Judges' Commentary: Time to Leave the Louvre

Ralucca Gera
Dept. of Mathematics
Naval Postgraduate School
Monterey, CA 93940
rgera@nps.edu

Michelle L. Isenhour
Operations Research Dept.
Naval Postgraduate School
Monterey, CA 93940

Jessica Libertini
Dept. of Applied Mathematics
Virginia Military Institute
Lexington, VA 24450

Eleanor Ollhoff
Mathematician
Bonn, Germany

Jack Picciuto
Systems Engineer
IT Cadre
Ashburn, VA

Troy Siemers
Dept. of Applied Mathematics
Virginia Military Institute
Lexington, VA 24450

Csilla Szabo
Skidmore College
Saratoga Springs, NY

Robert Ulman
US Army Research Office
Research Triangle Park, NC

Rui Wang
Office of Performance Measurement and Evaluation
New York State Office of Mental Health
Albany, NY

Introduction

Imagine that you are at the Louvre in Paris, France, standing and admiring Leonardo da Vinci's *Mona Lisa*, or maybe Antonio Canova's *Psyche Revived by Cupid's Kiss*. Suddenly, there is a commotion, perhaps a loud explosion. The alarm sounds and you must evacuate. What do you do?

More than 5,200 teams investigated responses to such a scenario as part of the 2019 ICM™. The teams used the iterative mathematical modeling process to develop interdisciplinary solutions that would allow museum

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emergency planners to explore a range of options, policies, and procedures to evacuate visitors from the museum quickly and safely.

Problem D, "Time to Leave the Louvre," was this year's problem in network science or operations research. Intentionally less structured this year, the problem was designed to give teams considerable latitude in the development of a solution. Since the Louvre is the largest art museum in the world, we expected teams to be unfamiliar with its physical layout and number of visitors. We anticipated that teams would also be uninformed about its current policies and procedures. Even the tasks to be accomplished were not explicitly specified.

After a brief explanation of the judges' expectations, we offer a discussion of the seven Outstanding papers. As you will see, the very best student teams

- appropriately framed and scoped the problem,
- made valid and justifiable assumptions,
- applied a mathematical model (or combination of models),
- thoroughly examined the model,
- described how the model informs policy, and
- even investigated portability of their model to other large crowded structures.

Judges' Criteria

Since the overall objective was to evacuate visitors from the museum quickly and safely, the most critical items that the judges looked for were

- **implementation of a dynamic evacuation model** representing the flow of visitors during the evacuation, and
- **inclusion of results** of the evacuation tests or simulations.

Basically, the judges wanted the student teams to provide a reasonable answer to the question, "How long will it take to evacuate?"

Additionally, to resolve some of the deliberate ambiguity associated with the problem, the judges expected the student teams to **describe and implement submodels for many of the key evacuation model inputs**, such as a description of the physical space, location of incident(s), quantity and initial distribution of visitors, and locations of exits.

The final item that the judges considered essential to a strong solution was the **inclusion of outcome-based policy and procedural recommendations** for emergency management of the Louvre.

As is always the case, the professional expertise and experience of this year's judging panel spanned a variety of disciplines, including evacuation research, applied mathematics, mathematical modeling, network science, operations research, and engineering.

From the perspective of the judges, the four items described above served as their *minimal* expectations. Therefore, the judges looked also for a variety of other elements, including

- identification of potential bottlenecks in the model, which limited movement towards the exits;
- the injection of emergency personnel into the model;
- consideration of various threats, including potential incident locations inside the Louvre and their implications on route availability in the evacuation model;
- human behavioral impacts on the dynamics of the crowd movement; and
- an example adaptation and implementation of the model to other large, crowded structures.

The inclusion of an evacuation simulation was not specified nor implied; however, many student teams attempted to include a visualization of the model dynamics or tried to apply a commercially-based simulation of the evacuation. In evaluating the use of simulation, the judges looked for a logical continuation from the mathematical model to the simulation. The expectation was that any simulation should be an implementation of the model (or models) previously described by the student team.

In addition to assessing the quality of the model, the judges were looking for papers with excellent exposition in their writing, an aspect that is strongly connected to the interdisciplinary nature of the ICM. Unfortunately, many teams struggle with this part of the process, which is why this issue of this *Journal* also includes an On Jargon column on exposition [Libertini and Siemers 2019]. While even some of the strongest papers fell short of this goal, the judges were seeking papers with

- a well-written executive summary that included results,
- model development understandable by a non-specialist, and
- frequent ties that drew meaningful and convincing connections between the real-world phenomena and the inputs and outputs of the model.

Discussion of Outstanding Papers

Without a doubt, the judges sought papers that

- applied a recognized modeling process using good science and mathematics,

- found measurable results,
- conducted additional analyses, and
- communicated the entire process with both clarity and completeness.

A common theme this year was that many of the papers receiving the distinction of Outstanding were well-structured, often using a graphic to describe the method of solution and then centering the rest of the paper around this image.

Additionally, all of the Outstanding papers attempted to answer the primary question, "How long will it take to evacuate?" Some of those evacuation times may not be realistic, but the judges value the effort put forth to develop the model and obtain a solution. Ultimately, seven papers earned the distinction of Outstanding. We offer some highlights from these papers, as well as possible areas of improvement, since even the best papers are never perfect.

Duke University: "Time to Leave the Louvre: A Computational Network Analysis"

This paper was not only selected as an Outstanding Winner but also received the Leonhard Euler Award and a COMAP Scholarship Award. The judges were extremely impressed by the team's approach to tackle the problem on both the micro-level, modeling individual behavior with an agent-based model, and on the macro-level, by creating a network flow model to determine the maximum flow and evacuation time. Overall, the paper is very well organized and the writing clear and concise, with modeling steps and output coherently laid out for the reader.

