用来进行定位。根据当时人员的位置，一条定制的最优疏散路径会显示在手机应用上；

6. 同时，电梯控制系统（联合技术公司奥的斯公司产品）派遣电梯到失火楼层；

7. 智能视频分析系统（联合技术公司Interlogix公司的产品）会监控在电梯等候厅的人员状态。一旦所有人员都已经进入电梯，智能视频分析系统会发送一个"Go"命令给电梯并让电梯去疏散楼层；

对于以上所述的POC 1，联合技术公司在联合技术气候、控制与安防上海研发中心工程大楼进行了验证。该工程大楼具有三层，总面积大约是600平方米。四种主要疏散策略被测试，并且每种策略的疏散时间被记录下来。

策略1：没有消防指示牌，没有电梯，只有楼梯1可以使用；

策略2：没有消防指示牌，有电梯，只有楼梯2可以使用；

策略3：有消防指示牌，有电梯，只有楼梯3可以使用；

Figure 9. Otis Shibayama Testing Tower in Japan (39 stories, 154 meters) (Source: UTRC)
图9. 日本奥的斯Shibayama测试塔（39层，154米）（来源：联合技术研究中心）

used the elevator regardless of the guidance, which consequently increased elevator waiting time and total evacuation time.

For POC 2, UTC is conducting tests at Otis Japan's Shibayama Testing Tower (STT) (Figure 9). The objectives of this POC include demonstrating an integrated intelligent egress system for multiple floors at STT. The current egress system includes one elevator (including elevator controllers), egress indicators, smoke sensors, and five surveillance cameras. As same as POC 1, all these systems are products from UTC. Another objective is to evaluate OEO rules at STT for multiple floor evacuations.

UTC has set up the intelligent egress system (with products from GST, Otis and Interlogix) at STT. Next, based on OEO rules, the egress system at STT can automatically implement elevator dispatching control and elevator motion control in real-time, such as determining the egress priority for affected floors and controlling the elevator doors' opening and closing in according to the loading. Furthermore, the intelligent egress system will integrate lobby occupancy detected by cameras to support automatic implementation of the OEO rules.

As for future POCs, UTC plans to set up an intelligent egress system at Otis' Xizi Otis factory in Hangzhou, which has a three-floor office building with larger areas and multiple elevators to further evaluate the proposed system in a greater scale.

Emerging and Future Enabling Technologies

In addition to the capabilities listed above, UTC sees the benefit from development in the areas below:

Threat propagation modeling: Threat propagation modeling can support intelligent egress, especially for egress path planning. In order to help people avoid risks during evacuation, it is important to understand the evolution of threats, such as smoke and fire propagation (Figure 10). With such knowledge, an intelligent egress system can then better optimize an egress path in real-time to guide people to safe areas (Tomastik, 2008).

Egress path planning: As mentioned previously, an egress path is usually pre-defined when people configure the egress system for the building; however, a pre-defined path does not consider real-time risks such as fire, smoke positions, people congestion, and so on. Real-time and dynamically updated egress paths are important. Normally, path planning is a

