Applying a network flow model to quick and safe evacuation of people from a building: a real case

Claudio Arbib, Henry Muccini, Mahyar Tourchi Moghaddam
Department of Information Engineering, Computer Science and Mathematics
University of L'Aquila – Via Vetoio, Coppito – 67100 L'Aquila, Italy
{claudio.arbib, henry.muccini}@univaq.it; mahyar.tourchimoghaddam@graduate.univaq.it

Abstract

We present a computational component that allows to evaluate the minimum time necessary to evacuate people from a place (e.g., a public building). The space and time dimension are discretized according to metrics and models in literature. The component formulates and solves a linearized, time-indexed flow problem [3] on a network that represents feasible movements of people monitored at a suitable frequency. This computational component is the core part of an IoT infrastructure aimed at monitoring crowds in public spaces for planning evacuation paths. The CPU time to solve the model is compliant with real-time use. An application of the algorithm to a real location with real data is described, and diverse uses of the methodology are presented.

Keywords: Safe evacuation; Network optimization; Emergency handling; Linear programming.

1 Introduction

Crowded public venues are significantly under risk, and casualties may be caused by hazards of various nature and possible consequent overcrowding. Evacuation plans are becoming more and more elaborated, and restrictive regulations are imposed by law both in normal exercise of public services and when organizing public events. A good evacuation plan takes into account different types of crises and emergencies (e.g., earthquake, fire, ...), different scenarios, and different risks. Safe and first aid zones are carefully identified,

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as well as evacuation paths to safe areas[1].

While very elaborated, standard emergency plans may still suffer of limitations. First, they are mostly *design-time* and do not take *real-time* data into account. Consequently, an emergency plan may suggest people in an auditorium to move to the outside park when fire originated right in that area; or, it may suggest evacuation routes that are currently not walkable. Secondly, once paths from buildings to external safe areas are drawn, directions for their use are normally care of human operators — when available — and are based on a partial view on how emergency is constraining the building area. Third, while the release of an evacuation plan may take weeks and requires external reviewers for approval, only few people typically (and unfortunately) read them[2].

To cope with the above issues, this paper uses a *run-time network flow model* that, based on both design (e.g., building dimension and structure, room capacities, door capacities) and run-time information (e.g., current amount of people in the building, in specific rooms and corridors) easily acquired via IoT devices, may support the quick evacuation of people in case of hazard. The model, developed in the late eighties [3], has a combinatorial nature, as it decomposes both space (building plan) and time dimension into finite elements: *unit cells* and *time slots*. The building topology is then represented as a graph with nodes corresponding to cells, and arcs to connections between adjacent cells. Run-time data are used to create an acyclic digraph that models all the feasible transitions between adjacent cells at any given time slot, given the current occupancy status of each cell. Minimizing the total evacuation time corresponds then to solve a mathematical program that, in the final refinement, has the form of a linear optimization problem.

In the present context, an optimal solution does not have — of course — a big prescriptive validity: in other words, optimal flows through the building might in general be difficult to implement in practice (in case of risk, people tend to move quite unpredictably). The interest of an optimal solution mainly lies in its numerical value, that is the minimum amount of time necessary, in ideal conditions, to let a given distribution of people out of the place. This number can be used to monitor safety conditions from time to time. In fact, the main plus with respect to standard evacuation plans, are:

i) Optimal solutions can continuously be updated thanks to the efficient mathematical structure of the problem, so evacuation guidelines can be adjusted according to visitors positions that evolve over time. *ii)* In this way, evacuation plans can be based on real-time information. Just to indicate one advantage, paths that become suddenly unfeasible can automatically be discarded by the system. *iii)* The model can be incorporated into a mobile app supporting emergency units to evacuate closed or open spaces. *iv)* Problem solutions for different time horizon provide a Pareto frontier that relates available time to the best possible people outflow in the given conditions. All that given, our overall view (backed up by ongoing work) is to integrate the mathematical model and algorithm here proposed with an *IoT infrastructure* and a *mobile app*.

The paper is organized as follows. Literature is briefly discussed in Section 2. Section 3 presents the flow model. Section 4 refers on how model parameters should be set up to deal with real cases. The application of the model to a real exhibition venue is presented in Section 5, while the IoT architecture including the flow model component is presented in Section 6. Conclusions are finally drawn in Section 7.