The team begins with a very strong executive summary, which many papers lack. In their summary, the team introduces the problem, briefly outlines the model, gives specific model output, and addresses strengths and weaknesses of the model. The Introduction, Background, and Restatement of the Problem sections are average as compared to other papers. However, the Assumptions section is another aspect of the paper that sets it apart from others. The authors state the assumptions and also justify them with references to support their modeling choices. Few papers make this effort in justifying assumptions. The team continues to provide in-text citations throughout the paper, an approach that the judging panel wished all teams would apply.

The team analyzes the problem on two levels, individual behavior simulated with an agent-based model and a larger network flow model. They use NetLogo, a multi-agent programmable modeling environment, to create simulations of individual behavior in small sections of the museum. While several other papers use this approach, this paper stands out in the clear manner in which it steps the reader through the set-up and parameter selection. The team offers a flowchart, shown in **Figure 1**, as a helpful addition to understand the rules that govern the agent movement.

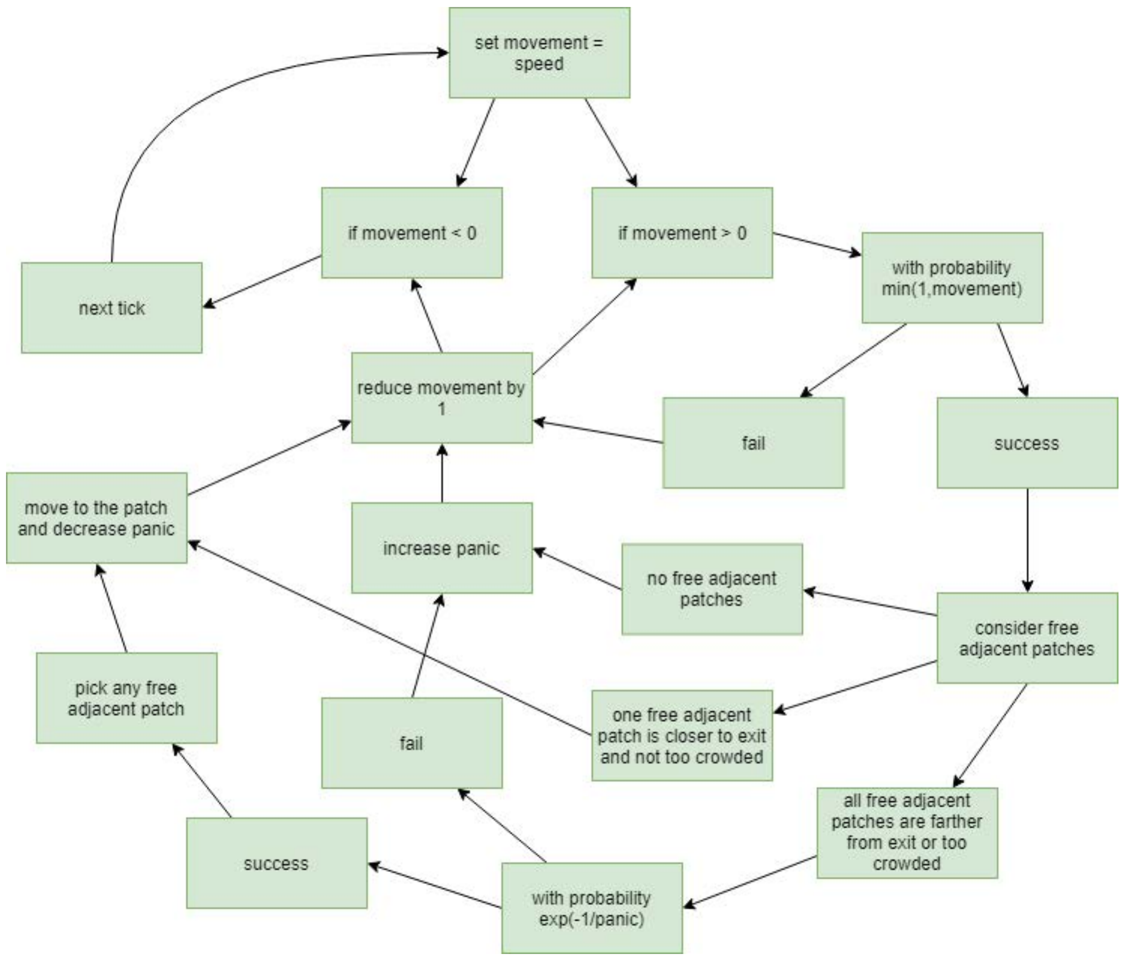


Figure 1. Flowchart describing the Duke University team's agent-based model.

Another strength of the paper is that it considers human behavior and incorporates a "panic parameter" in the agent movement; it also assumes a probability distribution of speeds for agents that is supported by research of an evacuation, and uses distances calculated from Google Maps.

The paper continues by taking a macro-view of the problem. The team creates a directed graph/network to model the flow through the museum structure, with vertices representing sections of the museum and weighted edges representing flows along pathways (hallways, stairs, etc.). The team calculates the maximum flow rate for evacuation of the Louvre and uses it to find the minimum time for evacuation.

The team provides a thorough analysis of bottlenecks using both a NetLogo simulation and the network flow model to identify locations of congestion and later to recommend where to place additional exits. These areas are clearly labeled in figures provided in the paper as shown in **Figure 2**.