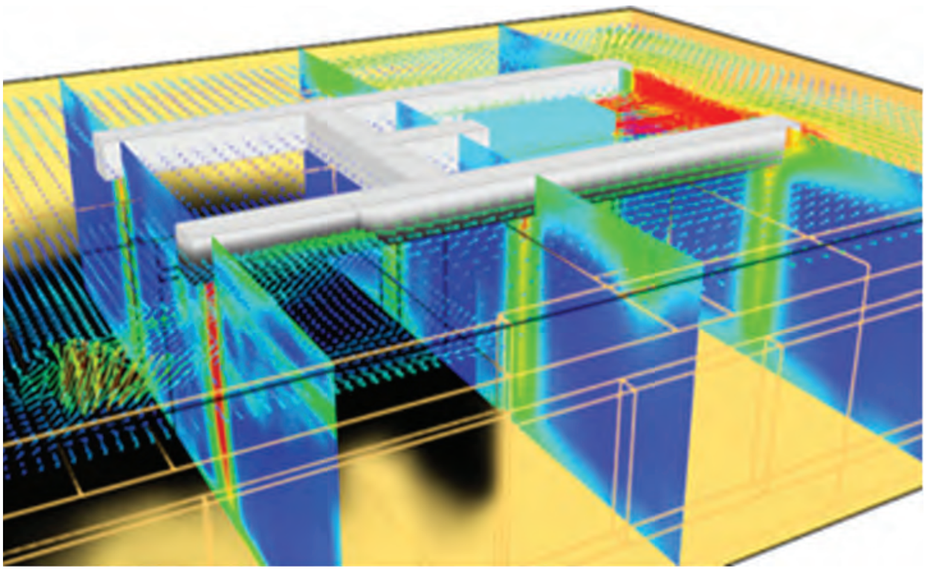

Figure 10. Smoke propagation modeling (Source: UTRC)
图10. 烟雾扩散模拟（来源：联合技术研究中心）

策略4：有消防指示牌，有电梯，只有楼梯4可以使用；

在策略1和2中，为给测试参与者模拟一个陌生环境（并解决测试中可能产生的学习效应），人员需要无指引地找到被随机选出的两组楼梯。在策略3和4中，人员被指引找到另外两组楼梯。

在测试中，由于人员可以同时使用电梯和楼梯，并且接受逃生指示，策略3具有最优的性能。和策略1相比，策略3大概减少了40%的逃生时间。策略4和策略3具有相似的性能，但是策略4中更多的人不管逃生指示牌的指示而使用电梯，从而增加了电梯等待时间并增加了总的逃生时间。

对于POC2，联合技术公司正在图九所示的日本奥的斯Shibayama测试塔（STT）进行测试（图9）。这个POC的目标如下：展示对于多层楼的集成智能疏散系统。目前的智能疏散系统包含一个电梯（包含电梯控制器），疏散指示牌，烟雾传感器，和五个监控摄像头。和POC1一样，POC2中的所有产品全部由联合技术公司开发。在STT测试多层楼中的人员撤离操作规范。

联合技术公司已经在STT部署了整套智能疏散系统。下一步，基于人员撤离操作规范，STT的疏散系统将实现自动电梯派遣控制与电梯运行控制（包括决定受影响楼层的疏散优先级，根据负载自动控制电梯门的开关等）。而且，未来智能疏散系统将整合监控摄像头探测的大厅人员占用信息以支持人员撤离操作规范的自动实施。

对于未来的POC，联合技术公司计划在杭州西子奥的斯制造楼设立智能疏散系统。该楼具有三层并且每一层拥有更大的平面空间，同时有多台电梯，以进一步评估在更大空间下智能疏散系统的性能。

新兴的和未来应用技术

除了以上介绍的技术之外，联合技术公司还提出以下的新技术作为紧急疏散未来发展的方向：

危险情况扩散模拟：危险情况的扩散模拟可以有效地支持智能紧急疏散，特别是紧急疏散的路径规划。为了帮助人群在紧急疏散时躲避危险情况，了解危险的演进非常重要，比如火情和烟雾的扩散趋势（图10）。有了这些知识，一个智能的紧急疏散系统可以更好的实时的计算优化的疏散路线，指引人群到达安全区域。