[1] The evacuation plan adopted during the Researchers Night event, hosted in the city of L'Aquila in 2016 (NdR2016) can be found at http://tiny.cc/ResearchersNight2016.

[2] The evacuation plan for the NdR2016 event was downloaded from website/mobile applications prepared for the event just 36 times against 5700 total visitors.

2 Literature review

Evacuation routing problems (ERP) for large scale roads and buildings are complex and subject to various modeling issues. In literature, the ERP is addressed by either static or dynamic algorithms. Indeed, a static network cannot properly model time related constraints, and a dynamic view can then be obtained by a sort of time expanded network that models flows over time. Choi et al [3] model building evacuation by dynamic flow maximization, considering variable capacities on some arcs as a function of flows in incident arcs. Taneja et al. [15] propose a more sophisticated bi-level network-based optimization model where an Interior Point algorithm is used to determine an optimal capacity arrangement for an efficient crowd evacuation. Chen et al. [2] propose a flow control algorithm that calculates evacuation paths depending on building plan and total number of evacuees. Computation in this case aims at minimizing total evacuation time and assigning an optimal number of evacuees to each evacuation path. However, as network size increases, the flow model can no longer be solved in reasonable time.

Recent research bases evacuation planning on a transshipment problem. For instance, Schloter et al. [14] study two classical flow models in order to deal with crowd evacuation planning: one algorithm aims at finding the best transshipment as a convex combination of simple lex-max flows over time; a second one computes earliest arrival transshipments that maximize the flow towards the sink for every point in time.

Other papers propose a hybrid optimization-simulation approach. To quote an example, Abdelghany et al. [1] integrates a genetic algorithm with a microscopic pedestrian simulation assignment model. The genetic algorithm looks for an optimal evacuation plan, while simulation guides the search by evaluating the quality of the plans generated. The obtained plan is claimed to outperform conventional plans that implement nearest-gate immediate evacuation strategies.

One of the most crucial issues addressed in the recent literature is the ability of finding good feasible solutions in short time. In general, a trade-off is observed between complex models that accurately describe the scenario, but cannot be solved quickly and thus call for heuristics (so loosing accuracy of solution and situation assessment), and simpler models that can be solved quickly and exactly, but lack from the viewpoint of scenario description. In this perspective, however, Choi et al.'s early paper [3] still provides in our mind a good starting point. Limited to a theoretical analysis at publication time, this paper now deserves reconsideration in the light of the progress done in LP solution tools. Nowadays solvers, in fact, get easily rid of very large problems in fractions of seconds: dealing with more variables helps on one hand obtain enough resolution to model the necessary details (in terms of both discretization and non-linearities); on the other hand, quick re-computation allows to cope with data that dynamically change over time.

3 A flow model to minimize total evacuation time

3.1 Building topology and crowd flows

The following network construction basically follows [3]. The topology of the building to be evacuated is described by a graph $G = (V, A)$ that in [3] is called *static network*. Nodes of G correspond to the unit cells i obtained by embedding the building into a suitable grid, see e.g. Figure 1. Grid geometry and size lead to different levels of accuracy. We do not discuss this issue in detail. We just observe that, in general, cells may have different shapes or sizes: for the purpose of our work what is important is that every cell can approximately be traversed, in any direction, in a single time slot. Cell 0 conventionally represents the outside of the building, or in general a safe place. Safe places can even be disconnected areas, but as their

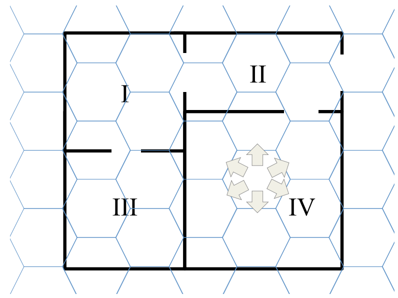

Figure 1: Room embedding into a bee-nest grid.

capacity is assumed large enough to guarantee safety, we will represent them all by a single cell (therefore what we assume about cells traversing time does not apply to cell 0). Arcs of G correspond to passages between adjacent cells: the passage has full capacity if cells share a boundary not interrupted by walls, and a reduced capacity otherwise. With no loss of generality, arcs are supposed directed. Let us denote:

$T =$ $\{0, 1, \ldots, \tau\}$, set of unit time slots;

$y_i^t =$ state of cell $i \in V$ at time $t \in T$, that is, the number of persons that occupy i at t: this number is a known model parameter for $t = 0$ (in particular, $y_0^0 = 0$) and a decision variable for $t > 0$;

$n_i =$ capacity of cell i: it measures the maximum nominal amount of people that i can host at any time (in particular, $n_0 \geq \sum_i y_i^0$); this amount depends on cell shape and size; if cells can be assumed uniform one can set $n_i = n$ for all $i \in V, i \neq 0$.