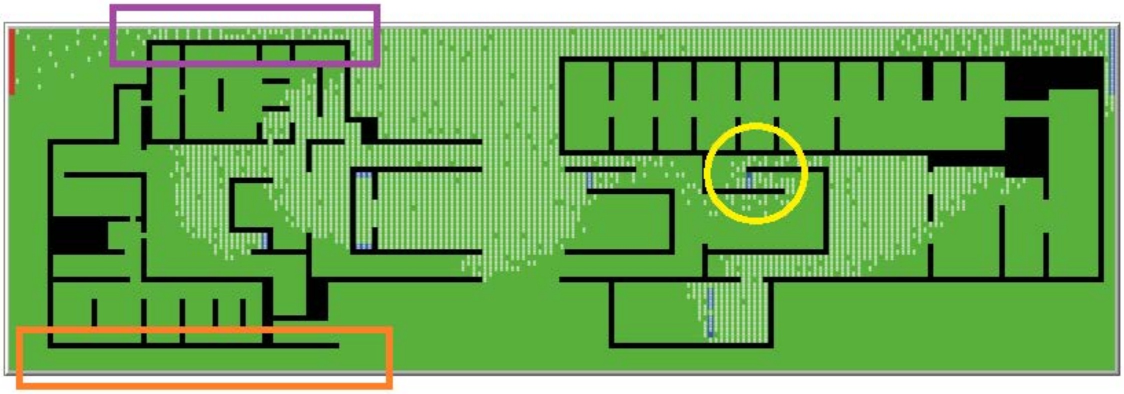


Figure 2. NetLogo simulation and bottleneck identification from the Duke University team's agent-based model.

The paper concludes with an excellent discussion of results, list of recommendations, and strengths and weaknesses of the models. Although some recommendations may be difficult to implement (e.g., additional exits and changed doorways), the team also has suggestions for technology and emergency personnel to aid in evacuations.

This was an Outstanding paper overall, but one area for improvement is in the sensitivity analysis. While the paper does perform a sensitivity analysis on some parameters used in NetLogo simulations, it falls short on connecting the analysis back to the key question, "How long will it take to evacuate the Louvre?" A helpful addition would be to report on how the evacuation time changes as the parameters are changed and possibly how additional exits reduce evacuation time.

Xi'an Jiaotong University:
"A Systematic Dynamic Route Planning Model"

This paper presents an emergency evacuation model that explores options to evacuate the Louvre while allowing emergency personnel to enter the building as quickly as possible. The team proposes a dynamic framework that accomplishes the required objectives while also considering scenarios, such as the scale or type of visitors. All unfolded subproblems or objectives are articulated in **Figure 3**, which facilitates an-easy-to-follow structure for readers.

Throughout the paper, the team clearly lists the assumptions and defines the mathematical symbols. The models applied are reasonable, with sufficient justifications. Moreover, the team provides bottleneck analysis and sensitivity analysis to support further the soundness of their work. The team provides a graphical depiction and overview of this modeling process and implementation (**Figure 4**).

The team's comprehensive work involves four major parts.

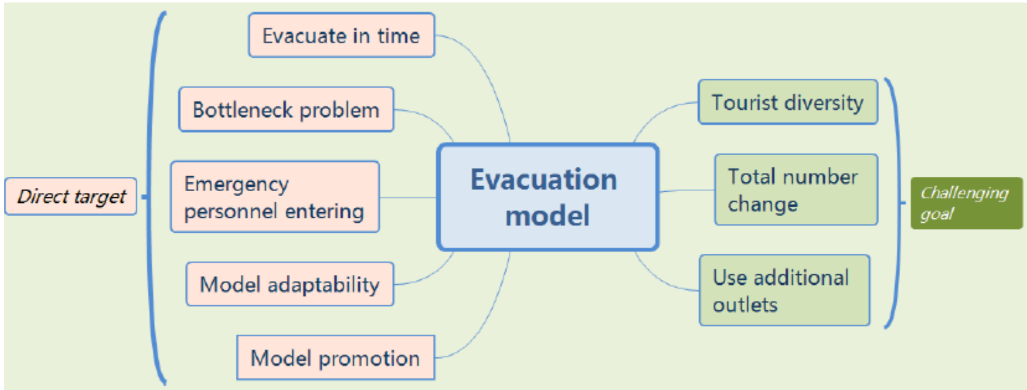


Figure 3. Dissection of the problem as articulated in the paper from Xi'an Jiaotong University.

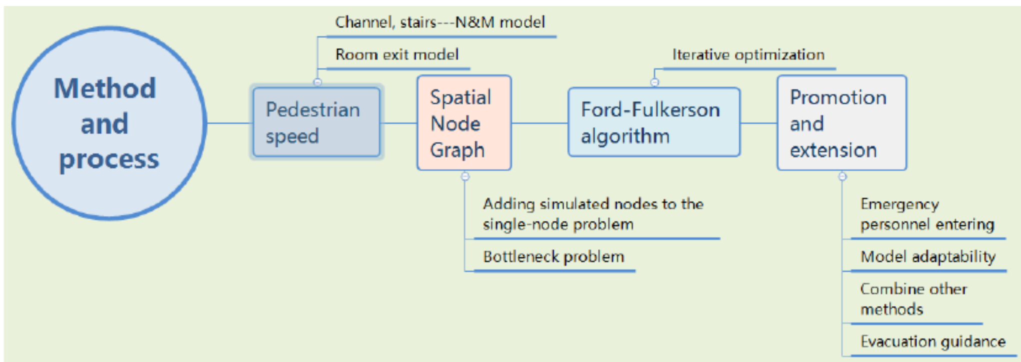


Figure 4. Method towards a solution as articulated in the paper from Xi'an Jiaotong University.

- First, they design multiple human flow-speed models for different locations, including staircases, corridors, and exits. They analyze the influence of individual factors, then apply the Nelson and MacLennan model found in the *SPFE Handbook of Fire Protection Engineering* [Hurley et al. 2016] to describe the relationship between evacuation speed and flow density, and implement a Stable Evacuation Speed (SES) model to assess the average evacuation speed.
- Second, they apply graph theory to establish a spatial node graph for the venue. Specifically, the team models the flow activities using graph theory and simplifies the "multi-target to multi-target" problem to a "single-goal to single-goal" scenario by adding two virtual nodes: a "sink point" that represents the external environment or the flow of people leaving the building from the exit, and a "source point" that does not have practical meaning but can reliably represent the remaining number of people. The team then incorporates these into traffic matrix models to carry out numerical calculations.
- Third, they set the optimization objective so that the exit flow speed at any time for all exits is the maximum that can be achieved, and then dynamically observe the evacuation and readjust the parameters through the use of an iterative process. They adopt the Ford-Fulkerson algorithm

to model the systematic planning of evacuation routes. The designed algorithms are able to handle both general and emergency cases, where a flow matrix and margin matrix can be derived in each iteration by identifying an additional "augmented path" from the source point to the sink point. Finally, the team obtains specific path planning from all traffic matrices.