紧急疏散路线规划：如前面所说，紧急疏散的路线一般是在人们设计建筑疏散系统时提前设置的。但是这种提前设置的疏散

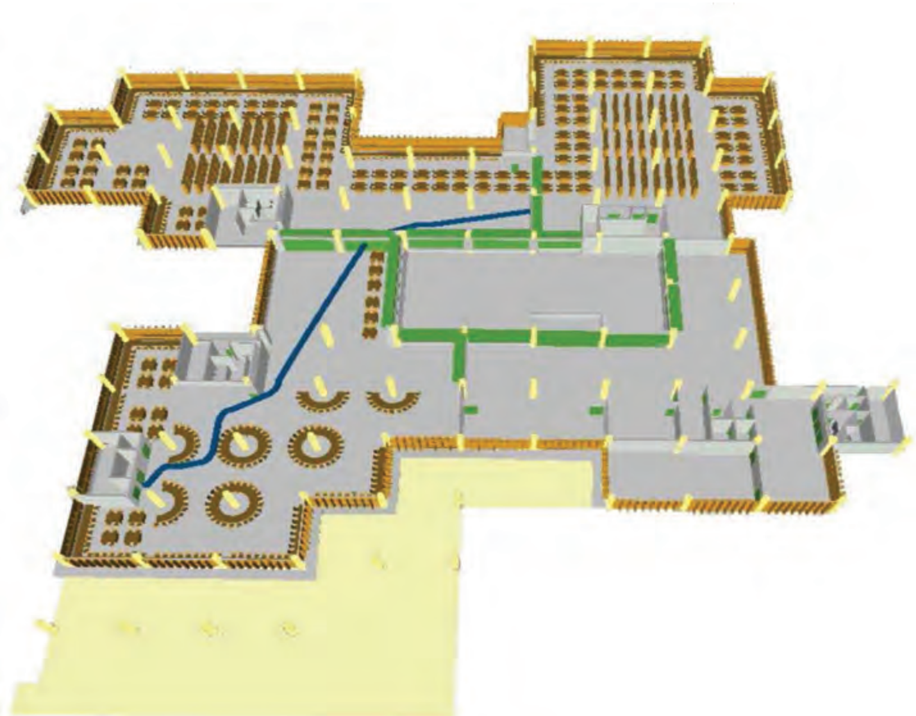

Figure 11. Example of indoor path planning for egresses (Source: Lin, 2013)
图11. 室内路线规划的例子（来源：Lin，2013）

multi-objective optimization problem. A dynamic egress path planning will need to minimize evacuation time and risk exposure to humans, while at the same time consider constraints, such as building layouts, egress path throughputs, and so on (Figure 11).

Building layouts creation: As discussed previously, using BIM can aid visualization of an egress system; however, creating BIM is currently a time consuming task which also requires professional CAD tools. Meanwhile, it is not easy to parse building layout information from BIM files to a path-planning module. New methods, such as using intelligent sensors to automatically capture building layouts and structures, or creating easy-to-use software tools to support BIM creation and data parsing, are also an interesting area to pursue.

Mobile platform: In previous sections, we have discussed a mobile platform for indoor localization and a mobile app for egress guidance. In the future, UTC hopes to enhance the mobile platform's functionalities (Figure 12) to let users be more connected with buildings, and to exchange information with building systems and other occupants.

Semantics for intelligent egress: Based on current usage of egress systems, a lot of semantic information can be extracted to improve the egress operation to be more efficient and effective. Industry needs to develop common standard semantic tagging to enable interoperability, and plug and play between systems.

UTC hopes that these new ideas can bring more fresh thoughts to Industrial and academic communities to advance technology development for intelligent egress; however, for advancing intelligent egress, technology development is just one element. Other elements, such as international code compliance, product certification, training for building occupants in following rules and guidance during emergencies, and so on, should all be carefully studied before UTC launches more advanced intelligent egress products for high-rise buildings.

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路线并没有考虑实时的危险情况（比如火灾烟雾的具体位置，人群的拥挤程度）。实时而且动态变化的疏散路线尤其重要。一般情况下，路线规划是一个多目标优化的问题。动态的疏散路线优化需要减少疏散时间，降低危险情况的接触，同时考虑建筑布局，疏散路线的人流吞吐量等限制条件（图11）。

建筑结构信息生成：如前所讨论，使用BIM可以帮助显示建筑紧急疏散系统的信息。但是，目前制作生成BIM需要花费大量的人力时间，并使用专业的CAD软件工具。同时就算有了BIM文件，从其中得到建筑布局信息用来做路线规划也不是容易的事情。我们需要发现新的方法，如使用智能传感器来自动捕捉建筑布局，或开发简单易用的软件来支持创建BIM和提取数据。这些问题也是一个比较有潜力的新的研究发展方向。