$x_{ij}^t =$ how many persons move from cell i to an adjacent cell j in $(t, t+1]$: this gives the average speed at which the flow proceeds from i to j;

$c_{ij} =$ capacity of the passage between cell i and cell j: this is the maximum amount of people that, independently on how many persons are in cell j, can traverse the passage in the time unit (independence on cell occupancy means neglecting system congestion: we will consider this issue later).

The flow model uses an acyclic digraph D with node set $V \times T$ and arc set

$$E = \{(i, t) \to (j, t+1) : ij \in A, t \in T\}$$

Referred to as *τ-time* or *dynamic network* in [3], D models all the feasible transitions (moves between adjacent cells) that can occur in the building in the time horizon T. Transitions are associated with the x-variables defined above, whereas y-variables define the occupancy of each room (and of the building) from time to time. The x- and y-variables are declared integer and subject to the following constraints:

$$y_j^t - y_j^{t-1} - \sum_{i:ij \in A} x_{ij}^{t-1} + \sum_{i:ji \in A} x_{ji}^{t-1} = 0 \qquad j \in V, t \in T, t > 0 \tag{1}$$

$$0 \leq x_{ij}^t + x_{ji}^t \leq c_{ij} \qquad t \in T, ij \in A \tag{2}$$

$$0 \leq y_i^t \leq n_i \qquad t \in T, i \in V \tag{3}$$

Equation (1) is just a flow conservation law: it expresses the occupancy of cell j at time t as the number y_j^{t-1} of persons present at time $t-1$, augmented of those that during interval $(t-1, t]$ move to j from another cell $i \neq j$, minus those that in the same interval leave cell j for another room $i \neq j$. Box constraints (2), (3) reflect the limited hosting capability of the elements of G.

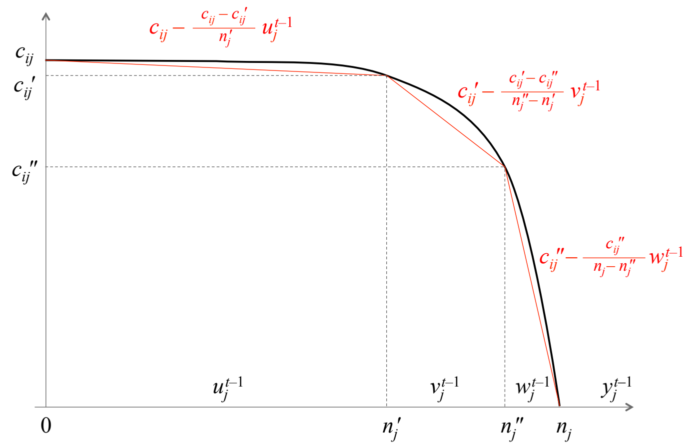

Figure 2: Congestion curve and a linearization.

3.2 Maximizing outflow in a given time

To model the relation between time and people outflow, one can try to maximize the number of persons evacuated from the building within τ:

$$\max \quad y_0^\tau \tag{4}$$

This is the *Max Flow Problem* (MFP) considered in [3]. To find the minimum total evacuation time, one can solve an MFP for different τ, looking for the least value that yields a zero-valued optimal solution. To reduce computation time, this optimal τ can be computed by logarithmic search. The method can thus provide the decision maker with the Pareto-frontier of the conflicting objectives $\min\{\tau\}, \max\{y_0^\tau\}$. The linear structure of the model allows its solution with a large number of variables. Adding variables can help improve model granularity by reducing space and time units (e.g., counting people every 5 seconds instead of every minute). More importantly, it can also help approximate the non-linearities of arc capacities. In fact, c_{ij} constant in (2) fails to model congestion, that is a situation in which the speed at which the system empties is a decreasing function of room occupancy. A more accurate model of congestion requires arc capacity to be a concave decreasing function of room occupancy, see Figure 2. Linearizing concavity one can rewrite