- In their fourth and final part, they evaluate the adaptability of the proposed framework. The team addresses three types of bottleneck problems (imbalance in channel flow, uneven distribution of exports, and single room export) through quantitative experiments. The adaptive analysis also addresses a wide range of considerations and various types of potential threats.

Overall, the judges found this team's submission to be complete and the construction of their models to be sound; but the panel also noted several areas that could have been stronger. For example, rather than providing a standard conclusion, the team lists the strengths and limitations of their work, while the policy and procedural recommendations as well as overall conclusions are buried elsewhere in the text. The paper would have been stronger if the team had captured a summary at the end. From a more technical standpoint, in addition to the limitations stated for the model, the judges were concerned that the calculation and storage cost of the method could become expensive and may even be impossible as the number of visitors reaches a certain threshold; the team could have also included an analysis of this complexity.

Northeastern University in Shenyang, China

This submission by a team from Northeastern University in Shenyang, China is an exemplary demonstration of interdisciplinary modeling complete with a well-organized and constructed write-up of their work.

The paper starts with a concise executive summary that includes the actual quantitative results. Most other submissions neglect to put results in the summary and instead focus on what the team will be doing (techniques, models, etc.). A vital part of any executive summary is to give the reader the actual results of the paper!

Many other teams use multiple models to capture ways to exit the Louvre in an emergency situation. This team includes a diagram of their modeling and thought process to enable the reader to follow more easily their modeling process from start to finish. Shown in **Figure 5**, this flowchart is a great reference for how the team tackles the problem.

Many other factors make this paper stand out in this year's competition. Specifically, the team does not assume that each of the floors is the same. They account for different layouts, population densities, square footage, and other attributes that need to be modeled differently. For each floor,

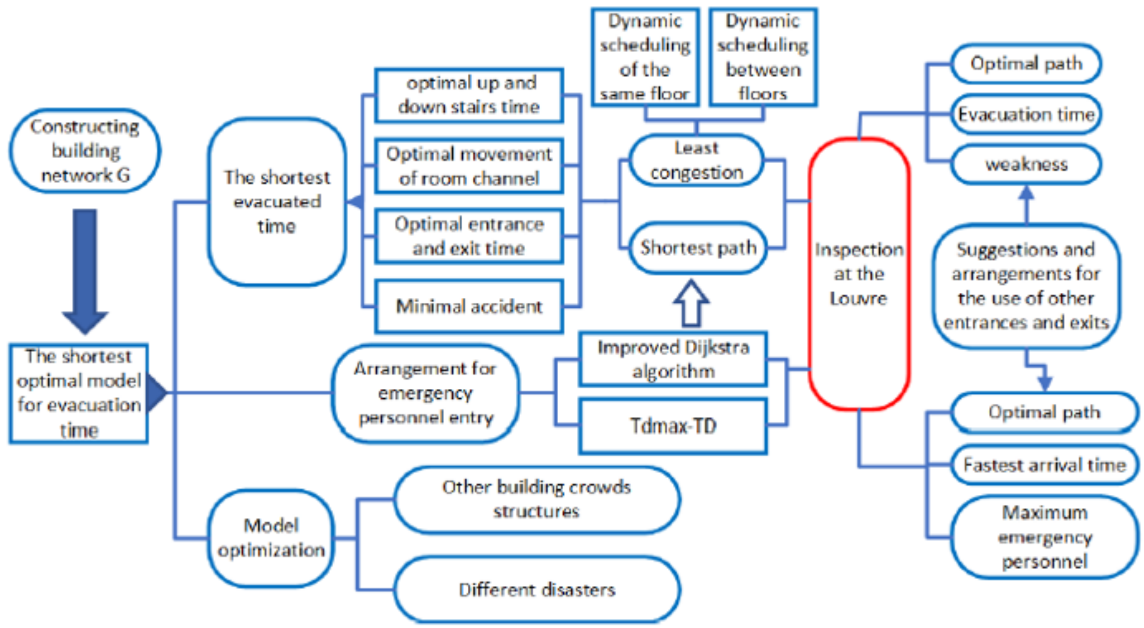


Figure 5. Flowchart describing the Northeastern University in Shenyang team's methodology to solve the problem.

the team determines the time to evacuate that floor and compares it to a random and naïve evacuation to help show the benefit of their model. Comparing a proposed solution to a baseline is a powerful technique to demonstrate the benefits of the model.

The team also categorizes disasters into five unique levels of severity, from a smoke alarm all the way to a major explosion or attack. Not all emergencies should be treated the same; the severity factor impacts the time for both the entry of emergency personnel and the evacuation of visitors.

Another way that this paper distinguishes itself is the diversity of recommendations and the methods by which the team introduces them to the reader. While not all recommendations might be feasible for a historic museum like the Louvre, the team offers a myriad of ideas that could help this museum, or any large common area visited by volumes of people on a daily basis, in an emergency evacuation situation. The team uses the easy-to-follow diagram in **Figure 6** to address several areas when dealing with a large-scale evacuation of a population with a wide range of physical abilities, together with multilanguage barriers.

The team also discusses how their modeling to evacuate the Louvre could be applied to other structures. Very few other teams took the time to try to apply their techniques to structures other than the Louvre.