移动平台：在之前的章节中，我们已经讨论了一个用来协助室内定位的移动平台以及用来疏散导航的移动应用。在未来，联合技术公司希望加强这个移动平台的功能（图12），以使用户能够更加紧密的和建筑系统连接，从而和建筑系统以及建筑的其他用户更好的交互信息。

智能疏散的语义信息：根据目前紧急疏散系统的日常使用，我们可以提取很多语义信息，以改进紧急疏散系统使其更加有效和高效。工业界需要开发更加普遍的标准语言标签来使启用系统间的信息交互，互相兼容以及即插即用。

联合技术公司希望以上提出的新理念可以帮助工业界以及学术界为改进智能疏散的技术开发带来新想法。但是，为改进智能疏散，技术的发展只是一个方面，其他的重要问题比如国际规范的准守，产品的认证，以及建筑乘员在紧急情况下符合规定和引导的培训等等，都必须得到严格的研究与论证。这些问题也都必须在联合技术公司为高层建筑推出更加先进的智能疏散产品前得到仔细的研究。

Figure 12. Example of mobile platform for egress application (Source: UTRC)
图12. 用于紧急疏散的移动平台的示例（来源：联合技术研究中心）

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References:

American Society of Mechanical Engineers.. (2013). **Safety Code for Elevators and Escalators.**

Bukowski, R.W. (2007). **"Emergency Egress Strategies for Buildings"**, International Interflam Conference, London, England, 159-168.

CTBUH. (2010). **International Applications of Elevators for Fire Service Access and Occupant Egress in Fires.**

DailyMail. (2015). **First Pictures of Dubai Hotel's Ravage Interior.** Available at: http://www.dailymail.co.uk/news/article-3380987/Dubai-hotel-smoulders-day-fire-ripped-luxury-building-guests-reveal-people-climbed-escape-photographer-avoided-flames-dangling-hundreds-feet-air-rope.html

International Code Council (ICC). (2012). **International Building Code (IBC).**

Kinateder, M.T., Omori, H. and Kuligowski, E.D. (2014). **The Use of Elevators for Evacuation in Fire Emergencies in International Buildings.**

Khaled, N. and Bayyoumi, A. (2012). **A Simulation Study of the Effect of Mosque Design on Egress Times.** WSC-2012, Berlin.

NIST. (2008). **Final Reports from the NIST World Trade Center Investigation.** September 2005 and November 2008.

Oldfield, P., Trabucco, D. and Wood, A. (eds.) (2014). **"Roadmap on the Future Research Needs of Tall Buildings"**, Council on Tall Buildings and Urban Habitat: Chicago.

Romano, K., Rusert, M. and Reeve, H. (2015). **Integrated and Intelligent Buildings: An imperative to People, the Planet and the Bottom Line.** CTBUH, New York.

Stojanović, D. and Stojanović, N. (2014). **"Indoor Localization and Tracking: Methods, Technologies and Research Challenges",** Facta Universitatis, Series: Automatic Control and Robotics. 13(1), pp.57-72.

Stranieni P., Bora G., Hsu A. and McColl, D. (2014). **Use of Elevators During Emergencies.** CTBUH, Shanghai.

Tomastik, R., Narayanan, S., Banaszuk, A. and Meyn, S. (2010). **Model-Based Real-Time Estimation of Building Occupancy During Emergency Egress.** Pedestrian and Evacuation Dynamics 2008 (pp. 215-224). Springer Berlin Heidelberg.

Lin, Y-H., Liu, Y-S., Gao, G., Han, X-G., Lai, C-Y. et al. (2013). **The IFC-Based Path Planning for 3D Indoor Spaces.** Advanced Engineering Informatics, Elsevier.