$$y_i^{t-1} = u_i^{t-1} + v_i^{t-1} + w_i^{t-1} \qquad x_{ij}^t = \phi_{ij}^t + \chi_{ij}^t + \psi_{ij}^t \tag{5}$$

with $u_i^{t-1}, v_i^{t-1}, w_i^{t-1}$ non-negative and subject to upper bounds

$$u_i^{t-1} \leq n_i' \qquad v_i^{t-1} \leq n_i'' - n_i' \qquad w_i^{t-1} \leq n_i - n_i' \tag{6}$$

Arc capacity constraints (2) are then replaced by

$$\begin{array}{rcccl} 0 & \leq & \phi_{ij}^t & \leq & c_{ij} - \dfrac{c_{ij} - c_{ij}'}{n_v'} u_j^{t-1} \\ 0 & \leq & \chi_{ij}^t & \leq & c_{ij}' - \dfrac{c_{ij}' - c_{ij}''}{n_j'' - n_j'} v_j^{t-1} \\ 0 & \leq & \psi_{ij}^t & \leq & c_{ij}'' - \dfrac{c_{ij}''}{n_j - n_j''} w_j^{t-1} \end{array} \tag{7}$$

Consistency of the ϕ, χ and ψ variables with the x flow variables requires $\chi = 0$ ($\psi = 0$) if ϕ (if χ) does not saturate its capacity. This is ensured, at optimality, by the properties of basic solutions. After rephrasing

(7):

$$
\begin{array}{rclcrcl}
0 & \leq & \phi_{ij}^t & & \phi_{ij}^t + a_{ij} u_j^{t-1} & \leq & c_{ij} \\
0 & \leq & \chi_{ij}^t & & \chi_{ij}^t + a'_{ij} v_j^{t-1} & \leq & c'_{ij} \\
0 & \leq & \psi_{ij}^t & & \psi_{ij}^t + a''_{ij} w_j^{t-1} & \leq & c''_{ij}
\end{array} \tag{8}
$$

where

$$
a_{ij} = \frac{c_{ij} - c'_{ij}}{n'_j} \qquad a'_{ij} = \frac{c'_{ij} - c''_{ij}}{n''_j - n'_j} \qquad a''_{ij} = \frac{c''_{ij}}{n_j - n''_j}
$$

and $a_{ij} < a'_{ij} < a''_{ij}$, we observe the following fact (that can be generalized to any piecewise linear approximation of the congestion curve).

Proposition 1. *Suppose that, in a feasible solution, $\bar{u}_i^t < n'_i$ and $\bar{v}_i^t > 0$. Let*

$$
\delta = \min\{n'_i - \bar{u}_i^t, \bar{v}_i^t\}
$$

Then a solution with $u_i^t = \bar{u}_i^t + \delta$, $v_i^t = \bar{v}_i^t - \delta$ and the other components unchanged is also feasible and no worse than the given one.

Proof. See [3]

It is worth mentioning that, the polyhedron in the new varables is not necessarily integral. For large flows, however, the linear relaxation provides a sufficiently good approximation to an optimal integer solution.

4 Setting model parameters

To get a reliable model, parameters must be set to numbers that reflect reality. Those numbers depend on several considerations, the most relevant being: model granularity, walking velocity in various conditions (on a flat, on staircases etc.), door (and staircase) entrance capacities, room (and staircase) capacities.

4.1 Model granularity

The issue of model granularity touches both spatial and temporal units, and affects the shape and size of the unit cells in which the building is decomposed, as well as the slots that form the evacuation time horizon.

As described in the previous sections we embed the building plan into a grid, whose cells are assumed *isometric*: that is, can be crossed in any direction in the same amount of time. That amount will define the time slot duration, and cells will be regarded as virtual unit rooms that communicate one another via physical or virtual (i.e., open space) doors, see Figure 1.

Grid geometry can vary. Ideal isometric cells are circles, but circles are not embeddable into a grid with adjacent cell sides. Hexagon cells are a good compromise between isometry and plan embedding. However, in our study case we found room sizes and shapes well compatible with a square grid where each room is split into an integer number of cells.