This team does an outstanding job with selecting a model, defining a manageable set of variables, modifying and applying the model to fit the scenario and providing a clear solution to the reader. This team does not get lost in the modeling and forget the problem that they were trying to

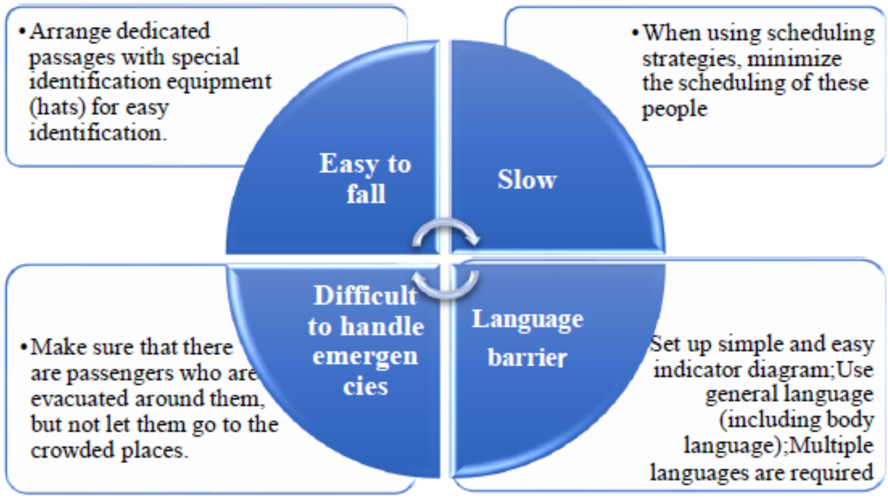


Figure 6. Ideas presented by the team from Northeastern University in Shenyang, China to reduce overall evacuation time.

solve.

Although the judges were impressed by the overall quality of this paper, the panel also noted that it could have been made even stronger with the inclusion of some additional sensitivity analyses.

Seattle Pacific University: "Getting a Move On When the Louvre's Bombed"

The team from Seattle Pacific University creates a network model to determine the placement of exit signs, follows with agent-based modeling for simulation and validation, and complements the agent-based model with a differential equation model on the network capturing the deterministic behavior and providing a theoretical base for their solution.

The team visualizes their work with a heat map of the network based on each location's proximity to an exit, as shown in **Figure 7**. The team uses the information in order to identify flow and potential bottlenecks in the network.

The team's spectral-graph-theory-based approach and the unique use of the Laplacian set the paper up for success by finding upper bounds on the theoretical conductivity and potential for bottleneck.

The team uses agent-based modeling to simulate the response of the Louvre's emergency personnel, taking into account different arrival times. The team goes a step further to demonstrate how this arrival time depends on the varying population density, as shown in **Figure 8**. The inclusion of this graph explains why the arrival of emergency personnel is important and how the arrival impacts the larger evacuation scenario.

Lastly, the team uses differential equations to create a differential flow model to determine the flow rate from site to site, given the density of the

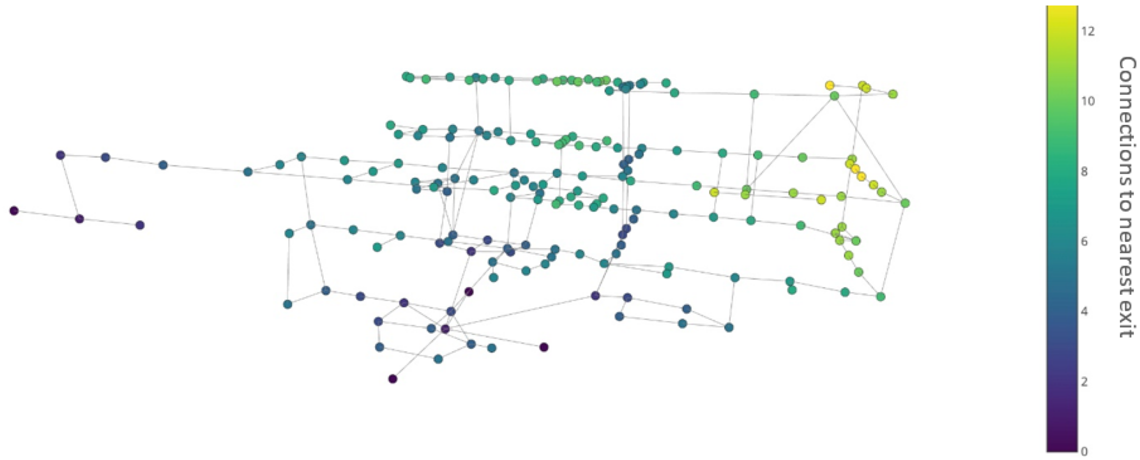


Figure 7. Seattle Pacific University's heat map of the network model, based on proximity to exits.

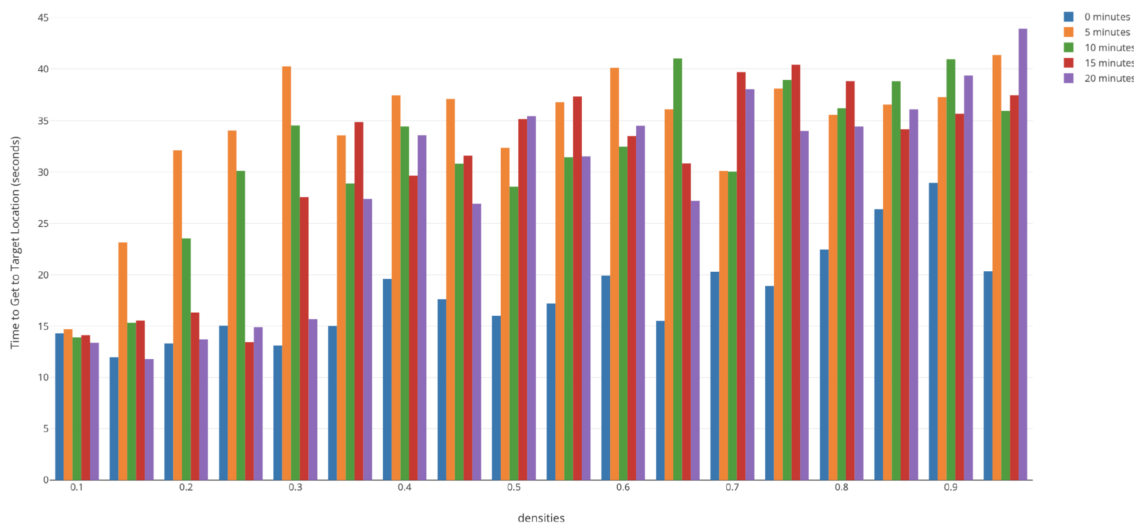


Figure 8. Arrival time (in seconds) of emergency personnel as a function of density, by the team from Seattle Pacific University.