4.2 Walking velocity

The cornerstone on which the length of each unit time slot in T — and consequently its reciprocal, the monitoring frequency — is established, is the *free flow walking velocity*, i.e. the speed at which humans prefer to walk in non-congested and non-hampered conditions. Clearly, its value varies for different categories of people (child, adult, elderly, disable etc.) and slope (flat, upstairs, downstairs). This parameter is important to perceive the distance that an individual can possibly walk during a specific period of time. Through its evaluation one can define the cells in which an area is to be divided for best approximation of traveling time. Table 1 reports different evaluations of pedestrian free flow velocity found in literature.

Table 1: Pedestrian free flow velocity.

Flat (m/s) under 65	over 65	**Reference**	**Stairs** (m/s) up	down	**Reference**
1.36		Fruin 1971 [6]	0.56	0.65	Fruin 1971 [6]
1.36		Weidmann 1993 [17]	0.61	0.69	Weidmann 1993 [17]
1.25	0.97	Knoblauch et al. 1996 [9]	0.8 ± 0.19		Kratchman 2007 [10]
1.042 - 1.508	0.889 - 1.083	TranSafety Inc. 1997 [16]	0.59	0.76	Jiang et al. 2009 [7]
1.20		Ye et al. 2008 [18]	0.81 ± 0.13		Fang et al. 2012 [5]
			0.83	0.86	Patra et al. 2017 [12]

We assume the free flow walking speed for a flat surface equal to 1.25 m/s. Furthermore, in our study, the flow is rarely upward and almost all people are supposed to go to safe places located at the building ground floor: for this situation, we consider a downstream free flow speed of 0.76 m/s.

4.3 Door capacity

The capacity of a door depends on such various aspects as user composition, door type (always open, open when used, turnstile), crowdedness and, last but not least, door width. A study by Daamen et al. [4] focuses on the relationship between door capacity, user composition and stress level, arguing an average 2.8 persons per second for a 1-meter width door (p/m/s). Peschl [13] found 2.25 p/m/s. Public authorities fix different standards for door capacities: for example, the Dutch Ministry for Housing, Regional Development and the Environment allows considering a maximum of 90 persons per meter width during a safe escape time of one minute; the same flow rate is suggested by the Japanese building standard law.

Experiments conducted by Kretz et al. [11] demonstrate a linear decrease of the capacity with increasing bottleneck width (ranging from 2.2 p/m/s for 40 cm to 1.78 p/m/s for 70 cm width) as long as only one person at a time can pass. Larger doors, however, are credited a constant value of 1.8 p/m/s.

None of the aforementioned studies considers bidirectional flow through doors, and so do we in our optimization model: in fact, although bidirectional flows are in principle possible, they will never occur in an optimal solution even without considering flow rate reductions due to collisions.

We assume 1.2 p/m/s for every door, meaning that a maximum number of 6 persons can pass through a 1-meter width door per time slot (5 seconds). We also assume capacity proportional to door width.

Staircase capacity is treated differently. Fruin [6] measures a maximum flow capacity of 5.5881 persons/s for a 5.6 width staircase, i.e., about 1 p/m/s. Weidmann [17] obtains 0.85 p/m/s for the same parameter. We stay at Fruin's estimate and use 1 p/m/s for each staircase in our example.

4.4 Cell capacity

The *pedestrian density* is the number of persons per square meter monitored at any time. This information is crucial for crowd safety and evacuation performance, as movements are dramatically reduced in highly dense areas. As density increases, pedestrian movements become constrained and flow rate consequently decreases. According to UK fire safety regulations, the maximum allowed density corresponds to 0.3 square