crowd at both sites. This flow model builds on the adjacency matrix of the network and the agent-based model through the use of a model analogous to a non-Newtonian fluid model. Here their model captures the behavior of the system by solving numerically for the change in density of each room. Considering the density distribution over time for all rooms, the team identifies when rooms are empty, experiencing a bottleneck, or at equilibrium.

The team does an outstanding job of summarizing the results of their simulations by using graphs such as the one in **Figure 9**. Here they also demonstrate how the type of density (uniform versus partitioned) and number of exits (or blockage of exits) impact the overall evacuation times.

Overall, the paper is very well written; it states the assumptions clearly and nicely folds in existing work. More importantly, the team structures the paper around a single theme—what the evacuation plan means—which make the work cohesive and extremely relevant.

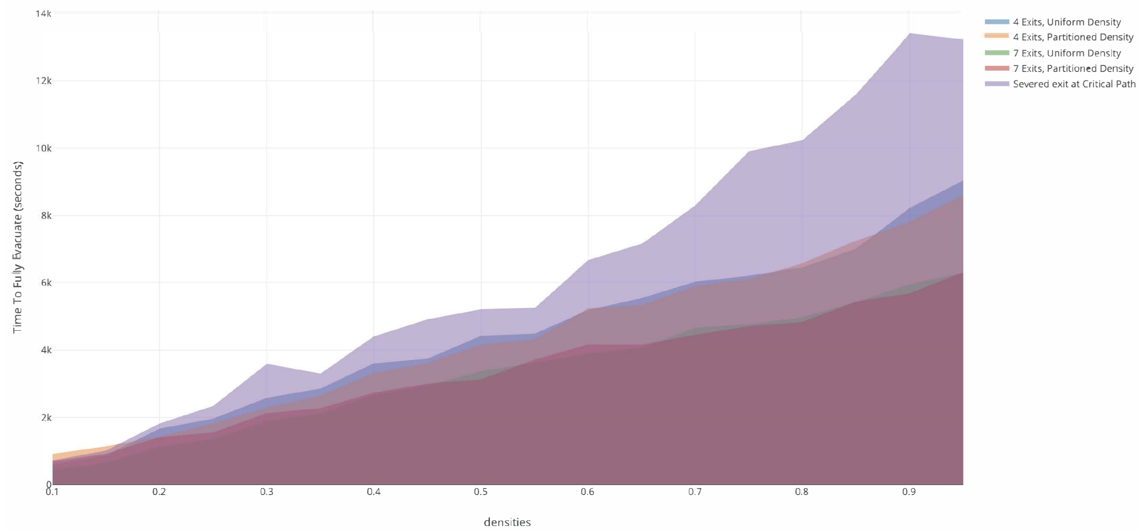


Figure 9. Seattle Pacific University's summary of results.

The paper ends with an appealing counterintuitive conclusion based on their research, that "our methods of identifying bottlenecks indicate that there are situations where a longer path might actually reduce congestion and hence counterintuitively speed up progress."

Their simple and useful recommendations with signage towards the exit signs speaks to the relevancy of their work, as they are implementable and appropriate for this modern age.

Although the judges were impressed with this paper, they noted that some of the methodologies and the concepts behind the models were not always clear, and the paper could have been even stronger if the team had targeted their explanations to an interdisciplinary audience who may not be familiar with the specific techniques.

Xi'an Jiaotong Liverpool University: "Escape the Louvre"

While many teams abstract the problem too much in an attempt to cover a more generalized building, the team from Xi'an Jiaotong Liverpool University really focuses on unique characteristics of the Louvre. Also, while most of the papers come to the unsurprising conclusion that stairwells and doorways are bottleneck areas, this paper goes further and looks at the specific Louvre stairwells and analyzes their geometries (rectangular stairs, spiral stairs, double stairs), dimensions, slopes, and carrying capacities.

This paper does an excellent job of exploring sensitivities by considering a variety of cases, including the number of open exits as well as cases where terrorists are present, causing a part of the Louvre to be impassible. The team also makes great use of visualizations to illustrate how they tailor their work specifically to the Louvre, such as is shown in **Figure 10**.

In considering differing characteristics of the tourists themselves, many

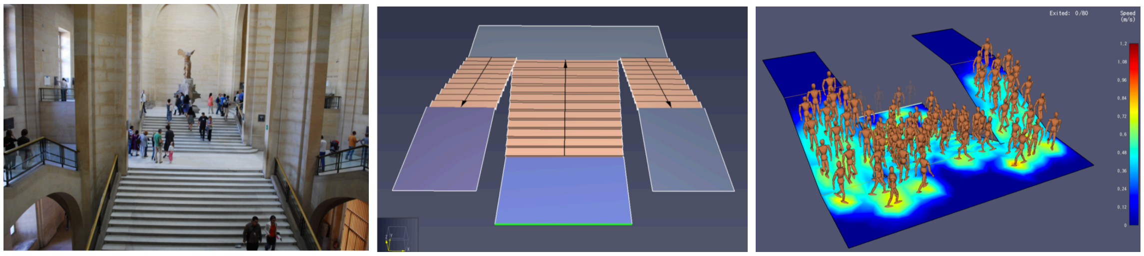


Figure 10. The Louvre's Daru staircase, Xi'an Jiaotong Liverpool University's model of it, and their simulation of flow of people on that staircase.

teams identify handicapped tourists; but this team goes one (small) step further to state the scarcity of ramps and suggests that more be installed for safety and faster evacuation. Overall, the team's focus on Louvre-specific details is a clear way for the team to demonstrate their ability to translate between the real world and their model.