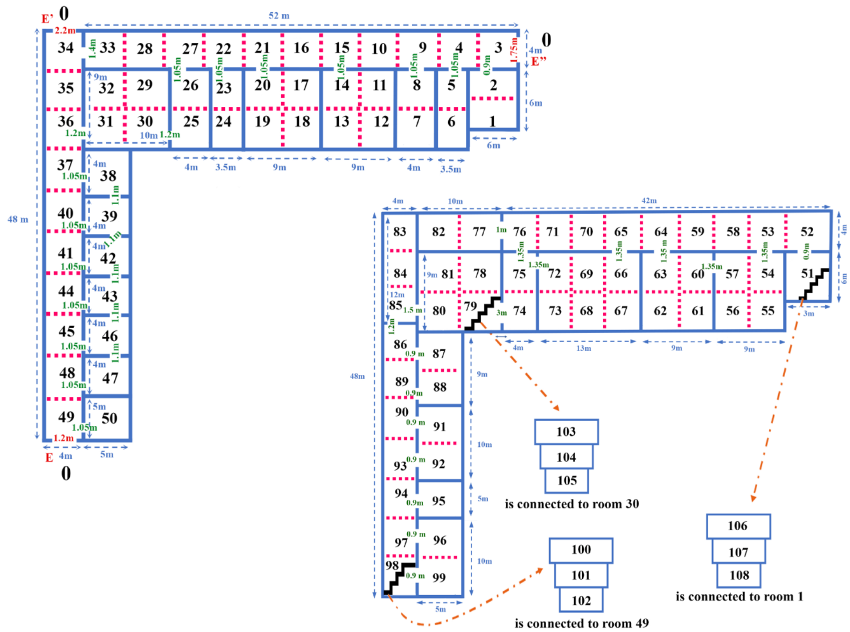

Figure 3: Embedding of Palazzo Camponeschi's plan into a square grid: ground floor up-left; first floor down-right.

meters per standing person, a value that increases to 0.5 for public houses, to 1.0 for dining places, to 2.0 for sport areas and to 6 for office areas. In our case study — gallery indoor space — the maximum capacity of each cell is calculated by assuming 0.8 square meters per visitor, that is 1.25 persons per square meter.

5 Example of application

Using the measures discussed in the previous section, we next describe an application of the model of Section 3.2 to the safe evacuation of Palazzo Camponeschi, a building in l'Aquila (Italy) normally used for exhibitions. Safety conditions of the building, which consists of 31 rooms including corridors, are supervised by L'Aquila Fire Brigade. Rooms sizes vary in a large range, and so the average time of a person to cross them from door to door is required. As explained in §3.1, we split each room in unit cells, each behaving as a (virtual) quasi-square room that can be traversed in a unit time slot. In practice, we embedded the building plan into a quasi-square grid as shown in Figure 3.

The embedding results in a graph with 109 nodes (Figure 4) corresponding to the cells of Figure 3 and including node 0 as safe place. Adjacent cells are linked by 259 arcs which allow people flow inside the building. All arcs are assumed bidirectional except the three towards the safe place. A time slot corresponds to the time required for crossing one cell: using average free flow speeds from §4.2 and considering cell size, we obtained time slots of 5 seconds each, and therefore the monitoring frequency. Door capacities vary according on size and features. As a rule of thumb, no more than 6 persons can pass through a 1-meter width door per monitoring frequency. Since downward free flow speed on stairs is lower than on a flat, staircase and related arc capacities are reduced to 5 persons/meter every 5 seconds.

We next report the simulation of an emergency occurring in two different conditions in terms of building occupancy (Scenarios 1 and 2) and route prescription. In both simulations, we computed the minimum time

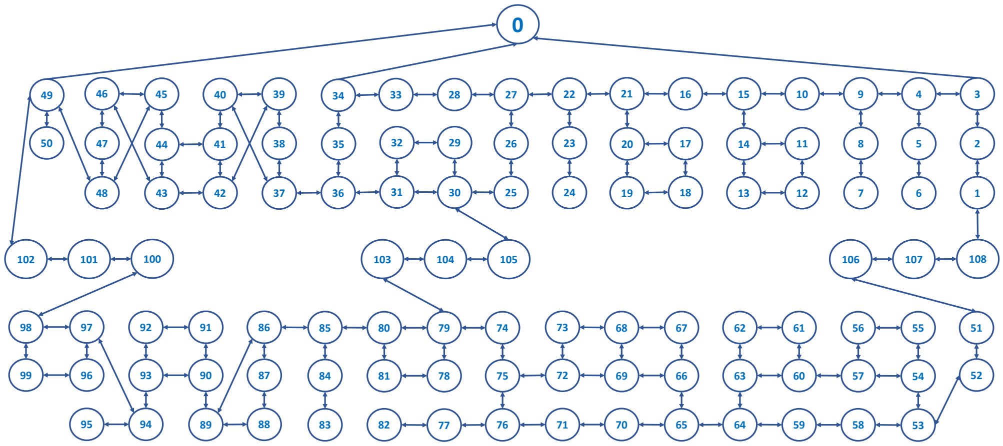

Figure 4: Network associated with the plan of Figure 3.

required to N persons, randomly distributed in the building room, for reaching a safe place. The code for simulation was written on OPL language and solved on CPLEX version 12.8.0. We ran all the experiments on a Core i7 2.7GHz computer with 16Gb of RAM memory under Windows 10 pro 64-bits.

Table 2: Evacuation and computation time - Scenario 1: a) ideal flows; b) prescribed routes.

τ	evacuees (a)	CPU Time (a)	evacuees (b)	CPU Time (b)
1	30	0,29 sec	30	0,29 sec
2	60	0,43 sec	60	0,43 sec
3	90	0,42 sec	90	0,21 sec
4	120	0,36 sec	120	0,37 sec
5	150	0,39 sec	150	0,28 sec
6	180	0,43 sec	180	0,34 sec
7	210	0,59 sec	210	0,32 sec
8	240	0,68 sec	240	0,28 sec
9	270	0,50 sec	270	0,31 sec
10	300	0,81 sec	300	0,32 sec
11	330	0,61 sec	330	0,43 sec
12	360	0,93 sec	360	0,37 sec
13	390	1,10 sec	390	0,56 sec
14	420	0,82 sec	417	0,45 sec
15	450	0,95 sec	442	0,46 sec
16	480	1,06 sec	467	0,48 sec
17	510	1,15 sec	492	0,48 sec
18	528	1,15 sec	511	0,54 sec
19			524	0,65 sec
20			528	0,56 sec

In the first simulation we suppose an initial occupancy of $N = 528$: this datum comes from an experiment performed in L'Aquila during the Researchers Night event on 29 September 2017, when the simultaneous presence of 528 people in Palazzo Camponeschi was recorded as peak value.

We solved problem (1)-(8) for $\tau = 1, 2, \ldots$ until a solution of value N is found. Table 2 reports the number of evacuees (column 2) at each τ and the computation time of each resolution step (column 3). In terms of evacuation time, everyone has reached a safe place in 1 minute and 30". As shown in the table, computations require 1.15 seconds (presolve included) in the worst case and are therefore totally compliant with real-time applications.

In a second scenario, we repeated the simulation doubling the number of people in the building. In this

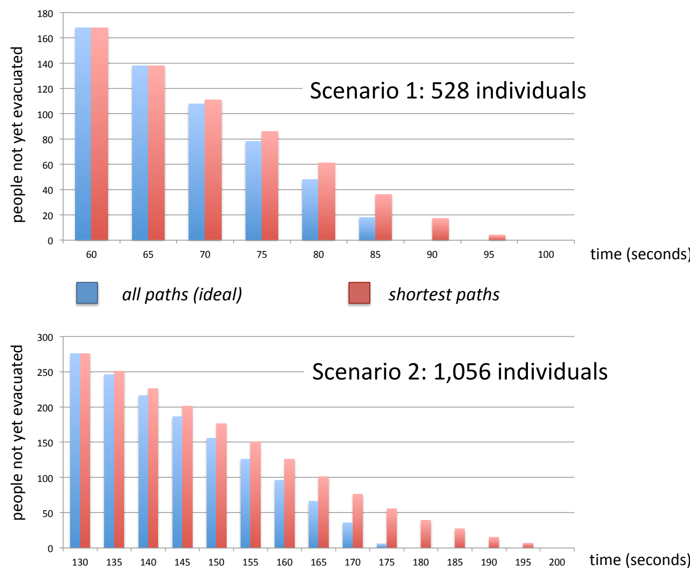

Figure 5: Ideal evacuation and evacuation along shortest paths in two scenarios.

case everyone can reach a safe place after 36 time slots, i.e., 3 minutes. Also in this case computation time is definitely short, being always under 3.39 seconds including presolve.