This team's use of a genetic algorithm (GA) was one of the most novel approaches seen in the final rounds of judging; and as previously noted, the specificity they brought to the problem was also seen as a strength in final judging.

However, even the best papers have room for improvement; in this case, the panel noted that the paper could have been strengthened by clarifying how the components in the GA (genes and chromosomes) aligned with characteristics of the population in the Louvre.

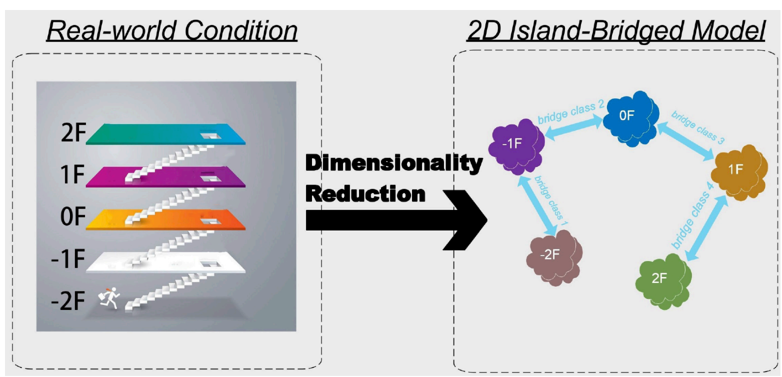
Nanjing University: "Analysis of the Optimal Evacuation Plan Based on 2D and 3D Models"

There were several factors that identified this paper from the Nanjing University team as Outstanding, but the main factor was the manner in which it was written. This well-written paper has a cohesiveness and flow that makes it a wonderful example of an interdisciplinary modeling paper. The clear and understandable way in which the team explains how they build their 2D Island-Bridge Model and the figures that they use to illustrate the model are exemplary. **Figure 11** clearly illustrates this team's methods to build their model.

In addition to these figures, the explanation of assumptions and how the team accommodates them in their model is coherent and complete. Another aspect of their submission that stood out is consideration of the source/location of the danger and how this affects evacuation time and routes. They also have a realistic discussion of how the "additional" exits could be utilized.

The recommendations from the Nanjing University team are both reasonable and actually implementable, such as installing additional sensors to monitor tourist density and adding a navigation function to the Afflu-

a. Depiction of factors.



b. Dimensionality reduction method.

Figure 11. Nanjing University team's use of figures to explain their model.

ences app to help with emergency situations. These are both recommendations that could be followed by the Louvre staff to assist evacuation efforts.

While the judges definitely found this paper to be Outstanding, there is always room for improvement. The judges noted that the first two models that this team uses are well constructed and utilized; however, the derived evacuation times appear to be unrealistically short. Additionally, the team develops a third model, a 3-D model; and the judges questioned whether it was a constructive addition to the paper. Teams are encouraged to evaluate whether their models are giving reasonable results and whether the use of an additional model really adds value to the analysis or results.

University of Electronic Science and Technology of China: "A Model for Determining Evacuation Routes"

The team from the University of Electronic Science and Technology of China uses an ant-colony algorithm to create their Visitor Emergency Evacuation (VEE) model, which they apply to analyze the Louvre's visitor patterns. The team applies sound modeling that allows them to focus on the specifics of certain areas inside the Louvre. They present evacuation results for several different situations.

The team models the daily and weekly variations in the number of visitors by deriving it from the Affluences wait times. They model the variation in visitor density by noting that there are three signature art treasures in the Louvre and assuming that those areas would have three times as many people as other similar spaces. They also model the topology of the Louvre, taking into account the width of passages, which along with the model of the standard person's size, gives rise to the number of people who will fit and be able to flow through the passages and stairways.

The evacuation model starts using ant-colony routing; but then the team modifies this algorithm to take into account the fact that if people see a long queue, they will likely leave and try another exit. The team also uses their model to estimate the width of stairs and other passageways and make the flows proportional to the widths. So the final algorithm has an attraction to follow others, but a repulsion to avoid long queues. The judges were impressed by the creativity and effectiveness of this approach.

The team also models the entrance of emergency personnel. They assume that different staircases will be used, so as to not create more congestion. They use a Dijkstra routing algorithm for the emergency personnel, but the team does not explain why their existing model was insufficient or why they needed to introduce a whole new model. They do discuss dynamically changing link weights depending on congestion, so the judges thought that perhaps the Dijkstra algorithm may be used to facilitate this. However, the judges should not have to guess the rationale for adding a model; the explanation is incumbent on the teams.

Using these algorithms and the Louvre model, the team calculates optimal evacuation routes, describes the process in detail, and presents the routes in **Figure 12**, with (orange) arrows indicating the direction of evacuation.

Based on data from the Louvre, they find the maximum number of visitors in the Louvre at any one time is 10,380, for which they calculate that it would take approximately 7 min to evacuate—a value that appears to be too low. They then investigate the effects of opening additional exits and find that doing so saves approximately 1 min in evacuating their maximum-size crowd of 10,380.

They conduct sensitivity analysis on the speed of evacuation as well as on the capacity of the stairs. There is a qualitative discussion of the use

Figure 12. Optimal evacuation route presented by the University of Electronic Science and Technology of China.

of the model on other structures, noting that there may be issues for a tall building, with many floors using the same stairwells. The summary gives a good overview of the sensitivity analysis results, and the recommendations are also good; but the judges noted that the team should have taken the opportunity to summarize the results from the rest of the paper.