This first simulation depicts an ideal situation in which flows autonomously choose the best among all the available routes in the building. Of course, managing such an ideal evacuation is not easy and perhaps unpractical. As a general practice, in fact, evacuation is conducted through pre-determined routes. In a second simulation, then, we suppose that the prescribed evacuation routes are the shortest paths from any cell to the safe place. In this situation, evacuating 528 (1056) individuals takes of course more time: 1 minute and 40" (3 minutes and 20").

By comparing this simulation to the previous one, we observe that people flows plainly for some time (1 minute and 5" in the first scenario, 2 minutes and 10" in the second). After that time, shortest routes start experiencing congestion, and evacuation is slowed down. The phenomenon is illustrated in the charts of Figure 5: as one can expect, the tail of people still in the building increases with initial occupancy.

6 An IoT Evacuation Handling Infrastructure

The mathematical model and algorithm described in this paper are part of an *IoT infrastructure* for evacuation handling. The IoT infrastructure, whose architecture is sketched in Figure 6, is designed to collect the required run-time data. It is studied to be tolerant to faults (therefore to guarantee correct response also in emergency case), performant (in terms of computational time and resources), and to include both situational awareness sensors (such as disaster detectors, people counters, DVR cameras, and RFID technologies to count the number of people in closed spaces, to get information about their velocity, and direction) and actuators (e.g., to close or open windows or doors, to display evacuation information). The computational component adopted, that is the subject of the present paper, will thus become the central element that, while inputting situational awareness information, will provide evacuation recommendations.

This information is going to be displayed into a mobile app. The main goal of the application, to be run on a tablet, is to show a 2D-representation of the monitored space providing also contextual data on where

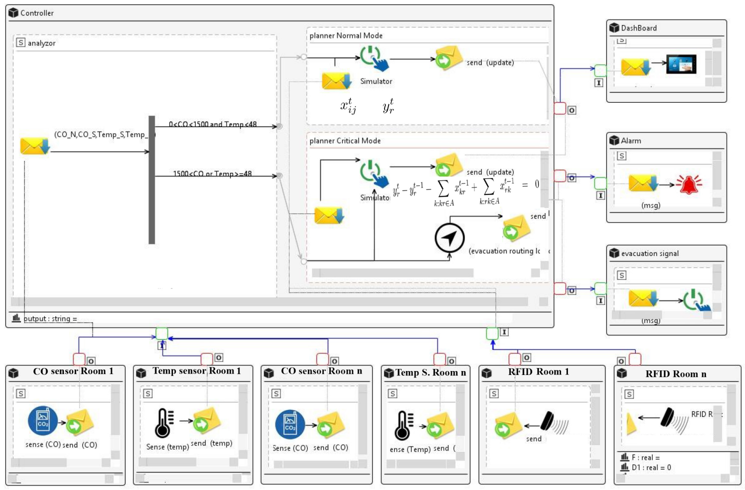

Figure 6: Architecture of the IoT infrastructure.

the crowd is at any time, and how it moves in normal and emergency cases. In this line, we have recently implemented the visualization of the crowd heat-map on mobile devices. Given such a visualization, actuators might be piloted directly from the mobile app in order to direct people through the fastest evacuation path.

While we do not expect, neither wish to, remove humans from the decision process, our project wants to support their decisions by providing run-time information — that could be unavailable otherwise — by periodically re-calculating best evacuation paths or evaluating minimum evacuation time under conditions that can vary from time to time. Just to list a couple of possibilities, (a) new sources of emergencies can be shown at run-time, (b) unexpected human behaviors can be taken into account.

7 Conclusions

This work uses a run-time network flow model for supporting the rapid evacuation of people from a building in case of emergencies. The model takes as input both static information (such as building dimension and structure, room capacities, door capacities) and run-time information (such as number of people in the building, number of people in specific rooms and corridors) acquiring it through IoT devices.

The building topology is described by a graph. Run-time data are used to create a time-indexed acyclic digraph that models all the feasible transitions between adjacent rooms at any time. Minimizing the total evacuation time corresponds to solve max flow problems with non-linear capacities that model congestion. Preliminary evaluations have been conducted on a real case.

Future work includes to: i) enrich the model with further design-time and run-time information to make the evacuation plan more accurate; ii) empirically evaluate the model in extensive scenarios, and to compare estimated vs. real data (as, e.g., those generated during evacuation tests); iii) complete the realization of the IoT infrastructure and app mentioned in Section 6 using the computational component here developed.

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