Conclusion and Recommendations for Future Participants

As the judges read through the final papers, they were pleased to see papers that stood out for a variety of reasons, including

- strong expository writing,

- creative and diverse modeling approaches that addressed unique aspects of the problems stemming from architectural issues or human behavior,
- clever visualizations to help readers digest the results,
- good use of citation practices,
- ingenious approaches to the sensitivity analyses,
- attempts to transfer their analyses to other large buildings, and
- practical recommendations informed by the analyses presented in the paper.

Each of the seven Outstanding papers has its own strengths, and we encourage future teams to learn from these examples. Additionally, each had room for improvement, and many of the imperfections cited were common across the whole field of more than 5,000 submissions for this problem. Therefore, we encourage participants to take note of those areas and keep them in mind as they develop their own solutions.

As always, teams should bring their own strengths to a problem—one of the joys of the ICM is that there is not one single "right" way to model the problem, and the judges are always impressed by the ingenuity that teams bring to the problem.

Also, teams should keep time management in mind; the ICM problems are wide-ranging and involved, and it is important to submit a well-written and complete solution paper.

Lastly, the judges would like to stress the importance of participating in the competition with academic integrity practiced in good faith; in other words, teams are expected to do their own work and make use of proper citations to appropriate references wherever applicable. Sadly, many teams are disqualified for lack of academic integrity, and we would like to see more teams avoid this outcome by making a habit of practicing academic integrity.

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About the Authors

Dr. Ralucca Gera is the Associate Provost for Graduate Education and Professor of Mathematics at the Naval Postgraduate School. She is also a researcher in the Center for Cyber Warfare at the Naval Postgraduate School, as well as an associate researcher in the Network Science Center at United States Military Academy. Her research interests are in graph theory and network science, with applications to the study of the Internet, cyber networks and natural language processing, sponsored by multiple Dept. of Defense organizations. Dr. Gera is the founder and director of the Academic Certificate in Network Science. She actively participates in network science education of the young generation through teaching short courses for professors and researchers, and organizing workshops for teachers. She has published over 50 journal and conference papers, one chapter book, and one edited book in mathematics and network science.

Michelle L. Isenhour is an Assistant Professor in the Operations Research Dept. at the Naval Postgraduate School in Monterey, CA. She has an M.S. in Applied Mathematics from Western Michigan University and a Ph.D. in Computational Science and Informatics from George Mason University in Fairfax, VA, where she researched pedestrian and crowd modeling in the Center for Computational Fluid Dynamics under Dr. Rainald Löhner. Her research focuses on microscopic modeling and simulation of pedestrians during emergency scenarios, with a particular emphasis on initial response.

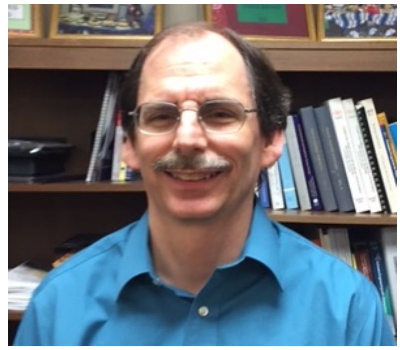
Dr. Jessica M. Libertini holds advanced degrees in both engineering and applied mathematics. She has served as Senior Engineer at General Dynamics, National Research Council Fellow at West Point, Science & Technology Policy Fellow in the Office of the Secretary of Defense, and currently Associate Professor at Virginia Military Institute. She became involved with the MCM/ICM in 2008, first serving as a team advisor, then as a triage judge and commentary writer, and now as a head judge.

Eleanor Ollhoff studied at the University of Tennessee and has a background in undergraduate mathematics instruction and pedagogy and pure mathematics, specifically low-dimensional topology and differential geometry. She taught in the Mathematics Dept. at Appalachian State University, the University of Tennessee, and the U.S. Military Academy. She started as an ICM triage judge in 2014, and has been on the final judging panel for three of the past four years.

Dr. Jack Picciuto has over 10 years of judging mathematical modeling competitions, including the ICM, MCM™, HiMCM™, and the Moody's Math Challenge. He previously served on the mathematics faculty at the U.S. Military Academy, and since his retirement from the U.S. Army, he has worked as a senior systems engineer and consultant in the private sector.

Dr. Troy Siemers has a Ph.D. in Mathematics from the University of Virginia. He has worked at the Virginia Military Institute in the Dept. of Applied Mathematics since 1999 and since 2010 as department head. He has been a triage judge for ICM for several years and a finals judge for two years, and has taught the VMI senior capstone course based on preparing for the ICM contest. He has conducted research with faculty in Economics and Business, Physics, Psychology, Chemistry, and Applied Mathematics.

Csilla Szabo is a Teaching Professor of Mathematics at Skidmore College in Saratoga Springs, NY. She received a bachelor's degree in mathematics from Western New England University in Springfield, MA in 2004 and her Ph.D. in mathematics from Rensselaer Polytechnic Institute in Troy, NY in 2010. Csilla's research interests include mathematical biology and network science. Prior to Skidmore, Csilla was a visiting assistant professor at the U.S. Military Academy and at Bard College. She participated in the MCM/ICM as a student and more recently as a team advisor and as a final judge.



Robert Ulman received his B.S. from Virginia Tech, M.S. from Ohio State University, and Ph.D. from the University of Maryland, all in electrical engineering. He worked as a communication systems engineer at the National Security Agency 1987–2000. Since then, he has been at the Army Research Office, where he worked as the program manager in wireless communications networking. More recently, he has been building a new program in Network Science and Intelligent Agents, engaging European scientists, and facilitating collaboration with U.S. laboratory scientists.

Rui Wang is a research and data scientist at the New York State Office of Mental Health, with academic background in biostatistics and computer science. She has 17 years of progressive experience of developing and managing analytics deliverables for healthcare programs. Her expertise includes exploratory data analysis, data mining, machine learning, statistical modeling, and forecasting.